Published online October 27, 2006

Estimating Plant-Available Nitrogen Release from Manures, Composts, and Specialty Products

Eric S. Gale, Dan M. Sullivan,* Craig G. Cogger, Andy I. Bary, Delbert D. Hemphill, and Elizabeth A. Myhre

ABSTRACT

Recent adoption of national rules for organic crop production have stimulated greater interest in meeting crop N needs using manures, composts, and other organic materials. This study was designed to provide data to support Extension recommendations for organic amendments. Specifically, our objectives were to (i) measure decomposition and N released from fresh and composted amendments and (ii) evaluate the performance of the model DECOMPOSITION, a relatively simple N mineralization/immobilization model, as a predictor of N availability. Amendment samples were aerobically incubated in moist soil in the laboratory at 22°C for 70 d to determine decomposition and plant-available nitrogen (PAN) (n = 44), and they were applied preplant to a sweet corn crop to determine PAN via fertilizer N equivalency (n = 37). Well-composted materials (n = 14) had a single decomposition rate, averaging 0.003 d^{-1}. For uncomposted materials, decomposition was rapid (>0.01 d^{-1}) for the first 10 to 30 d. The laboratory incubation and the full-season PAN determination in the field gave similar estimates of PAN across amendments. The linear regression equation for lab PAN vs. field PAN had a slope not different from one and a y-intercept not different than zero. Much of the PAN released from amendments was recovered in the first 30 d. Field and laboratory measurements of PAN were strongly related to PAN estimated by DECOMPOSITION (r^2 > 0.7). Modeled PAN values were typically higher than observed PAN, particularly for amendments exhibiting high initial NH_4–N concentrations or rapid decomposition. Based on our findings, we recommend that guidance publications for manure and compost utilization include short-term (28-d) decomposition and PAN estimates that can be useful to both modelers and growers.

Recent adoption of national rules for organic production (USDA, 2002) have stimulated greater interest in organic farming and meeting crop N needs using manures, composts, and other organic materials. Current Pacific Northwest Extension recommendations for N-based amendment application, based on limited data, estimate that first-season N availability (% of total N) is 0 to 20% for separated dairy solids, 20 to 40% for dry-stack dairy manure (Bary et al., 2000), and 10 to 30% for uncomposted yard trimmings (Cogger et al., 2002). Broiler litter is one of the major N sources used in organic production in the Pacific Northwest, but current Extension guidance (Bary et al., 2000) relies on professional judgment in extrapolating research results from other regions. Estimates of PAN for other N sources used most often in organic agriculture such as fish, feather, and seed meals often are not readily available, except from the supplier. National guidance for manure use in organic crop production (Kuepper, 2003) provides only typical total N analyses for manures with no estimate of PAN.

Correlations between C and N analyses of specific organic materials and the amount and timing of available N release have been reported for crop residues (Vigil and Kissel, 1991; VanLauwe et al., 1997; Trinsoutrot et al., 2000), animal manures (Castellanos and Pratt, 1981; Chae and Tabatabai, 1986), components of dairy manure (Van Kessel et al., 2000), and municipal biosolids (Gilmour et al., 2003). As C/N decreases, the percentage of lignin in a residue typically decreases, and the amount of residue that is rapidly decomposed in soil during the first 30 d in soil increases (Ajwa and Tabatabai, 1994; Van Kessel et al., 2000). While C/N is a good indicator of PAN released for fresh crop residues or manures, it not as useful as a general indicator for a set of organic materials that may include fresh organic matter such as crop residues, partially decomposed organic matter such as stored manure, and composts. Composting or storage of organic materials with low C/N typically reduces the decomposability of residue, but it often does not appreciably change C/N, because both C and N losses usually accompany decomposition (Hansen et al., 1993). Knowledge of amendment decomposition kinetics is especially helpful for organic materials with low C/N. For example, for biosolids with C/N of 5 to 10, Gilmour et al. (1985) and Gilmour et al. (2003) reported a linear relationship with a slope not significantly different than one between net amendment N mineralized (% of organic N) and decomposition in soil.

Computer simulation models have shown potential for predicting N mineralization under a wide range of conditions. With proper calibration and verification, many models have the potential to be used for data interpretation, education, and decision support in soil N management (Schaffer et al., 2001). One general criticism of models, however, is the need for further verification (Wagner et al., 1998), particularly using data independent of those used to develop and parameterize the model (McGechan and Wu, 2001).

The model DECOMPOSITION is a mechanistic computer simulation model first described by Gilmour and Clark (1988) and subsequently described in detail by Gilmour (1998). The model uses first-order kinetics to estimate PAN. Most other models that describe N mineralization processes also utilize first-order kinetics, mod-

Eric S. Gale and Dan M. Sullivan, Dep. of Crop and Soil Science, Oregon State Univ., Corvallis, OR 97331. Craig G. Cogger, Andy I. Bary, and Elizabeth A. Myhre, Dep. Crop and Soil Sciences, Washington State Univ., 7612 Pioneer Way E., Puyallup, WA 98371. Delbert D. Hemphill, Dep. Horticulture, Oregon State Univ. North Willamette Research and Extension Center, Aurora, OR 97002. Received 14 Feb. 2006. *Corresponding author (Dan.Sullivan@oregonstate.edu).

Published in J. Environ. Qual. 35:2321–2332 (2006).
Technical Reports: Waste Management
doi:10.2134/jeq2006.0062

677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: PAN, plant-available nitrogen; FNE, fertilizer nitrogen equivalency.

ified for environmental variables (McGechan and Wu, 2001). DECOMPOSITION is a relatively simple model by today's standards. It simulates only the mineralization/immobilization of N following organic amendment application. The model has proved to be reasonably accurate in predicting PAN from municipal biosolids. In an evaluation of the model DECOMPOSITION using 30 different biosolids with field sites in Arkansas, Michigan, Virginia, and Washington, Gilmour et al. (2003) found good agreement between observed PAN vs. simulated PAN during one growing season using actual decomposition kinetics, weather, and amendment analytical data ($r^2 = 0.72$). With three biosolids and one site, Gilmour and Skinner (1999) also found good agreement between observed PAN versus modeled PAN using DECOMPOSITION ($r^2 = 0.67$). Findings from the model have been used to develop national guidance for biosolids application based on average air temperature and irrigation (Gilmour et al., 2000).

The current study was designed to provide data to support Extension recommendations for organic amendments. Specifically, our objectives were to (i) measure decomposition and N released from fresh and composted amendments and (ii) evaluate the performance of the model DECOMPOSITION, a relatively simple N mineralization/immobilization model as a predictor of N availability.

MATERIALS AND METHODS

Description of Amendments

Amendments used in this study are grouped into four categories: a fresh amendment vs. compost product comparison (n = 28 samples), other broiler litter (n = 5), other composts (n = 6), and specialty products (n = 5; Table 1).

Materials in the fresh amendment vs. "compost product" group (broiler litter, separated dairy solids, yard trimmings, and rabbit manure) were selected to allow structured comparisons between fresh and composted materials from the same source. Amendments included in the fresh amendment vs. "compost product" group came from the same processors in both Year 1 and Year 2, and were delivered to field experiment sites at the same time (±3 d). Broiler litter, separated dairy solids, and yard trimmings were included in the Oregon and Washington field experiments in both Year 1 and Year 2, whereas rabbit manure was included only in Year 2.

Broiler litter was obtained from a production broiler facility (Mossy Rock, WA) that routinely markets a compost product to farmers and landscapers. Although marketed as compost, the amendment production process includes only periodic turning of large windrows without moisture addition. The fresh broiler litter was dry-stacked for 56 d (2002 sample) or 14 d (2003 sample). The composted broiler litter samples were dry-stacked for 84+ d in both years.

Separated dairy solids were collected from a dairy (Woodburn, OR) that employed a flush manure handling system. A mechanical separator removed the coarse, fibrous fraction of the manure as it passed from the animal confinement area to a storage lagoon. Fresh dairy solids were stored less than 7 d at the dairy. Composted dairy solids were produced in windrows that were turned weekly over a 60-d period with a self-propelled windrow turner. At each turning, moisture was added (if needed) to maintain moisture of 500 to 600 g kg^{-1} in the compost windrow.

Yard trimmings and yard trimmings compost were produced at a large indoor commercial compost facility in Puyallup, WA. Yard trimmings consisted of approximately a 60:40 mixture (v/v) of woody tree and shrub trimmings mixed with grass clippings. Both yard trimmings and yard trimmings compost were ground with a hammer mill to reduce particle size on receipt at the facility. The yard trimmings then were placed in windrows, and allowed to heat for 7 d with periodic turning to kill weed seeds. The yard trimmings compost was prepared by placing yard trimmings in windrows and turning a minimum of 5 times over a 40-d period with a compost pile turner. Moisture was added at each turning, and windrows received forced aeration based on automated feedback from temperature probes placed in the windrows. After 40 d, the compost was placed in larger curing piles for at least 20 additional d. Before delivery to field experiments, large debris >11 mm (>7/16 in.) was removed from the yard trimmings compost by screening.

