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Nitrogen Mineralization from Canola Meal or Cottonseed Meal with or without Soapstock

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***Abstract*. Nitrogen (N) release rate from organic materials through mineralization is affected by the organic material and environmental conditions. Determining rates of mineralization for canola (*Brassica rapa* L.) meal and cottonseed (*Gossypium hirsutum* L.) meal with or without soapstock (a waste byproduct of seed oil extraction) will establish appropriate application rates for consumers. Canola meal, cottonseed meal, cottonseed meal with soapstock, or no treatment (control) was incorporated at a rate of 4.9 g·m^{-2} N into three loam soils. Experimental units were incubated for 0, 3, 7, 14, 30, or 60 days while maintaining moisture at 60% water-holding capacity and then analyzed for NH_4-N and NO_3-N, then plant available N was calculated as NH_4-N+NO_3-N. Ammonium increased with each seed meal amendment during the first 14 days of incubation and then decreased. Nitrate increased in seed meal treatments during the first 14 days of incubation and then continued to increase as NH_4-N ions declined. Canola meal and cottonseed meal with or without soapstock increase plant-available soil N.**

Seed meals are byproducts of oilseed processing. Oil is extracted from cottonseed and canola seed for cooking purposes, although recent interest in using these oils for production of biofuels has increased. A hexane extraction method (Zeigler et al., 1982) is used to remove oil from the seeds leaving meal and soapstock as byproducts. Soapstock is an undesirable chemical compound removed by a chemical reaction during caustic refining (Kuk et al., 2005). Soapstock consists of low-quality fatty acids (Davis et al., 2002). Processors add it to meal because it increases nutritional value for animal feed and provides a means of disposal (Kuk et al., 2005).

Seed meals have the potential to be suitable organic fertilizers. They are relatively high in nutrients and easily soluble compounds that make them biodegradable and a source of macro- and micronutrients. Cottonseed meal and canola meal generally contain 6% to 7% N, 2% phosphorus, and 2% potassium and have a pH of 6.0 to 6.5 (Mitchell, 2008) with a carbon-to-nitrogen (C/N) ratio of 8:1 (Gale et al., 2006). Such a low C/N ratio suggests that seed meals will behave as a nutrient source rather than immobilize soil N through microbial activity. Information concerning mineralization rates of cottonseed meal and canola meal is limited. Snyder et al. (2009) showed that mineralization of Brassicaceae seed meals ranged from 30% to 81% in a 96-d period. Greater N mineralization occurred in meal-amended plots than control plots and mineralization rates for meals adequately supplied N for plant growth (Snyder et al., 2009). Gale et al. (2006) examined decomposition and availability of N released from manure, compost, and specialty products (pelleted organic fertilizer, feather meal, and canola meal) under field and laboratory conditions to determine accuracy of mineralization prediction models based on C/N ratios. Specialty products with C/N ratios of 4 to 8 decomposed 76% and released an average of 78% of the plant-available N from the products in 70 d, whereas broiler litter with higher C/N ratios of 8 to 10 released only 40% of plant-available N in 70 d (Gale et al., 2006). Kelderer et al. (2008) sought to improve use of commonly used organic fertilizers by determining N mineralization rates. Mineralization rates for castor (*Ricinus communis* L.) seed meal and three seed cakes were tested. After 14 d of incubation, 16% of N mineralized from castor seed meal, whereas 3% mineralized from seed cakes of undefined seed sources (Rigen Plus; Europa Trading s.r.l.), 13% mineralized from seed cakes consisting of soya (*Glycine max* L.) and maize (*Zea mays* L.) (Fertilvegetal; Delta concimi s.a.s.), and 22% mineralized from seed cakes of unidentified seed types (Ecolverdepiu; Sala s.r.l.). After 60 d of incubation, 27% of N mineralized from castor seed meal and 20% from unidentified seed cakes (Rigen Plus), 21% mineralized from the seed cakes containing soya and maize, and 30% mineralized from unidentified seed cakes (Ecolverdepiu). Many synthetic fertilizers such as ammonium nitrate rapidly release plant-available N as they dissolve in water. In contrast, seed meal mineralization occurs with microbial degradation; thus, mineralization from seed meals is slower than N release from ammonium nitrate and other synthetic highly soluble fertilizers. Kelderer et al. (2008) found that soil N increased 75% after 14 d and 71% after 60 d with ammonium nitrate.

Rate of N mineralization from seed meals depends on several factors including organic composition of the residue, soil temperature and water content, drying and rewetting events, and soil characteristics (Cabrera et al., 2005). Snyder et al. (2010) conducted a study using ^{15}N-labeled Brassicaceae seed meals to investigate the production of biologically active glucosinolate degradation products that might reduce microbial activity thereby reducing N mineralization. They found that Brassicaceae seed meals can be used to increase inorganic N in soil and that glucosinolate degradation products have different short-term effects on the microbially mediated soil N cycle.

Determination of decomposition rates for cottonseed meal and canola meal are needed to establish application rates. The objective of this study was to determine mineralization of NH_4-N and NO_3-N from three mineral soils amended with cottonseed or canola meal.