Fresh rabbit manure without bedding was obtained from a rabbit production facility near Corvallis, OR. The rabbit manure compost was produced in small outdoor windrows (50 m long, 1 m high and 2 m wide) in summer. Windrows were turned with a compost pile turner and moisture was added at least six times during 60 d of active composting. Some soil underlying the windrows was incorporated during composting. The finished rabbit manure compost was covered with plastic sheeting in the fall. The cover was removed just before transport to the field experiment locations the following spring.

The remaining organic materials used in the study (other broiler litter, other composts, specialty products; Table 1) came from a variety of sources and were included in selected laboratory incubations and field trials. Other broiler litters (n = 6) were obtained from broiler production facilities; information on storage and/or composting time and methodology was not available. Other composts (n = 6) included two samples of composted dairy solids from additional local facilities, one sample of solids from an anaerobic dairy manure digester, and three samples of composts prepared by a Puyallup, WA composting school. The anaerobically digested dairy solids were collected from a complete mix digester, operating at 36°C with a mean residence time of 28 d. The composts from the compost school were produced from a 40:20:15:5:10 v/v mixture of yard trimmings, separated dairy solids, cereal straw, horse manure, and laying-hen manure that was composted for approximately 180 d under passive aeration. Specialty amendments (n = 5) included two samples of pelleted organic fertilizer derived from fish byproducts, two feather meals, and one canola (*Brassica* spp.) meal.

Amendment Sampling, Handling, and Preparation for Analyses

Amendments were transported to the field experiment sites no more than 7 d before field application, and kept under cover. Immediately before amendment application at each field experiment, composite amendment samples for inorganic N analysis and for use in soil incubation experiments were collected, subsampled, placed into 1-L zippered polyethylene bags, then frozen within 24 h of collection. Each composite amendment sample was a subsample derived from a mixture of 20 grab samples collected from the amendment pile or bag.

Total solids in the fresh and thawed amendment samples were determined by drying at 55°C. There was no consistent difference between total solids in fresh samples or in samples thawed after freezing.

Field Studies

'Jubilee' sweet corn (*Zea mays* L.) was grown at both field sites located at the WSU Research and Extension Center

Table 1. Laboratory analyses and field application rates for organic amendments used in field and laboratory trials.

Treatment	Field location	Year	Total solids	C	N	C/N	NH_4–N	NO_3–N	Field application rate (dry weight)	Total N application rate
			g kg^{-1}	g kg^{-1}	g kg^{-1}		g kg^{-1}	mg kg^{-1}	Mg ha^{-1}	kg ha^{-1}
Fresh vs. "compost product" comparison										
Broiler litter	OR	2002	707	372	41.9	9	7.21	62	5	207
Broiler litter	WA	2002	759	365	41.9	9	8.27	56	5	191
Broiler litter	OR	2003	768	339	34.6	10	4.67	150	5	173
Broiler litter	WA	2003	778	356	35.1	10	4.93	223	5	178
Broiler litter "compost"	OR	2002	679	365	42.2	9	6.51	30	5	200
Broiler litter "compost"	OR	2003	673	351	37.2	9	8.09	40	5	168
Broiler litter "compost"	WA	2003	631	337	41.2	8	9.33	45	4	169
Broiler litter "compost"	WA	2002	655	361	41.3	9	5.34	187	5	189
Dairy solids	OR	2002	207	434	13.6	32	0.69	<3	31	428
Dairy solids	WA	2002	195	421	21.1	20	1.79	<3	31	660
Dairy solids	OR	2003	229	418	14.6	29	1.16	<3	35	507
Dairy solids	WA	2003	182	425	15.5	27	2.40	6	28	429
Dairy solids compost	OR	2002	228	406	20.4	20	0.64	36	35	709
Dairy solids compost	WA	2002	237	379	20.3	19	0.58	93	35	702
Dairy solids compost	OR	2003	231	387	19.5	20	0.43	138	35	682
Dairy solids compost	WA	2003	211	396	19.4	20	0.75	15	32	622
Rabbit manure	OR	2003	251	338	31.3	11	9.32	<3	13	408
Rabbit manure	WA	2003	244	339	28.7	12	6.08	<3	11	304
Rabbit manure compost	OR	2003	423	179	19.0	9	0.03	1978	18	349
Rabbit manure compost	WA	2003	439	178	16.9	11	0.01	1019	19	321
Yard trimmings	OR	2002	424	304	23.5	13	2.54	47	18	427
Yard trimmings	WA	2002	505	271	21.8	12	2.37	23	23	496
Yard trimmings	OR	2003	351	235	17.9	13	3.05	7	15	273
Yard trimmings	WA	2003	389	246	16.7	15	4.08	<3	21	353
Yard trimmings compost	OR	2002	552	284	13.9	20	0.28	18	24	329
Yard trimmings compost	WA	2002	574	324	14.7	22	0.09	<3	26	379
Yard trimmings compost	OR	2003	574	247	20.3	12	0.81	268	25	505
Yard trimmings compost	WA	2003	561	241	19.9	12	1.67	3	30	605
Other broiler litter										
Bulk broiler litter	WA	2003	607	332	35.1	9	6.48	6	–	–
Bulk broiler litter	WA	2002	722	336	35.1	10	6.73	93	–	–
Bagged broiler litter	OR	2003	783	321	40.5	8	5.62	816	5	213
Bulk broiler litter	WA	2003	584	364	36.4	10	9.70	4	–	–
Bulk broiler litter	WA	2003	640	346	36.6	9	6.69	9	–	–
Other composts										
Anaerobically digested dairy solids	OR	2003	279	365	18.6	20	2.41	<3	42	789
Dairy solids compost	WA	2002	321	271	24.5	11	0.13	1504	–	–
Compost school compost	WA	2002	370	279	16.4	17	<0.01	151	49	802
Compost school compost	WA	2003	404	234	17.5	13	0.23	1126	44	768
Compost school compost	WA	2003	425	295	20.3	15	3.38	603	–	–
Dairy solids compost	WA	2002	267	441	16.6	27	0.14	664	30	496
Specialty products										
Pelleted fish byproduct	WA	2002	958	424	97.0	4	0.83	<3	2	186
Pelleted fish byproduct	WA	2003	956	414	90.9	5	1.10	13	1	123
Canola meal	WA	2003	975	452	56.6	8	0.11	18	3	156
Feather meal	WA	2002	945	523	137.2	4	1.98	50	2	259
Feather meal	WA	2003	738	354	35.5	10	5.47	198	–	–

at Puyallup, WA and at the OSU North Willamette Research and Extension Center near Aurora, OR. The Oregon site was located on a Willamette silt loam soil (fine-silty, mixed, superactive, mesic Pachic Ultic Argixerolls). The Washington site was located on a Puyallup fine sandy loam (coarse-loamy over sandy, mixed mesic Vitrandic Haploxerolls). The 2003 trials were conducted on acreage adjacent to the 2002 field trials (within the same field). The previous crop at the Oregon site in 2002 and 2003 was summer fallow. The previous crop at the 2002 Washington site was sweet corn followed by a winter triticale cover crop. The previous crop at the 2003 Washington site was sweet corn with no winter cover crop.

Pre-amendment soil samples collected in March or April of each year at each field site indicated that soil pH (>6.1) and soil test concentrations of P, Ca, Mg, and K were above established sufficiency levels for sweet corn production (Marx et al., 1999). At the Oregon sites only, blanket applications of soluble boron and sulfate of potash magnesia fertilizer ($K_2SO_4.2MgSO_4$) were applied before seeding to supply 1 kg B ha^{-1} and 30 kg S ha^{-1}. Soluble boron was sprayed on the soil surface with a boom sprayer. Granular sulfate of potash magnesia fertilizer was broadcast on the soil surface.

Both sites had a typical maritime Pacific Northwest climate with cool, wet winters and mild, dry summers. Mean growing season temperatures were 18°C in 2002 and 20°C in 2003 at the Oregon site, and 16°C in 2002 and 17°C in 2003 at the Washington site. Seeding dates were 25 May for the OR 2002 site, 13 June for the OR 2003 site, 21 May for the WA 2002 site and 28 May for the WA 2003 site. Degree days (0°C base temperature) from amendment application to harvest averaged 2240 across sites (Table 2). Growing season precipitation was 72 mm in 2002 and 42 mm in 2003 at the Oregon site, and 81 mm in 2002 and 37 mm in 2003 at the Washington site. Irrigation was supplied by solid-set sprinklers on a schedule designed to limit leaching losses but provide adequate moisture for crop production. Approximately 2.5 cm irrigation was supplied every 7 d during peak crop evaporative demand.