Materials and Methods

Experimental set-up. Soil was collected from three sites: a current agricultural production site most recently cropped with redbud (*Cercis canadensis* L.) trees (Norge loam, fine-silty, mixed, thermic Udic Paleustolls, 35% sand, 45% silt, and 20% clay; Oklahoma State University Botanical Garden Stillwater, OK), a recently disturbed construction soil (clay loam, 35% sand, 37.5% silt, and 27.5% clay; Oklahoma State University, Stillwater, OK), and previously disturbed soil collected from a residential site that was constructed in the late 1950s (loam, 50% sand, 30% silt, and 20% clay) adjacent to the north side of the Oklahoma State University campus, Stillwater, OK (elemental analyses shown in Table 1). The soil pHs were 5.8 at the agricultural production site, 8.0 for the recently disturbed construction

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soil, and 7.5 for the previously disturbed soil as measured using a pH probe in 1:5 soil: deionized water. For each site, soil was collected from the top 15 to 20 cm at five locations within the site. The samples were thoroughly mixed for each site. To maintain soil integrity as closely as possible to field condition, but remove large rocks and other debris, soils were sieved through a 12-mm mesh screen and air-dried and then placed in separate 473-mL plastic cups (Solo Cup Company, Lake Forest, IL) at 300 g (58.8 cm^3) per cup. One cup was prepared for each soil, meal type, sampling date, and replication. Cottonseed meal with or without soapstock or canola meal without soapstock (elemental analysis shown in Table 2) was thoroughly mixed into each soil at the recommended fertilizer rate for turf and landscape plants of 4.9 $g \cdot m^{-2}$ N (Beard, 1972) (300 mg cottonseed meal per cup or 420.4 mg canola meal per cup). Therefore, the same amount of N was added with each amendment. Total N in each seed meal was determined by a total N analyzer (Leco TruSpec, St. Joseph, MI).

Treatments were replicated three times, randomized, and maintained in darkness at 22 °C. Incubation was initiated by adding tap water to soil in each cup to achieve 60% of water-holding capacity by weight. This was calculated as target weight to achieve 60% water-holding capacity = [(water saturated soil weight-air dried soil weight)*60%] + air-dried soil weight for each soil and meal treatment. No drainage occurred at any irrigation event. Tap water was added to each treatment every 72 h to maintain 60% water-holding capacity until sampling. Soil was sampled 0, 3, 7, 14, 30, and 60 d after incubation began. At sampling, soil was placed in a soil bag and dried in an oven at 30 °C to prevent N volatilization. Soil was then analyzed for total N (carbon and nitrogen analyzer; Leco TruSpec) and inorganic N (1M KC1 extraction followed by colorimetric flow-injection analysis; Lachat QuickChem 8000, Loveland, CO; Soil, Water, and Forage Analytical Laboratory, Oklahoma State University, Stillwater, OK).

Total plant-available N at each sampling time was estimated by the sum of NH_4-N and NO_3-N measured in the soil. Total inorganic N measured on the control was subtracted from plant-available N for each treatment and divided by the amount of organic N added to estimate how much added organic N mineralized.

Statistics. A split plot design with four meal treatments (described previously) and three soil types as the main plot, days of incubation as the subplot, and three replications was used. Data were analyzed using the GLM procedure in PC SAS Version 9.1 (SAS Institute, Cary, NC). A two-way factorial was used with treatment and days incubated as the factors of interest. Trend analyses were performed for each dependent variable by soil source and meal type, and equations were generated for significant trends.

Table 1. Selected chemical characteristics of the three soils used in this experiment.

Variable	Agricultural soil	Recently disturbed soil	Previously disturbed soil[z]
pH	5.7	8.0	7.4
NO_3-N ($kg \cdot ha^{-1}$)	45.6	6.8	31.1
NH_4-N ($kg \cdot ha^{-1}$)	2.4	1.11	1.9
Total N (%)	0.29	0.06	0.14
Plant-available P ($kg \cdot ha^{-1}$)[y]	27.6	2.4	5.9
Plant-available K ($kg \cdot ha^{-1}$)[y]	117.4	56.8	40.2

[z]Previously disturbed soil was collected from a residential area that was constructed in the late 1950s.
[y]Plant-available P and K were extracted using the Mehlich 3 method (Mehlich, 1984).
N = nitrogen; P = phosphorus; K = potassium.

Table 2. Chemical properties (pH, electrical conductivity, and soluble salts), elemental concentrations, and heavy metal concentrations of cottonseed meal, cottonseed meal with soapstock, and canola meal.

Variable	Cottonseed meal	Cottonseed meal with soapstock	Canola meal
	Chemical properties[z]		
pH	6.5	6.5	5.7
EC ($\mu S \cdot cm^{-1}$)	3770	4340	3380
Soluble salts (ppm)	2525.9	2907.8	2264.6
	Elemental concentrations[z]		
Phosphorus (%)	2.80	2.70	2.80
Calcium (%)	0.20	0.20	0.70
Potassium (%)	1.80	1.70	1.20
Magnesium (%)	0.70	0.60	0.60
Sodium (%)	0.30	0.20	0.10
Sulfur (%)	0.50	0.50	0.80
Iron ($mg \cdot kg^{-1}$)	90.1	78.3	242.4
Zinc ($mg \cdot kg^{-1}$)	65.7	62.9	68.0
Copper ($mg \cdot kg^{-1}$)	14.7	13.3	5.6
Manganese ($mg \cdot kg^{-1}$)	19.7	17.5	73.4
Total carbon (%)	45.5	44.9	45.0
Total N (%)	6.9	7.5	6.6
Ammonium N ($mg \cdot kg^{-1}$)	185.4	213.0	332.4
Nitrate N ($mg \cdot kg^{-1}$)	46.5	1.7	24.9
Organic N (%)	6.8	7.5	6.5
	Heavy metals[y]		
Arsenic ($mg \cdot kg^{-1}$)	ND[x]	ND	ND
Barium ($mg \cdot kg^{-1}$)	2.6	3.0	28.9
Cadmium ($mg \cdot kg^{-1}$)	ND	ND	ND
Chromium ($mg \cdot kg^{-1}$)	ND	0.42	0.56
Lead ($mg \cdot kg^{-1}$)	ND	ND	ND
Selenium ($mg \cdot kg^{-1}$)	2.0	2.1	2.7
Silver ($mg \cdot kg^{-1}$)	ND	ND	ND
Mercury ($mg \cdot kg^{-1}$)	ND	ND	ND