Table 2. Degree days elapsed between organic amendment incorporation and soil sampling for PAN determination in field and laboratory.†

	Field trial								Laboratory incubation	
			Soil sampling dates			Degree days elapsed				
Site year	Amendments (date applied)	Corn (date seeded)	Pre-plant	Mid-season‡	Harvest	Pre-plant	Mid-season	Harvest	Days	Degree days
OR 2002	25 April	25 May	23 May	9 July	5 September	324	1136	2292	14	308
OR 2003	14 May	13 June	11 June	10 July	12 September	482	1012	2335	42	924
WA 2002	3 May	21 May	17 May	1 July	10 September	151	849	2197	70	1540
WA 2003	30 April	28 May	14 May	13 June	4 September	168	618	2127	–	–

† Degree days calculated with 0°C base temperature.
‡ Mid-season soil samples collected at 3 to 4 leaf growth stage for WA experiments and 5 to 7 leaf growth stage for OR experiments.

Experimental Design

Organic amendment or urea fertilizer treatments were replicated four times within a randomized complete block design. Plots were 4.6 × 9.1 m (15 × 30 ft) with six rows of corn per plot (76-cm row spacing). Corn was seeded approximately 30 d following amendment application (Table 2). Plants were thinned to 40 000 plants ha^{-1} at the four-leaf growth stage.

Urea treatments (no organic amendment) supplied a total of 0, 56, 112, 168, or 224 kg N ha^{-1} during the growing season, split into starter and sidedress applications. Starter urea was broadcast 1 or 2 d before planting, with additional side-dress urea broadcast just before irrigation at the four- to six-leaf growth stage. The side-dress fertilizer application took place 1 to 3 d following the date of mid-season soil sample collection (Table 2). In Year 1, 28 kg ha^{-1} of urea-N was applied before planting with the remainder added at the six-leaf growth stage. In Year 2, 56 kg ha^{-1} of urea-N was applied before planting with the remainder at the six-leaf growth stage.

Organic amendments were weighed, and then broadcast on the soil surface. Amendment application rates (Table 1) were based on estimates of amendment PAN, targeted to supply 40 to 120 kg PAN ha^{-1} during the growing season, based on current Extension guidance for the Pacific Northwest (Bary et al., 2000). To calculate application rates, we estimated PAN (% of total N) of 45% for broiler litter, 10% for dairy solids, 30% for rabbit manure, 15% for yard trimmings, 10% for composts, and 50% for specialty products and assumed typical total N analyses and total solids concentrations. Urea was not applied to plots receiving organic amendments. Actual amendment application rates were determined after application by multiplying amendment application amount by measured total solids concentration. Amendments were incorporated into soil by rototilling to a depth of 15 cm. Broiler litter and rabbit manure were incorporated within 2 h of application to limit NH_3 loss. Other materials with lower potential for NH_3 loss were incorporated within 24 h.

Soil samples were collected at three times following organic amendment application: pre-plant (after 14 to 28 d), mid-season (after 44 to 75 d), and post-harvest (after 121 to 133 d; Table 2). Each sample was a composite of 8 to 12 soil cores (0- to 30-cm depth) collected per plot with a 25-mm-i.d. push probe. Soil samples were air-dried within 1 d to stop microbial activity.

Laboratory Incubations

Decomposition of amendment organic matter was estimated via incubation with soil. The incubation was performed at 22°C in sealed 0.95-L Mason jars, with three replicates per amendment sample. Soil for incubation was collected in May from each field site approximately 30 d before the start of the laboratory incubations, and held at field moisture at 4°C. At the start of each incubation, soil was allowed to warm to room temperature for 3 d, then sufficient moisture added to bring gravimetric soil moisture to 200 to 250 g kg^{-1}. Thawed amendment samples equivalent to 1 g dry weight were incorporated into 50 g soil for an application rate of 20 g kg^{-1} in Year 1. In Year 2, we reduced amendment incorporation rates to bring laboratory incubation amounts closer to those used in the field experiments. Incorporation rates were 5 g kg^{-1} for broiler litter samples, feather meal, and pelleted fish; other amendments were incorporated at a rate of 10 g kg^{-1}. Each incubation included soil-only control jars to allow calculation of net CO_2 evolution associated with amendment incorporation.

We used a titration method to determine CO_2 evolution in Year 1, and a gas chromatograph method to determine CO_2 in Year 2. Measurements were made after 3, 7, 14, 21, 28, 35, 42, 49, and 70 d. In Year 1, CO_2 was collected in vials containing 20 mL 1*M* NaOH that were placed inside the incubation jars. Vials were replaced inside the jars after each incubation interval. For CO_2 determination in Year 1, the carbonate trapped by NaOH was precipitated with excess $BaCl_2$, and the remaining NaOH was back-titrated with standardized 0.1 *M* HCl, using phenolphthalein as the indicator (Anderson, 1982). In Year 2, air was collected from sample jars by inserting a syringe through a rubber septum in the jar lid. Carbon dioxide was determined with a He-carrier gas chromatograph (Carle Series 100 AGC, Hach, Loveland, CO). A calibration experiment verified that the chromatograph CO_2 method used in Year 2 yielded comparable data to the titration method used in Year 1. We incubated 15 amended jars (5 amendments × 3 replicates) and determined CO_2 evolved after 3, 7, and 14 d. A regression between the two methods yielded an r^2 of 0.98, a slope not significantly different than one, and an intercept not significantly different from zero.

Inorganic N accumulation was measured using incubation intervals of 14, 42, and 70 d, and the same amendment incorporation rates were used to measure CO_2 evolution. For inorganic N measurement, moist soil (650 g dry wt.) + amendment were incubated in zippered 3.8-L polyethylene bags. The larger incubation samples provided a larger amount of soil for repeated subsampling, and allowed for ventilation while maintaining consistent soil moisture. The target soil moisture content used in this experiment (200 to 250 g H_2O kg^{-1}) allowed thorough mixing of the amendments with soil, and it allowed the soil aggregates to remain small. The small soil aggregates were easily subsampled, and porosity was maintained throughout the soil-amendment mixture. The zippered tops of the bags were left partially open during incubation to facilitate air exchange, thereby reducing the potential for denitrification. Incubation bags were placed within 20-L plastic tubs that contained moistened foam pads to increase humidity. At 14-d intervals, soil moisture in the bags was measured and replenished if necessary. Soil subsamples (15 g) for inorganic N analysis were collected from the bags on Day 0, 3, 7, 14, 42, and 70 in Year 1 and at Day 0, 14, 42, and 70 in Year 2, extracted with

50 mL 2*M* KCl, and refrigerated (4°C) until analysis. Additional soil samples were collected at each sampling date for determination of actual soil moisture. Soil moisture data were used to convert inorganic N concentrations in moist soil to a dry weight basis.

Soil and Amendment Analyses

Inorganic N in all soil samples and in amendment samples was determined by automated colorimetric methods after extraction with 2*M* KCl at the Oregon State University Central Analytical Laboratory. Ammonium-N was extracted from both fresh and dried amendment samples using a 1:5 solids/extractant ratio. Nitrate-N was extracted from only the fresh amendment samples, because nitrate is not volatilized when samples are oven-dried. After shaking for 30 min, KCl extracts were filtered through Whatman No. 42 paper and refrigerated before analysis. Extracts were diluted to prevent interference from dissolved organic matter in colorimetric N determinations. Ammonium-N was determined using a salicylate-nitroprusside method (Gavlak et al., 1994) and nitrate-N was determined by a cadmium reduction method (Gavlak et al., 1994). For total N and C determination, organic amendments were prepared by grinding to pass a 2-mm screen. Total N and C were determined using a combustion analyzer equipped with an infrared detector (LECO Instruments Model CNS 2000, LECO Instruments, St. Joseph, MI; Sweeney, 1989).

Calculations and Statistics

Total N concentrations (N_t) in amendment samples were calculated as:

$$N_t = \text{Total } N_{dried} - NH_4\text{–}N_{dried} + NH_4\text{–}N_{fresh} \quad [1]$$

where N_t = total N in fresh amendment (g kg^{-1}; dry wt basis), total N_{dried} = total N in dried amendment (g kg^{-1}; dry wt basis), NH_4–N_{dried} = NH_4–N in dried amendment (g kg^{-1}; dry wt basis), and NH_4–N_{fresh} = NH_4–N in fresh amendment (g kg^{-1}; dry wt basis).

For each field trial site-year, we calculated full-season PAN supplied by amendments with a two-step calculation. First, we used linear regression to calculate the fertilizer N efficiency coefficient (eff) for the urea fertilizer treatments:

$$N_{rec} = \text{eff} \times N_{rate} + b \quad [2]$$

where N_{rec} = N recovered at harvest (kg ha^{-1}), calculated as the sum of N in above-ground biomass at harvest + post-harvest soil nitrate N (0- to 30-cm depth); eff = fertilizer efficiency coefficient, or the fraction of fertilizer N that was recovered at harvest; N_{rate} = the rate of urea-N (kg ha^{-1}) applied for a given site and year; and b = N recovery intercept (kg ha^{-1}), a regression estimate of the N recovered from the zero N fertilizer control plot.

Then Eq. [2] was rearranged and amendment PAN calculated using a fertilizer N equivalency approach:

$$\text{Amendment PAN} = \frac{\left(\dfrac{N_{rectrt} - b}{\text{eff}}\right)}{\text{amendment N applied}} \times 100 \quad [3]$$

where PAN = percentage of amendment total N recovered (kg ha^{-1}); N_{rectrt} = N recovered (kg ha^{-1}) for a treatment receiving application of pre-plant organic amendment; eff and b are substituted from the fertilizer efficiency regression (Eq. [2]) for the appropriate site and year; and amendment N applied = total N application rate for each amendment (kg ha^{-1}; Table 1).

For field pre-plant soil samples, and for mid-season soil samples, we calculated PAN as the additional N recovered from soil following organic amendment application, as:

$$\text{PAN} = \frac{\text{treatment inorganic N} - \text{control N}}{\text{amendment N applied}} \times 100 \quad [4]$$

where PAN = percentage of amendment total N recovered (kg ha^{-1}) from amended soil; treatment inorganic N = soil NH_4–N + NO_3–N (kg ha^{-1}) for soil receiving amendment application; control N = soil NH_4–N + NO_3–N (kg ha^{-1}) for soil alone (no amendment or fertilizer applied); and amendment N applied = amendment total N applied (kg ha^{-1}).

Equation [4] was also used for laboratory PAN calculation, except that it was calculated using units of mg kg^{-1}.

Amendment decomposition, as measured by CO_2 evolution, was calculated as:

$$\text{Decomposition} = \frac{\text{treatment } CO_2\text{–C} - \text{control } CO_2\text{–C}}{\text{total C applied}} \times 100 \quad [5]$$

where decomposition = percentage of amendment C evolved as CO_2–C; treatment CO_2–C = cumulative CO_2–C evolved (mg) from soil receiving amendment application; control CO_2–C = cumulative CO_2–C evolved (mg) for soil alone; and total C applied = amendment C addition (mg).

Linear regression was performed using S-Plus (S-Plus 6.1 for Windows, Insightful). Regression equations for observed vs. modeled PAN were tested at P = 0.05 to determine whether the regression intercept was different than zero, and whether the slope of the regression equation was different than one.

Computer Simulation Model

The model DECOMPOSITION is a mechanistic model first described by Gilmour and Clark (1988) and described in detail by Gilmour (1998). The model uses first-order kinetics to estimate the rates of C and N transfer between six pools: fresh organic amendment (rapid and slow fractions), microbial biomass (indigenous and new), and soil organic matter (decomposable and recalcitrant) using daily time steps. Initial soil organic matter is divided equally between decomposable and recalcitrant pools. Default decomposition rate constants (d^{-1}) are 0.035 for fresh biomass, 0.00093 for indigenous biomass, and 0.00020 for decomposable soil organic matter. The recalcitrant soil organic matter pool does not decompose. The decomposition of amendments is modeled using a sequential first-order model where the rapid fraction is entirely decomposed before decomposition of the slow fraction begins. Amendment decomposition rate constants (k_r for the rapid pool and k_s for the slow pool) are determined from 25°C laboratory incubation data using a segmented regression of the natural log of the percent C remaining. Nitrogen mineralization and immobilization in the model are driven by C decomposition, microbial efficiency, and C/N of the amendment, biomass, and soil organic matter. Microbial efficiency is assumed to be 0.4. Carbon/nitrogen ratios are assumed to be 10 for soil organic matter and 8 for microbial biomass. As the amendment decomposes, if amendment C/N is >15, then soil inorganic N is immobilized in microbial biomass. The model assumes zero N loss via NH_3 volatilization or denitrification processes. Amendment decomposition rates (measured at 25°C) are modified for temperature using a Q_{10} approach and modified for soil moisture using a soil water factor scaled from

0 to 1 (Gilmour, 1998). Soil temperature is assumed to equal air temperature.

John Gilmour (John Gilmour, Fayetteville, Arkansas) received input data from our project consisting of a numeric amendment sample ID, amendment analyses for total N, total C, and NH_4–N (dry weight basis), and amendment application rate. Gilmour calculated fast and slow decomposition rate constants for use in the simulations (Table 3) using our data for cumulative amendment CO_2 loss over 70 d (Fig. 1). For use in the model, he multiplied our measured decomposition rate constants by 1.28, assuming a Q_{10} of 2, to estimate the amendment decomposition rate constant at 25°C. For modeling of inorganic N release in the laboratory incubations, Gilmour received data on soil moisture during incubation, temperature, and inorganic N recovered from the soil-only control (no amendment) at each soil incubation sampling date. For the field experiments, we provided Gilmour with dates of amendment application, daily average air temperatures collected from weather stations located within 1 km of each field site, and daily precipitation and daily irrigation application amounts.

Gilmour ran the DECOMPOSITION model (version DECOMP96) beginning on the date of amendment application to estimate inorganic N release from the organic amendments. The values generated in the model output represented

Table 3. Fitted kinetic parameters for sequential decomposition of organic amendments in the laboratory, and measured cumulative decomposition after 70 d at 22°C.†

				Sequential decomposition model parameters†			Laboratory‡
Treatment	Field location	Year	Applied in field?	k_r	k_s	Rapid fraction	Cumulative C loss in 70 d
				d^{-1}		% of total C	
Fresh vs. "compost product" comparison							
Broiler litter	OR	2002	yes	0.029	0.002	39	45 (0.7)
Broiler litter	WA	2002	yes	0.052	0.003	38	47 (0.6)
Broiler litter	OR	2003	yes	0.071	0.006	57	70 (6.6)
Broiler litter	WA	2003	yes	0.051	0.004	58	64 (3.6)
Broiler litter "compost"	OR	2002	yes	0.033	0.003	43	51 (0.9)
Broiler litter "compost"	WA	2002	yes	0.061	0.003	43	50 (0.6)
Broiler litter "compost"	OR	2003	yes	0.036	0.004	43	55 (15.4)
Broiler litter "compost"	WA	2003	yes	0.023	0.0002	33	33 (19.7)
Dairy solids	OR	2002	yes	0.017	0.008	32	55 (2.0)
Dairy solids	WA	2002	yes	0.018	0.008	39	55 (1.9)
Dairy solids	OR	2003	yes	0.020	0.007	45	58 (2.0)
Dairy solids	WA	2003	yes	0.032	0.017	64	81 (8.9)
Dairy solids compost	OR	2002	yes	0.004	–	–	24 (3.7)
Dairy solids compost	WA	2002	yes	0.006	–	–	33 (4.0)
Dairy solids compost	OR	2003	yes	0.005	–	–	29 (5.3)
Dairy solids compost	WA	2003	yes	0.005	–	–	28 (1.4)
Rabbit manure	OR	2003	yes	0.028	0.009	43	62 (2.9)
Rabbit manure	WA	2003	yes	0.031	0.005	63	69 (1.2)
Rabbit manure compost	OR	2003	yes	0.001	–	–	8 (1.1)
Rabbit manure compost	WA	2003	yes	0.003	0.0002	9	9 (1.6)
Yard trimmings	OR	2002	yes	0.011	0.001	16	21 (8.9)
Yard trimmings	WA	2002	yes	0.013	0.002	19	26 (5.5)
Yard trimmings	OR	2003	yes	0.009	0.001	13	18 (1.7)
Yard trimmings	WA	2003	yes	0.019	0.001	27	29 (7.7)
Yard trimmings compost	OR	2002	yes	0.002	–	–	13 (3.1)
Yard trimmings compost	WA	2002	yes	0.003	–	–	16 (2.6)
Yard trimmings compost	OR	2003	yes	0.001	–	–	6 (0.9)
Yard trimmings compost	WA	2003	yes	0.003	0.001	8	9 (1.3)
Other broiler litter							
Bulk broiler litter	WA	2003		0.039	0.001	46	47 (13.9)
Bulk broiler litter	WA	2002		0.020	0.002	18	24 (0.6)
Bagged broiler litter	OR	2003	yes	0.050	0.002	31	39 (2.1)
Bulk broiler litter	WA	2003		0.037	0.001	46	47 (0.4)
Bulk broiler litter	WA	2003		0.058	0.002	60	62 (4.3)
Other composts							
Anaer digested dairy solids	OR	2003	yes	0.009	0.006	25	39 (5.6)
Dairy solids compost	WA	2002		0.002	0.001	5	9 (0.5)
Compost school compost	WA	2002	yes	0.004	–	–	25 (2.2)
Compost school compost	WA	2003	yes	0.002	–	–	13 (4.9)
Compost school compost	WA	2003		0.003	–	–	19 (1.1)
Dairy solids compost	WA	2002	yes	0.003	–	–	20 (0.3)
Specialty products							
Pelleted fish byproduct	WA	2002	yes	0.050	–	–	97 (0.6)
Pelleted fish byproduct	WA	2003	yes	0.114	–	–	101 (5.7)
Canola meal	WA	2003	yes	0.088	0.008	74	82 (2.2)
Feather meal	WA	2002	yes	0.036	–	–	92 (0.9)
Feather meal	WA	2003		0.045	0.004	51	58 (8.3)

† Fitted kinetic parameters for sequential decomposition of organic amendments as described by Gilmour (1998), with k_r and k_s as rapid and slow fraction decomposition rate constants, respectively. Rapid fraction (% of total C) is the amount of organic C undergoing decomposition using first-order kinetics and k_r as the rate constant. After the rapid fraction is completely decomposed, the slow fraction (100 minus the rapid fraction percentage) is decomposed by first-order kinetics using k_s as the rate constant.