[z]Analysis by the Oklahoma State University Soil, Water, and Forage Analytical Laboratory.
[y]Analysis by Pace Analytical Services, Lenexa, KS. Sample preparation for all heavy metals except mercury was by Environmental Protection Agency (EPA) procedure #3050 and analysis was by EPA procedure #6010. Sample preparation and analysis for mercury was by EPA procedure #7471. Reporting limits ($mg \cdot kg^{-1}$) were as follows: arsenic 1.1, barium 1.1, cadmium 0.54, chromium 0.54, lead 0.54, molybdenum 2.2, nickel 0.54, selenium 1.6, silver 0.76, mercury 0.057.
[x]ND = not detectable.
EC = electrical conductivity; N = nitrogen.

Results

NH_4-N. Regardless of meal type, NH_4-N rapidly increased in all soil types during the first 14 d of incubation and then declined through the remainder of the study (Fig. 1). In contrast, NH_4-N concentration of all soils without meal (control) declined curvilinearly throughout the incubation period.

NO_3-N. The NO_3-N concentration increased curvilinearly throughout the incubation period in agricultural soil amended with any meal type (Fig. 2A). In nonamended agricultural soil, NO_3-N slightly increased curvilinearly throughout the incubation period, but by the end of the study, the NO_3-N concentration in amended soil regardless of seed meal type was three times the concentration in nonamended agricultural soil.

In the recently disturbed soil, the two cottonseed meal amendments resulted in a curvilinear increase in NO_3-N concentration such that the concentration increased for the first 30 d, then a plateau developed in which no further increase occurred between 30 and 60 d of incubation (Fig. 2B). In contrast, amendment of recently disturbed soil with canola meal resulted in a linear increase in NO_3-N throughout the 60-d incubation period. The NO_3-N slightly increased linearly throughout the 60-d incubation period in nonamended recently disturbed soil. At the end of the incubation period, soils amended with seed meal regardless of source contained approximately five times as much NO_3-N as nonamended soil from the same site.

In soil collected from an established residential site, NO_3-N increased curvilinearly