‡ Value in parenthesis is standard error of the mean (n = 3).

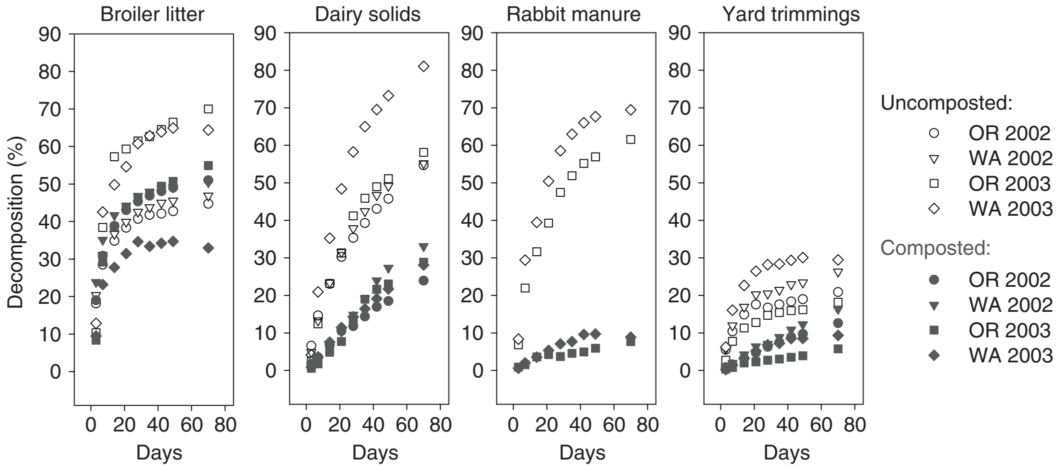

Fig. 1. Cumulative decomposition in the laboratory at 22°C for organic amendments incubated in soils from Washington (WA) and Oregon (OR) field sites in 2002 and 2003. Open symbols represent uncomposted organic amendments, whereas filled symbols represent amendments that were "composted." Fitted regression equations for cumulative decomposition of each amendment are shown in Table 3.

the difference between soil alone and a soil + amendment treatment. For laboratory simulations, moisture was assumed not to limit decomposition rate (water factor = 1). For field simulations, calculated soil water factors that were used to modify decomposition kinetics ranged from 0.7 to 0.9 for June, July, and August. Field simulations were run from the application of amendments in spring to whole plant harvest in September. Inorganic N availability from organic amendments was estimated for the following dates: pre-plant, mid-season, and at whole plant harvest for each site-year. Degree days elapsed (0°C base) at each sampling date are shown in Table 2.

RESULTS AND DISCUSSION

Decomposition of Fresh and Composted Amendments

We incubated the organic amendment sample collected from the bulk amendment pile or bagged amendment at each field site with the soil found at the site. This sampling method permitted direct comparison of amendment performance in the field and laboratory within each site-year. Amendments used at both field sites (fresh vs. composted product comparison) had similar C and N analyses within 2002 or 2003 (Table 1). Because each amendment sample was incubated with only one soil, we cannot statistically compare decomposition for amendments between the two soils. For amendment sources incubated in both soils (fresh vs. compost product comparison, $n = 14$), the average difference in 70-d decomposition between soils was small (2% of amendment total C).

Composting reduced cumulative decomposition (70 d in laboratory) from 62 to 29% of applied C for dairy solids, from 66 to 9% for rabbit manure, and from 24 to 11% for yard trimmings (Fig. 1; Table 3). Dry stacking of broiler litter (sold as "compost") did not consistently reduce amendment decomposition in soil. Amendments sold as broiler litter "compost" retained most of the characteristics of raw broiler litter: rapid decomposition during the first 7 d in soil, amendment C/N of 9 to 10, and NH_4–N of 5 to 9 g kg^{-1} (Table 1). Most of the difference in cumulative decomposition between composts and raw materials occurred during the first 7 to 30 d of incubation in soil at 22°C. Anaerobically digested dairy solids had decomposition (39% in 70 d) that was intermediate between raw dairy solids and composted dairy solids. Other composts included in the study averaged 17% decomposition in 70 d. Specialty products (fish, feather, and canola meals) had very high cumulative decomposition (average = 76% in 70 d) as expected for raw amendments with C/N of 4 to 8. Decomposition rates observed in this study are similar to those reported by others for fresh and composted organic amendments (Ajwa and Tabatabai, 1994; Gilmour, 1998).

Values for rapid and slow decomposition rate constants also reflect differences among amendments (Table 3). Composted amendments generally had a single rate of decomposition using the rate constant fitting procedure described by Gilmour (1998). Averaged over all composts ($n = 14$; excluding broiler litter "compost"), the average decomposition rate was 0.003 C d^{-1} (0.3% of remaining C per d). Values for rapid pool decomposition (k_r) demonstrated relative differences among materials in early decay rate (Table 3). For example, the first-order decay rate for the rapid pool (k_r) for fresh broiler litter was, on average, 2.0 times the k_r value for dairy solids. The k_r values for composted dairy solids, composted yard trimmings, and composted rabbit manure were of the same order of magnitude as the k_s values for their raw counterparts. This finding demonstrated that once the easily decomposable fraction of a raw material was broken down, the remaining material exhibited a decomposition rate similar to that of compost.

Plant-Available Nitrogen

We estimated fertilizer nitrogen equivalency (FNE) in the field trials using crop N uptake + post-harvest soil inorganic N as the measured response variable (Eq. [3]; Table 4). We chose crop N uptake + post-harvest soil inorganic N as the best indicator of FNE because it accounts for N mineralized late in the growing season, and it yielded a linear N response curve across all rates of applied fertilizer N. The FNE regression equations

Table 4. Linear regression equations describing effect of urea-N fertilizer rate on full-season nitrogen recovery (above-ground biomass N at harvest + post-harvest soil nitrate N) in field trials.†

Site year	Slope (eff) fertilizer efficiency	Intercept (b)	Adjusted r^2
		kg N ha^{-1}	
OR 2002	0.77	87	0.69
WA 2002	0.46	54	0.63
OR 2003	0.77	58	0.91
WA 2003	0.71	95	0.72

† N recovery = eff × N rate + b (Eq. [2]) for five urea-N rates: 0, 56, 112, 168, and 224 kg ha^{-1}.

used to estimate PAN had reasonable fertilizer N recovery efficiency, averaging 68% across the four field site-years (Table 4). We also determined FNE based on other crop response variables: crop N uptake, fresh weight ear yield, and chlorophyll meter readings of leaves (Gale, 2005). All methods used for estimating FNE yielded similar values for the organic amendment treatments. Coefficients of determination (r^2) between FNE determined using crop N uptake + post-harvest soil inorganic N (Eq. [3]) and other variables were: 0.80 for chlorophyll readings, 0.96 for crop N uptake, and 0.90 for fresh weight ear yield (Gale, 2005).

The laboratory incubation (70 d at 22°C) and the full-season PAN determination in the field (based on FNE) provided similar estimates of PAN across amendments (Fig. 2). The linear regression equation for lab PAN vs. field PAN had a slope not different from one and a y-intercept not different than zero. Other studies also have found a strong relationship between N mineralization in laboratory incubations and N mineralization or N uptake in field or greenhouse settings. Castellanos and Pratt (1981) found a strong relationship ($r^2 = 0.90$) between N released in a 70-d incubation of 10 manures in soil and PAN in a 10-mo cropping period. With soils amended with animal manures, Serna and Pomares (1991) found coefficients of regression ranging from 0.61 to 0.75 between laboratory incubations of 2 to 16 wk and N uptake by corn in a 6-wk culture chamber study. In soil amended with dairy manure at four rates over 2 yr, Haney et al. (2001) found r^2 values between a 24-d incubation and forage uptake in the field of 0.81 and 0.89.

Amendment C/N was an approximate indicator of mineralization potential in both field and laboratory experiments. Because of the strong correlation between field and laboratory PAN (Fig. 2), we show only field PAN vs. amendment C/N (Fig. 3). As C/N increased from 4 to 15, PAN decreased. Specialty products with C/N of 4 to 10 averaged 78% PAN, broiler litters with C/N of 8 to 10 averaged 40% PAN, rabbit manure with C/N of 11 and 12 averaged 27% PAN, yard trimmings with C/N of 13 to 15 averaged 19% PAN, and dairy solids with C/N of 20 to 32 averaged 9% PAN in the field trial. Composts with C/N from 9 to 27 averaged 7% PAN. The breakeven C/N for organic N immobilization and/or mineralization in DECOMPOSITION is 15, so our data are in approximate agreement with the model for this parameter.