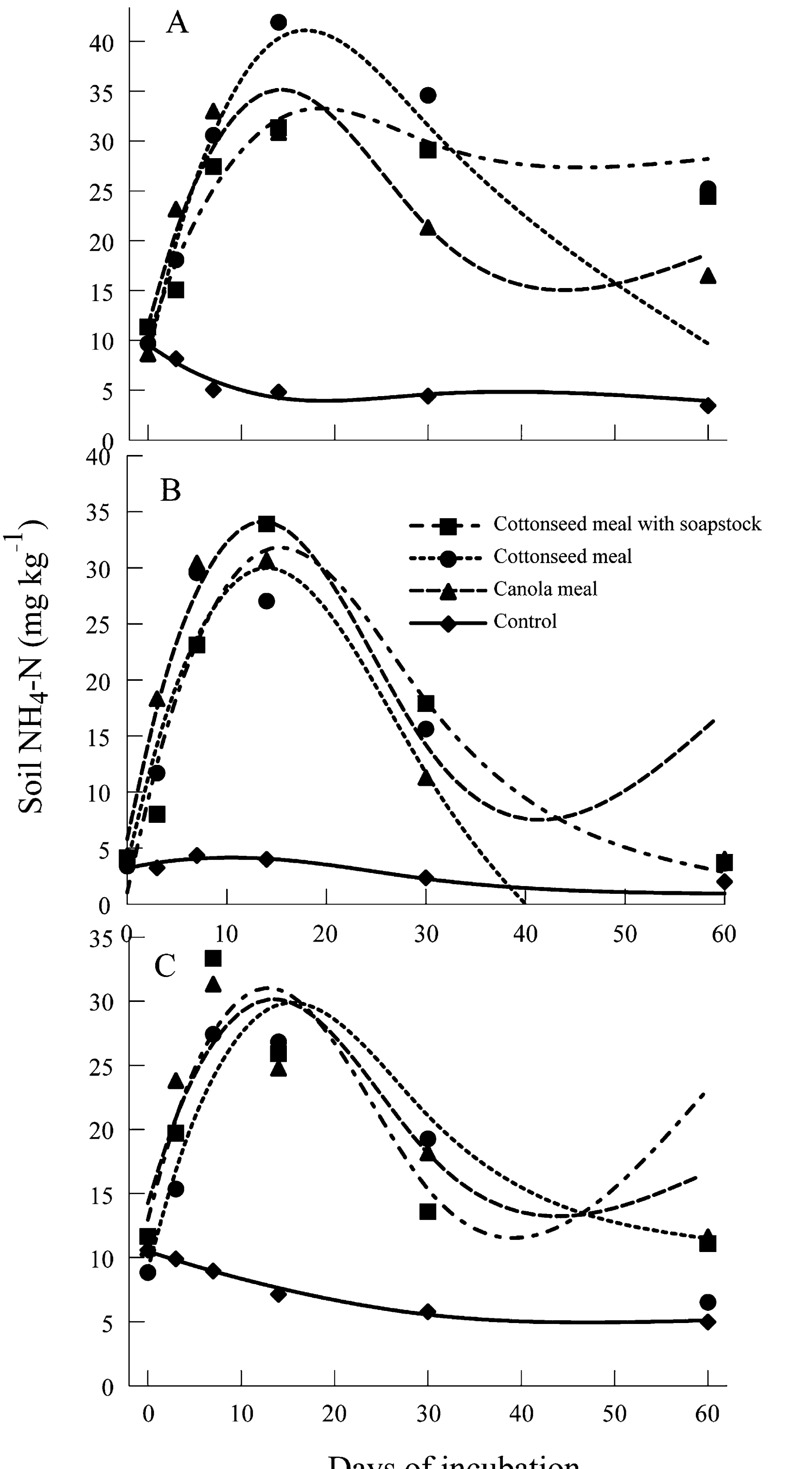

Fig. 1. Soil concentration of NH_4-N (mg·kg^{-1}) from an agricultural production site (**A**), recently disturbed construction site (**B**), or previously disturbed soil collected from a residential site that was constructed in the late 1950s (**C**) incorporated with cottonseed meal with or without soapstock, canola meal, or no treatment at 0, 3, 7, 14, 30, and 60 d of incubation. Regression equations for NH_4-N: soil (**A**) cottonseed meal $y = 8.46 + 4.22x - 0.16x^2 + 0.0015x^3$ ($P \leq 0.001$, $r^2 = 0.91$), cottonseed meal with soapstock $y = 10.32 + 2.77x - 0.10x^2 + 0.00098x^3$ ($P \leq 0.001$, $r^2 = 0.81$), canola meal $y = 11.44 + 3.60x - 0.16x^2 + 0.0017x^3$ ($P \leq 0.001$, $r^2 = 0.86$), control $y = 9.56 - 0.067x + 0.02x^2 - 0.00024x^3$ ($P \leq 0.001$, $r^2 = 0.88$); soil (**B**) cottonseed meal $y = 3.62 + 4.05x - 0.18x^2 + 0.0018x^3$ ($P \leq 0.001$, $r^2 = 0.79$), cottonseed meal with soapstock $y = 1.05 + 4.35x - 0.18x^2 + 0.0018x^3$ ($P \leq 0.001$, $r^2 = 0.82$), canola meal $y = 5.81 + 4.51x - 0.214x^2 + 0.00230x^3$ ($P \leq 0.001$, $r^2 = 0.91$), control $y = 3.23 + 0.19x - 0.011x^2 + 0.0018x^3$ ($P \leq 0.05$, $r^2 = 0.54$); and soil (**C**) cottonseed meal $y = 9.08 + 2.92x - 0.12x^2 + 0.0012x^3$ ($P \leq 0.001$, $r^2 = 0.89$), cottonseed meal with soapstock $y = 12.95 + 3.05x - 0.15x^2 + 0.0017x^3$ ($P \leq 0.05$, $r^2 = 0.61$), canola meal $y = 14.25 + 2.56x - 0.12x^2 + 0.0013x^3$ ($P \leq 0.001$, $r^2 = 0.68$), control $y = 10.50 - 0.24x + 0.0025x^2$ ($P \leq 0.001$, $r^2 = 0.82$). n = 3.

regardless of meal amendment such that concentration rose during the first 30 d of incubation and then remained steady (Fig. 2C). In the nonamended soil from an established residential site, NO_3-N slightly increased curvilinearly such that during the first 30 d, concentration increased and then remained steady. At the end of the study, the amended soil regardless of seed type had approximately three times the amount of NO_3-N compared with nonamended soil from the same site.

Total plant-available N. In the agricultural soil, total plant-available N increased rapidly during the first 14 d of incubation and then total plant-available N remained constant with cottonseed meal with soapstock or canola meal but slightly increased with cottonseed meal (Fig. 3A). Total plant-available N in nonamended soil slightly increased throughout the incubation period.

In contrast to the agricultural soil, the total plant-available N increased rapidly during the first 30 d of incubation in recently disturbed soil and in soil from an established residential area regardless of meal treatment (Fig. 3B–C). From 30 to 60 d, total plant-available N in recently disturbed soil or soil from an established residential area amended with cottonseed meal or cottonseed meal with soapstock slightly decreased, whereas total N in those soils amended with canola meal slightly increased during this time period. Total plant-available N in nonamended soil, regardless of soil source, slightly increased linearly throughout the 60-d incubation period.

Percentage of N mineralized. In the agricultural soil, the percentage of N mineralized increased rapidly for the first 14 d of incubation and then reached a plateau for all three seed meal sources (Fig. 4A). Cottonseed meal with or without soapstock reached a plateau at ≈70% mineralization, whereas canola meal reached a plateau at ≈55% mineralization. In the recently disturbed soil, N mineralization with cottonseed meal regardless of presence or absence of soapstock increased during the first 30 d of incubation and then declined slightly. In contrast, mineralization of N from canola meal in recently disturbed soil increased linearly throughout the 60-d incubation period. With soil from an established residential area, cottonseed meal with soapstock had the greatest mineralization (85%), whereas cottonseed meal and canola meal had less N mineralization (52% and 48%, respectively). Maximum mineralization with all three meal types occurred within 30 d of incubation.

Discussion

Decomposition rate depends on the organic material characteristics and soil. Cottonseed meal and canola meal exhibit characteristics favorable for release of inorganic N. The environment created to examine the release of inorganic forms of N from cottonseed meal and canola meal had adequate soil moisture (60% w/w) and air temperature (22 °C) to

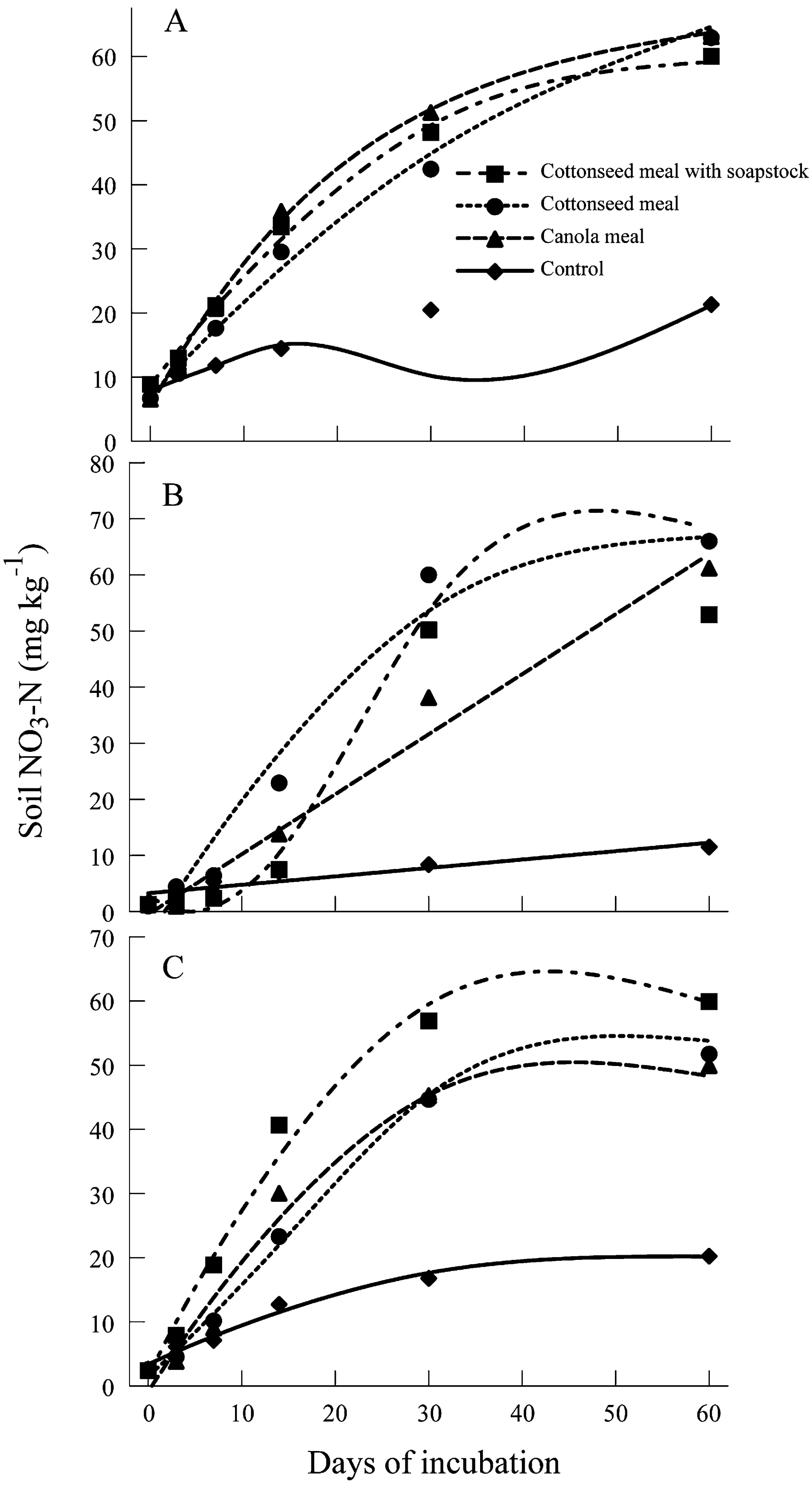

Fig. 2. Soil concentration of NO_3-N (mg·kg^{-1}) from an agricultural production site (**A**), recently disturbed construction site (**B**), or previously disturbed soil collected from a residential site that was constructed in the late 1950s (**C**) incorporated with cottonseed meal with or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 d of incubation. Regression equations for NO_3-N: soil (**A**) cottonseed meal $y = 7.04 + 1.56x - 0.010x^2$ ($P \leq 0.001$, $r^2 = 0.98$), cottonseed meal with soapstock $y = 8.75 + 1.86x - 0.017x^2$ ($P \leq 0.001$, $r^2 = 0.99$), canola meal $y = 5.54 + 2.65x - 0.046x^2 + 0.00030x^3$ ($P \leq 0.001$, $r^2 = 0.99$), control $y = 7.87 + 0.60x - 0.0063x^2$ ($P \leq 0.001$, $r^2 = 0.78$); soil (**B**) cottonseed meal $y = -4.63 + 2.694x - 0.025x^2$ ($P \leq 0.001$, $r^2 = 0.99$), cottonseed meal with soapstock $y = 2.85 - 1.31x + 0.16x^2 - 0.0020x^3$ ($P \leq 0.01$, $r^2 = 0.97$), canola meal $y = -0.50 + 1.07x$ ($P \leq 0.001$, $r^2 = 0.87$, control $y = 3.26 + 0.15x$ ($P \leq 0.001$, $r^2 = 0.60$); and soil (**C**) cottonseed meal $y = 1.51 + 1.28x + 0.019x^2 - 0.00043x^3$ ($P \leq 0.001$, $r^2 = 0.99$), cottonseed meal with soapstock $y = 1.61 + 2.89x - 0.032x^2$ ($P \leq 0.001$, $r^2 = 0.69$), canola meal $y = 0.88 + 2.26x - 0.024x^2$ ($P \leq 0.001$, $r^2 = 0.97$), control $y = 3.37 + 0.67x - 0.0065x^2$ ($P \leq 0.001$, $r^2 = 0.84$). n = 3.

promote microbial degradation of organic residues.