Laboratory incubations showed that composting reduced N availability for amendments with fresh C/N ratios below 15 (yard trimmings, rabbit manure), and increased N availability for dairy solids (Fig. 4). Composting reduced 70-d laboratory PAN from 25 to 5% for yard trimmings and from 42 to 19% for rabbit manure. Composting increased 70-d PAN from 1 to 8% for dairy solids. Composted dairy solids mineralized N at a slow rate for most of the incubation period, whereas fresh dairy solids immobilized N. Net immobilization during incubation lasted for 14 d for composted dairy solids and until the end of the 70-d incubation for fresh dairy solids. Plant-available N was similar for all broiler litters, regardless of whether they were sold as fresh or "composted." This finding is consistent with the decomposition data for fresh and composted broiler litters (Fig. 1), which showed that dry stacking of litter did not produce stable compost.

With the exception of the broiler litter "compost," PAN values reported for composted and fresh manures and yard trimmings are within the range reported in our study. For uncomposted poultry manures, PAN estimated from lab incubation was 18% of total N (Gilmour et al., 2004), 23 to 37% of total N (Tyson and Cabrera, 1993), and 38 to 58% of organic N (Preusch et al., 2002). For composted poultry manure, reported PAN values were 3 to 5% of total N (Tyson and Cabrera, 1993), 9% of total N (Kirchmann, 1990), and 1 to 9% of organic N (Preusch et al., 2002). These values are much lower than

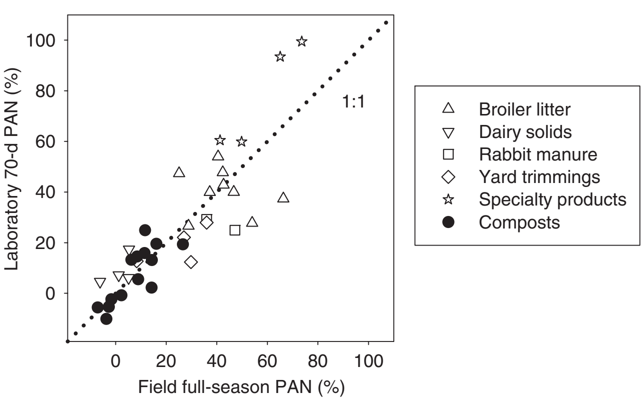

Fig. 2. Plant-available nitrogen (PAN) observed for the full season in the field vs. PAN observed at 70 d in laboratory incubations at 22°C.

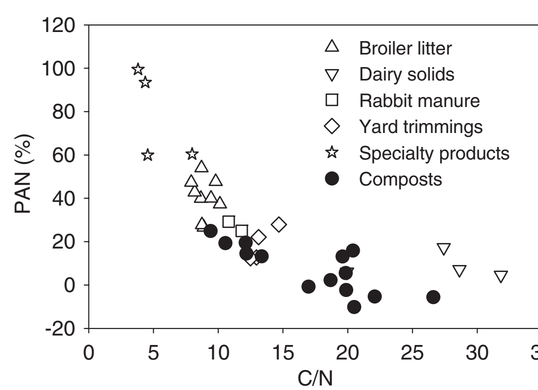

Fig. 3. Relationship between full-season PAN in field trials and organic amendment C/N.

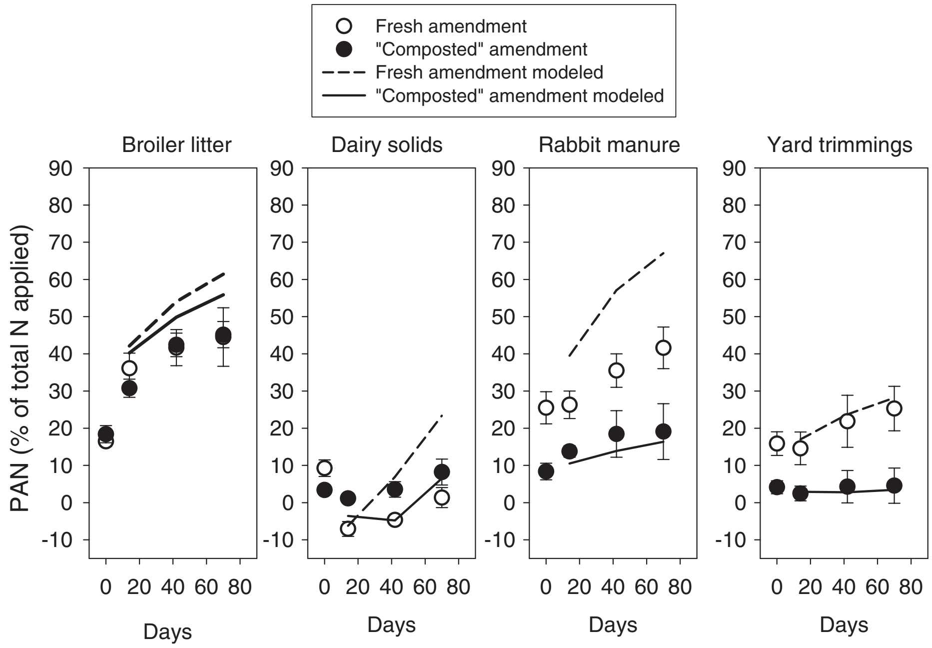

Fig. 4. Observed and modeled PAN for laboratory incubations of amendments included in the fresh vs. "composted" product comparison. Data points represent averages across soils and years (n = 2 for rabbit manure; n = 4 for others). Error bar is standard error of the mean computed across soils and years. Point estimates of PAN were estimated by the DECOMPOSITION model for 14, 42, and 70 d of incubation at 22°C.

for the dry-stacked broiler litter (sold as compost) reported in this study. Shi and Norton (2000) reported PAN of 7% for composted dairy solids, with most of PAN (6%) present at application. Van Kessel and Reeves (2002) reported a median value of 15% of dairy manure organic N mineralized in a 56-d incubation study that included 107 dairy manures with a median C/N ratio of 10. For yard trimmings composed of woody materials plus grass clippings, first-year PAN was 12% of total N in a laboratory incubation study (Sullivan et al., 2004), and 14% of total N in the first year of a field study (Bary et al., 2004). Plant-available N from composted urban yard trimmings mixed with food waste was near zero during the first season (Sullivan et al., 1998), and PAN from composted yard trimmings was 2% of total N (Hartz et al., 2000).

Model Verification: Laboratory and Field

Across all amendments, observed PAN was strongly correlated with PAN estimated by the DECOMPOSITION model, as demonstrated by regressions at 70-d in the laboratory (r^2 = 0.74) and for the full season in the field (r^2 = 0.78; Fig. 5). Although strongly correlated, modeled PAN was often greater than observed PAN. For the 70-d laboratory incubation, the slope of the regression line was not different than one, but the intercept was significantly greater than zero at P = 0.05. For the full season in the field, the regression line was not different than the 1:1 line in slope or intercept. Across all amendments, the average model overprediction of PAN determined by subtraction (modeled PAN minus observed PAN for each amendment) was 3% PAN at 14 d, 7% at 42 d, and 10% at 70 d in the laboratory (Table 5). In the field, the model overpredicted by an average of 3% PAN at preplant, 10% at mid-season, and 8% for the full season (Table 5).

The model consistently overpredicted PAN for amendments with high inorganic N concentrations at application and/or rapid decomposition rates in soil (Fig. 5; Table 5). Examples of these amendments include broiler litter, rabbit manure, and specialty products (fish, feather, and canola meal). For these materials, the discrepancy between modeled and observed values generally grew with incubation time (Fig. 4). At the end of the laboratory incubation (70 d), the model overpredicted by 11% PAN for all broiler litters (n = 13; including "composted" litter and other broiler litter), by 25% for rabbit manure (n = 2), and by 32% for fish, feather, and canola meal specialty products (n = 5). Several explanations for model lack-of-fit for these materials are possible. First, inorganic N may have been lost by processes that are not represented within the model. Second, the increase in lack-of-fit with incubation time suggests that the model predicted greater release of N from microbial biomass than was observed in our incubations.

The model was more accurate in predicting PAN from composts having a single decomposition rate constant than for uncomposted materials that had rapid and slow decomposition rate constants in the laboratory (Fig. 4) and in the field (Fig. 5). The composts had very low decomposition rates compared to fresh materials (Table 3). Compost PAN increased slowly with time in the laboratory (Fig. 4) and in the field (Table 5). Often the 70-d PAN for composted materials was close to that measured at the start of the incubation. Thus, the modeling of PAN for composts did not provide a strong test of

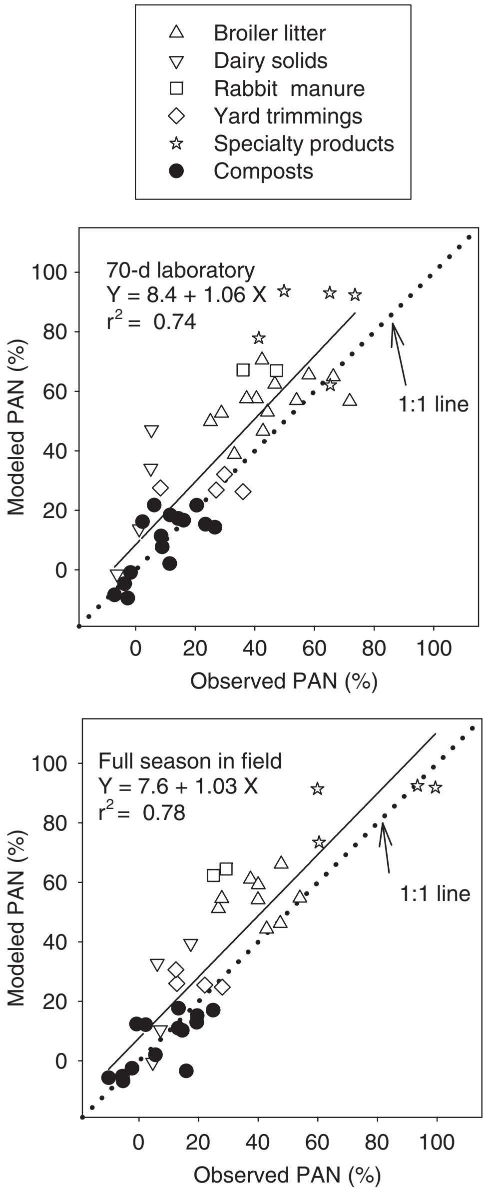

Fig. 5. Observed and modeled PAN for laboratory incubation at 22°C and for full-season field trials. Dotted line is 1:1 line.

model capacity to simulate N mineralization and/or immobilization processes.

CONCLUSIONS

Recommendations for Estimating PAN for Organic Amendments

Three categories of amendment PAN were observed in our study. Well-composted amendments with slow decomposition rates in soil supplied little PAN; their major value lies in supplying organic matter for improving soil tilth. Plant-available N varied widely for rapidly decomposing materials with C/N less than 15, with PAN increasing as C/N decreased. We recommend early season soil nitrate N monitoring when using these materials to supply N for crop production. Many of the amendments in this group contain substantial amounts of NH_4–N at application, which can be rapidly lost as ammonia gas if the amendment is not immediately incorporated by tillage. One amendment used in the study, separated dairy solids, immobilized available N for 30 to 60 d following soil incorporation in our studies. To avoid N deficiency, this amendment should be applied far enough ahead of seeding so that rapid decomposition in soil is completed before planting the crop.

This study demonstrated that field and laboratory measurements of PAN were strongly correlated with PAN modeled by DECOMPOSITION, a model that includes only the mineralization/immobilization portion of the nitrogen cycle. The model tended to overpredict PAN, particularly for amendments with high initial NH_4–N concentrations, and for amendments with rapid decomposition rates in soil. The simplest explanation for this discrepancy is that in our trials, some PAN was lost as NH_3. However, this explanation is not supported by the 1:1 relationship observed between field PAN (some potential for NH_3 loss) and laboratory PAN (very low potential for NH_3 loss). The strong correlations between measured and modeled PAN in the field trials suggested that the algorithms used by DECOMPOSITION to predict N mineralization from amendments are sufficiently detailed to use for planning purposes, when excellent N management practices are used. In situations where substantial PAN losses are expected, the mineralization/immobilization algorithms used in DECOMPOSITION must be integrated into a more complete model. Our study included only one amendment that demonstrated N immobilization (fresh dairy solids). Therefore, we did not obtain sufficient data to verify outputs from the N immobilization algorithms in DECOMPOSITION. The DECOMPOSITION model approach was most valuable for organic materials with C/N of 10 to 15. These materials had the widest range in N availability, depending on whether the organic fraction of the amendment was readily decomposable (e.g., fresh manure) or stable (compost).

This study demonstrated that traditional laboratory analyses of amendments (C/N and total N) and short-term laboratory incubations that determine decomposition and net available N released from amendments have value in providing improved estimates of field PAN for the first growing season. We suggest a minimum data set be used to characterize typical amendment characteristics in guidance publications for organic farmers and others that use manure to supply N, including: amendment total N, C/N, total solids, NH_4–N and NO_3–N, decomposition of the amendment determined after 7, 14, and 28-d incubation, and PAN released from the amendment after 28-d incubation at room temperature (approximately 22°C). Guidance should also include the number of independent amendment samples used to determine typical values. Having three decomposition data points (7, 14, and 28 d) is sufficient to demonstrate whether an amendment has been composted (relatively constant decomposition rate over time) or not composted (rapid decomposition in the first 7 d, followed by slower decomposition). In both our field and laboratory studies, a large fraction of amendment PAN was recovered in the first 28 d after application.

Table 5. Observed and modeled PAN for field and laboratory trials.

			Laboratory observed			Laboratory modeled			Field observed			Modeled for field		
Treatment	Field location	Year	Day 14	Day 42	Day 70	Day 14	Day 42	Day 70	Preplant	Mid-season	Full-season	Pre-plant	Mid-season	Full season
			%											
			Fresh vs. "compost product" comparison											
Broiler litter	OR	2002	39	31	29	38	47	53	16	24	27	31	44	51
Broiler litter	WA	2002	46	37	41	41	51	57	22	39	54	30	45	55
Broiler litter	OR	2003	27	44	42	46	61	71	22	25	48	41	54	66
Broiler litter	WA	2003	32	54	66	43	57	65	19	31	37	27	50	61
Broiler litter "compost"	OR	2002	24	33	37	40	51	58	27	36	40	32	45	54
Broiler litter "compost"	OR	2003	32	46	47	42	54	62	17	18	40	39	49	59
Broiler litter "compost"	WA	2003	31	46	43	39	44	47	19	10	43	29	40	44
Broiler litter "compost"	WA	2002	36	44	54	40	50	57	36	32	28	26	44	55
Dairy solids	OR	2002	−5	−5	−6	−3	−4	−1	−2	−1	5	0	−2	−1
Dairy solids	WA	2002	−6	−4	5	−4	16	34	1	−2	6	4	9	33
Dairy solids	OR	2003	−5	−6	1	−4	−5	14	−1	−3	7	0	−2	10
Dairy solids	WA	2003	−13	−4	5	−14	21	47	0	4	17	8	9	39
Dairy solids compost	OR	2002	0	−2	−2	−2	−2	−1	0	−1	−2	0	−2	−3
Dairy solids compost	WA	2002	0	4	14	−4	1	17	−1	−1	2	1	−1	12
Dairy solids compost	OR	2003	3	6	9	−4	−5	8	1	0	6	−1	−1	2
Dairy solids compost	WA	2003	1	7	11	−5	−13	2	1	−2	16	2	−2	−3
Rabbit manure	OR	2003	30	31	36	41	56	67	11	17	29	40	50	64
Rabbit manure	WA	2003	23	40	47	38	58	67	10	17	25	28	49	62
Rabbit manure compost	OR	2003	15	12	12	12	15	18	6	11	25	12	13	17
Rabbit manure compost	WA	2003	12	25	27	9	13	14	13	14	19	7	11	13
Yard trimmings	OR	2002	5	6	8	18	24	27	6	6	13	16	21	26
Yard trimmings	WA	2002	10	16	30	19	27	32	7	7	12	15	23	31
Yard trimmings	OR	2003	23	28	27	17	23	27	7	12	22	17	21	25
Yard trimmings	WA	2003	21	38	36	13	21	26	12	18	28	19	18	25
Yard trimmings compost	OR	2002	−1	−4	−4	−1	−4	−5	0	−2	−10	0	−3	−6
Yard trimmings compost	WA	2002	−1	−2	−3	−4	−8	−10	2	−2	−5	−1	−3	−7
Yard trimmings compost	OR	2003	5	9	9	6	8	11	5	6	15	6	7	10
Yard trimmings compost	WA	2003	6	14	16	11	15	17	8	8	19	9	13	15
			Other broiler litter											
Bulk broiler litter	WA	2003	25	42	44	41	50	53	–	–	–	–	–	–
Bulk broiler litter	WA	2002	17	27	33	28	34	39	–	–	–	–	–	–
Bagged broiler litter	OR	2003	20	29	25	36	44	50	12	21	47	32	39	46
Bulk broiler litter	WA	2003	39	65	72	43	52	57	–	–	–	–	–	–
Bulk broiler litter	WA	2003	37	55	58	48	60	66	–	–	–	–	–	–
			Other composts											
Anaer digested dairy solids	OR	2003	13	15	14	2	1	17	6	6	13	1	1	11
Dairy solids compost	WA	2002	10	15	23	9	12	15	–	–	–	–	–	–
Compost school compost	WA	2002	1	5	2	5	3	16	2	2	1	0	1	12
Compost school compost	WA	2003	6	8	6	10	15	22	11	8	13	9	12	18
Compost school compost	WA	2003	18	23	21	16	13	22	–	–	–	–	–	–
Dairy solids compost	WA	2002	4	11	7	3	7	8	3	3	6	2	2	−5
			Specialty products											
Pelleted fish byproduct	WA	2002	61	58	65	58	87	93	64	73	93	30	80	92
Pelleted fish byproduct	WA	2003	47	51	50	78	91	94	48	59	60	35	86	91
Canola meal	WA	2003	39	39	41	54	69	78	36	60	60	23	60	73
Feather meal	WA	2002	62	60	74	49	84	92	44	45	99	26	75	92
Feather meal	WA	2003	32	58	65	42	54	62	–	–	–	–	–	–

Decomposition over 28 d is also suitable for determining whether a single decomposition rate constant, or two rate constants (rapid and slow decomposition) are appropriate representation of decomposition kinetics for use in computer simulation models.