Total plant-available N concentration was typically constant for each treatment and soil type; thus, only the N form changed. As organic N mineralized transforming to inorganic forms, the total amount of N should not change unless N was lost by NH_3 volatilization or denitrification. Because no change in total N was detected, NH_3 volatilization or denitrification either did not occur or was below detection limits of this study.

Increased NH_4-N concentration occurred from mineralization of the seed meals (Fig. 1). Part of mineralization as ammonification occurs when organic N is converted to NH_4-N mediated by soil microbes (Sylvia et al., 2005). Materials with C/N ratios below 20, such as cottonseed or canola meals, contain enough N to meet the needs of respiring soil microorganisms. Application of organic residues to soil is typically accompanied with an initial increase in soil microbial populations that feed on the new supply of organic material. Microbial populations then decline and stabilize at steady-state conditions (Sylvia et al., 2005). Mineralization of organic N reflects microbial populations in that the NH_4-N concentrations initially increase and then steadily decrease as readily available organic N decreases. Ammonium-N derived during mineralization is then converted into NO_3-N through nitrification. Ammonium was highest in all soils after 14 d of incubation and then decreased with time.

Nitrate is produced by nitrification when NH_4-N ions are oxidized by soil bacteria to yield NO_3-N (Brady and Weil, 2008). Nitrate concentration lagged behind increased NH_4-N (Figs. 1 and 2). Formation of NO_3-N followed trends in which the mineralization of organic N produced NH_4-N that was then available for soil bacteria to transform into NO_3-N. As NH_4-N concentration peaked and began to decline, NO_3-N concentration increased in the soils. Increases in NO_3-N concentration occurred for all of the seed meal treatments.

Mineralization of organic N into inorganic forms occurred in seed meal treatments in each soil type. Many plant nutrients are most available in soils with a near neutral pH of 6.0 to 7.0 and that contain the most diverse communities of soil microbes and bacteria (Sylvia et al., 2005). The amount of N mineralized steadily increased in the agricultural soil, which had a pH of 5.8. Organic N mineralized more slowly in recently disturbed soil, which had a pH of 8.0 and in previously disturbed soil with a soil pH of 7.5 (Fig. 3). Loam soil with slightly acidic pH (i.e., the agricultural soil) mineralized 60% to 87% of the organic N from seed meals during 60 d of incubation (Fig. 4A). Loam soil with high pH (recently disturbed soil) mineralized 83% organic N from cottonseed meal without soapstock and 86% from cottonseed meal with soapstock during the first 30 d of incubation, whereas canola meal without soapstock mineralized 56% during 60 d of incubation (Fig. 4B). Clay loam with high pH (previously

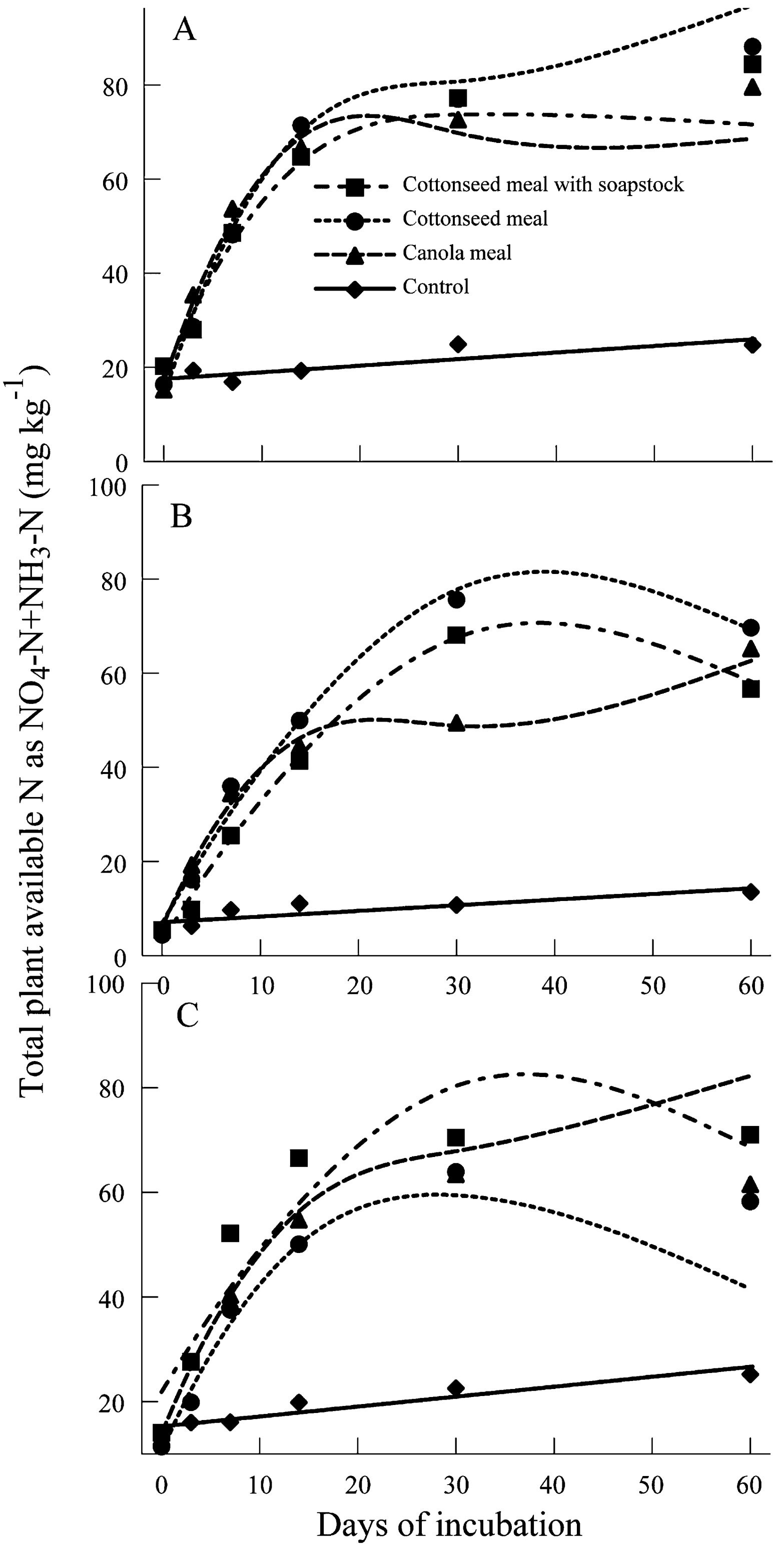

Fig. 3. Total plant-available nitrogen (N) (NH_4-N+NO_3-N) (mg·kg^{-1}) from an agricultural production site (**A**), recently disturbed construction site (**B**), or previously disturbed soil collected from a residential site that was constructed in the late 1950s (**C**) incorporated with cottonseed meal with or without soapstock or canola meal or no treatment at 0, 3, 7, 14, 30, and 60 d of incubation. Regression equations for total plant-available N: soil (**A**) cottonseed meal $y = 14.14 + 6.30x - 0.19x^2 + 0.0018x^3$ ($P \le 0.001$, $r^2 = 0.98$), cottonseed meal with soapstock $y = 18.20 + 4.97x - 0.14x^2 + 0.0012x^3$ ($P \le 0.001$, $r^2 = 0.97$), canola meal $y = 16.98 + 6.26x - 0.21x^2 + 0.0020x^3$ ($P \le 0.001$, $r^2 = 0.99$), control $y = 17.54 + 0.14x$ ($P \le 0.01$, $r^2 = 0.98$); soil (**B**) cottonseed meal $y = 6.90 + 3.68x - 0.44\,x^2$ ($P \le 0.001$, $r^2 = 0.88$), cottonseed meal with soapstock $y = 3.03 + 3.38x - 0.040x^2$ ($P \le 0.001$, $r^2 = 0.94$), canola meal $y = 6.21 + 4.78x - 0.16x^2 + 0.0016x^3$ ($P \le 0.001$, $r^2 = 0.79$), control $y = 7.08 + 0.12x$ ($P \le 0.01$, $r^2 = 0.44$); and soil (**C**) cottonseed meal $y = 10.59 + 4.20x - 0.11x^2 + 0.00081x^3$ ($P \le 0.001$, $r^2 = 0.98$), cottonseed meal with soapstock $y = 21.85 + 3.12x - 0.039x^2$ ($P \le 0.01$, $r^2 = 0.59$), canola meal $y = 13.88 + 4.62x - 0.13x^2 + 0.0012x^3$ ($P \le 0.001$, $r^2 = 0.98$), control $y = 15.25 + 0.19x$ ($P \le 0.001$, $r^2 = 0.63$). n = 3.

disturbed soil) mineralized 44% to 70% of the organic N from seed meals during the first 30 d of incubation (Fig. 4C). Inorganic N in canola meal treatments at Day 14 for soil was 52% for the agricultural soil, 36% for recently disturbed construction soil, and 38% for previously disturbed soil from a residential site. These percentages were similar to those of Gale et al. (2006) who found that plant-available N released from canola meal was 39% on Day 14 and 41% on Day 70. Seed meals mineralized at higher rates than broiler litter with C/N ratios of 8 to 10, which averaged 40% plant-available N release in 70 d (Gale et al., 2006).

The U.S. Environmental Protection Agency (EPA) regulates land application of biosolids (EPA, 1995). Application limits are based on heavy metal pollutants. The heavy metal concentrations in the three seed meals tested in this study were either well below EPA 503 thresholds or not detectable (Table 2). This suggests that there is little concern about introducing contaminants to the soil with application of these meals.

Because seed meals are organic materials that must be decomposed before nutrients are released to the soil, and the release happens relatively slowly, plants are able to absorb the nutrients as they become available. In contrast, soluble fertilizers release nutrients quickly, and those nutrients can be leached from the root zone or volatized into the atmosphere resulting in nutrients being unavailable for plant uptake. The slower release of nutrients from seed meals may result in more of the nutrients being absorbed by target plants than nutrients from highly soluble fertilizers (i.e., a greater N use efficiency). In this study, cottonseed meal regardless of presence or absence of soapstock released 70% of N in agricultural soil and greater than 80% of N in soil from recently disturbed soil. In soil from an established residential site, 70% of N was mineralized from cottonseed meal with soapstock, whereas 50% of N was mineralized from cottonseed meal without soapstock. Less N was mineralized from canola meal in the agricultural soil and the soil from a new construction site than from the cottonseed meals, but in soil from the established residential area, N mineralization from canola meal was similar to N mineralization from cottonseed meal. Previous research has shown that the addition of N as a synthetic organic fertilizer (isobutylidendiurea) or mineral fertilizer containing both NO_3 and NH_4 (Entec 26) resulted in a greater net accumulation of N than the amount of N initially added (Gioacchini et al., 2006). This greater net N accumulation was attributed to a priming effect in which more N was released from the soil than what was released without the addition of N fertilizer. In the current study, some of the N release may have been from N in the soil as well as N from cottonseed or canola meal.