ACKNOWLEDGMENTS

This project was supported by Initiative for Future Agriculture and Food Systems Grant no. 2001-52101-11349 from the USDA Cooperative State Research, Education and Extension Service. We thank John Gilmour for running the DECOMPOSITION computer simulation model using our inputs. Soil and organic amendment analyses were performed by the Oregon State University Central Analytical Laboratory under the supervision of Will Austin. Joan Sandeno graciously provided assistance with laboratory research and editing of the manuscript.

REFERENCES

Ajwa, H.A., and M.A. Tabatabai. 1994. Decomposition of different organic materials in soils. Biol. Fertil. Soils 18:175–182.

Anderson, J.P.E. 1982. Soil respiration (Method 41–3.2). p. 841–845. *In* Methods of soil analysis. Chemical and microbiological properties. Agronomy Monograph 9 (Part 2). ASA, CSSA, and SSSA, Madison, WI.

Bary, A.I., C.G. Cogger, and E.A. Myhre. 2004. Yard trimmings as a source of nitrogen for crop production. Compost Sci. Util. 12(1): 11–17.

Bary, A.I., C.G. Cogger, and D.M. Sullivan. 2000. Fertilizing with manure. Pacific Northwest Extension Publication 533. Washington State University Cooperative Extension, Pullman, WA.

Castellanos, J.Z., and P.F. Pratt. 1981. Mineralization of manure nitrogen–correlation with laboratory indexes. Soil Sci. Soc. Am. J. 45:354–357.

Chae, Y.M., and M.A. Tabatabai. 1986. Mineralization of nitrogen in soils amended with organic wastes. J. Environ. Qual. 15:193–198.

Cogger, C., A. Bary, and D.M. Sullivan. 2002. Fertilizing with yard trimmings. Publ. EB1926-E. Washington State Univ. Cooperative

Extension. Pullman, WA. Available at http://cru.cahe.wsu.edu/CEPublications/eb1926e/eb1926e.pdf (verified 26 July 2006).

Gale, E.S. 2005. Estimating plant-available nitrogen release from manures, composts, and crop residues. M.S. thesis. Oregon State University, Corvallis, Oregon.

Gavlak, R.G., D.A. Horneck, and R.O. Miller. 1994. Plant, soil, and water reference methods for the western region. Western Regional Extension Publ. 125, Univ. Alaska-Fairbanks.

Gilmour, J.T. 1998. Carbon and nitrogen mineralization during co-utilization of biosolids and composts. p. 89–112. *In* S. Brown, J.S. Angle, and L. Jacobs (ed.) Beneficial co-utilization of agricultural, municipal and industrial by-products. Kluwer Academic Publ., Dordrecht, the Netherlands.

Gilmour, J.T., and M.D. Clark. 1988. Nitrogen release from wastewater sludge: A site-specific approach. J. Water Pollut. Control Fed. 60: 494–498.

Gilmour, J.T., M.D. Clark, and G.C. Sigua. 1985. Estimating net N mineralization from carbon dioxide evolution. Soil Sci. Soc. Am. J. 49:1398–1402.

Gilmour, J.T., C.G. Cogger, L.W. Jacobs, G.K. Evanylo, and D.M. Sullivan. 2003. Decomposition and plant-available nitrogen in biosolids: Laboratory studies, field studies, and computer simulation. J. Environ. Qual. 32:1498–1507.

Gilmour, J.T., C.G. Cogger, L.W. Jacobs, S.A. Wilson, G.K. Evanylo, and D.M. Sullivan. 2000. Nitrogen management protocols for biosolids beneficial reuse. Final report. Water Environment Federation Project 97-REM-3. WEF stock no. D00307. Water Environment Federation, Alexandria, VA.

Gilmour, J.T., M.A. Koehler, M.L. Cabrera, L. Szajdak, and P.A. Moore, Jr. 2004. Alum treatment of poultry litter decomposition and nitrogen dynamics. J. Environ. Qual. 33:402–405.

Gilmour, J.T., and V. Skinner. 1999. Predicting plant-available nitrogen in land-applied biosolids. J. Environ. Qual. 28:1122–1126.

Haney, R.L., F.M. Hons, M.A. Sanderson, and A.J. Franzluebbers. 2001. A rapid procedure for estimating nitrogen mineralization in manured soil. Biol. Fertil. Soils 33:100–104.

Hansen, R.C., H.M. Keener, C. Marugg, W.A. Dick, and H.A.J. Hointink. 1993. Composting of poultry manure. p. 131–153. *In* H.A.J. Hoitink and H.M. Keener (ed.) Science and engineering of composting: Design, microbiological and utilization aspects. Renaissance Publications. Worthington, OH.

Hartz, T.K., J.P. Mitchell, and C. Giannini. 2000. Nitrogen and carbon mineralization dynamics of manures and composts. HortScience 35:209–212.

Kirchmann, H. 1990. Nitrogen interactions and crop uptake from fresh and composted ^{15}N-labelled poultry manure. J. Soil Sci. 41:379–385.

Kuepper, G. 2003. Manures for organic crop production. Appropriate Technology Transfer for Rural Areas (ATTRA). Fayetteville, AR. Available at http://www.attra.org/attra-pub/PDF/manures.pdf (verified 26 July 2006).

Marx, E.S., J. Hart, and R.G. Stevens. 1999. Soil test interpretation guide. EC 1478. Oregon State University Extension, Corvallis, OR.

McGechan, M.B., and L. Wu. 2001. A review of carbon and nitrogen processes in European soil nitrogen dynamics models. p. 103–171. *In* M.J. Schaffer, L. Ma, and S. Hansen (ed.) Modeling carbon and nitrogen dynamics for soil management. Lewis Publishers, Boca Raton, FL.

Preusch, P.L., P.R. Adler, L.J. Sikora, and T.J. Tworkoski. 2002. Nitrogen and phosphorus availability in composted and uncomposted poultry litter. J. Environ. Qual. 31:2051–2057.

Schaffer, M.J., L. Ma, and S. Hansen. 2001. Preface. *In* M.J. Schaffer, L. Ma, and S. Hansen (ed.) Modeling carbon and nitrogen dynamics for soil management. Lewis Publishers, Boca Raton, FL.

Serna, M.D., and F. Pomares. 1991. Comparison of biological and chemical methods to predict nitrogen mineralization in animal wastes. Biol. Fertil. Soils 12:89–94.

Shi, W., and J.M. Norton. 2000. Microbial control of nitrate concentrations in an agricultural soil treated with dairy waste compost or ammonium fertilizer. Soil Biol. Biochem. 32:1453–1457.

Sullivan, D.M., S.C. Fransen, A.I. Bary, and C.G. Cogger. 1998. Fertilizer nitrogen replacement value of food residuals composted with yard trimmings, paper, or wood wastes. Compost Sci. Util. 6(1):6–18.

Sullivan, D.M., T.J. Nartea, A.I. Bary, C.G. Cogger, and E.A. Myhre. 2004. Nitrogen availability and decomposition of urban yard trimmings in soil. Soil Sci. 169:697–707.

Sweeney, R.A. 1989. Generic combustion method for determination of crude protein in feeds: Collaborative study. J. Assoc. Off. Anal. Chem. 72:770–774.

Trinsoutrot, I., R. 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.

Tyson, S.C., and M.L. Cabrera. 1993. Nitrogen mineralization in soils amended with composted and uncomposted poultry litter. Commun. Soil Sci. Plant Anal. 24:2361–2374.

USDA. 2002. The National Organic Program Standards [Online]. USDA, Washington, DC. Available at http://www.ams.usda.gov/nop/NOP/standards.html (accessed 2 Sept. 2004; verified 26 July 2006).

Van Kessel, J.S., and J.B. Reeves, III. 2002. Nitrogen mineralization potential of dairy manures and its relationship to composition. Biol. Fertil. Soils 36:118–123.

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.

VanLauwe, B., J. Diels, N. Sanginga, and R. Merckx. 1997. Residue quality and decomposition: An unsteady relationship? p. 157–166. *In* G. Cadisch and K.E. Giller (ed.) Driven by nature: Plant litter quality and decomposition. CAB International, Wallingford, UK.

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.

Wagner, M.G., M.L. Cabrera, and N.N. Ranells. 1998. Nitrogen and carbon cycling in relation to cover crop residue quality. Soil Water Conserv. 53:214–218.