The current recommended N rate is 4.9 g·m^{-2} N for turf (Beard, 1972) and 9.8 to 19.6 g·m^{-2} N to landscape planting beds (Hensley, 2010). This study suggests that slightly higher rates may be applied when

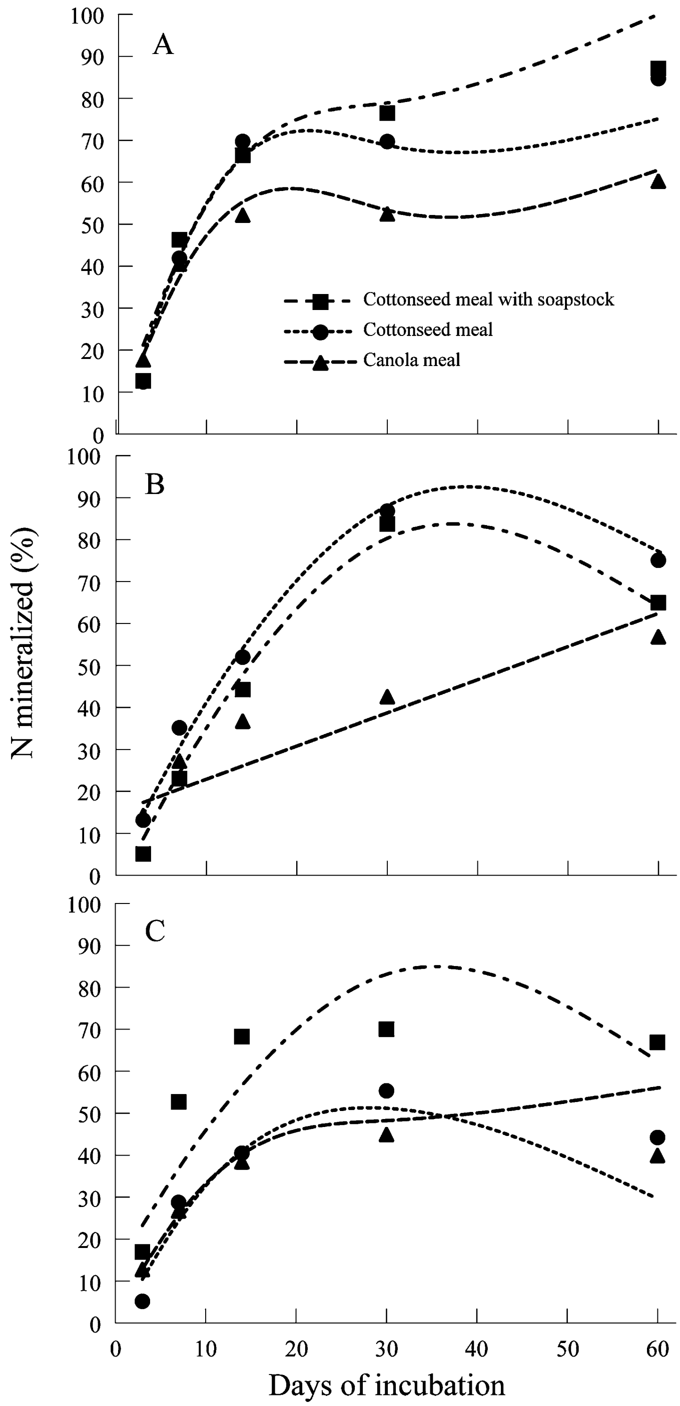

Fig. 4. Percentage of nitrogen (N) mineralized from an agricultural production site (**A**), recently disturbed construction site (**B**), or previously disturbed soil collected from a residential site that was constructed in the late 1950s (**C**) incorporated with cottonseed meal with or without soapstock or canola meal or no treatment at 3, 7, 14, 30, and 60 d of incubation. Regression equations for total plant-available N: soil (**A**) cottonseed meal $y = -4.06 + 8.44x - 0.28x^2 + 0.0027x^3$ ($P \leq 0.001$, $r^2 = 0.97$), cottonseed meal with soapstock $y = 1.20 + 7.33x - 0.22x^2 + 0.0021x^3$ ($P \leq 0.001$, $r^2 = 0.96$), canola meal $y = 0.54 + 6.76x - 0.24x^2 + 0.0024x^3$ ($P \leq 0.001$, $r^2 = 0.98$); soil (**B**) cottonseed meal $y = 1.58 + 4.49x - 0.054x^2$ ($P \leq 0.001$, $r^2 = 0.86$), cottonseed meal with soapstock $y = -4.31 + 4.49x - 0.056x^2$ ($P \leq 0.001$, $r^2 = 0.92$), canola meal $y = 14.68 + 0.79x$ ($P \leq 0.001$, $r^2 = 0.58$); and soil (**C**) cottonseed meal $y = -2.30 + 4.64x - 0.12x^2 + 0.00087x^3$ ($P \leq 0.001$, $r^2 = 0.96$), cottonseed meal with soapstock $y = 12.0 + 3.93x - 0.051x^2$ ($P \leq 0.01$, $r^2 = 0.49$), canola meal $y = 0.84 + 4.43x - 0.13x^2 + 0.0012x^3$ ($P \leq 0.001$, $r^2 = 0.98$). n = 3.

using cottonseed meal or canola meal because less than 100% of the N mineralized from the meals during the 60-d incubation period. Application of seed meals may result in less fertilizer damage to plants than soluble fertilizer during hot periods as a result of the slower release rate and less concentrated nutrients in the plant root zone.

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