Nitrogen Availability from High-nitrogen-containing Organic Fertilizers

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SUMMARY. Limited soil nitrogen (N) availability is a common problem in organic vegetable production that often necessitates in-season fertilization. The rate of net nitrogen mineralization (N_{min}) from four organic fertilizers (seabird guano, hydrolyzed fish powder, feather meal, and blood meal) containing between 11.7% and 15.8% N was compared in a laboratory incubation. The fertilizers were mixed with soil from a field under organic management and incubated aerobically at constant moisture at 10, 15, 20, and 25 °C. N_{min} was determined on samples extracted after 1, 2, 4, and 8 weeks. Rapid N_{min} was observed from all fertilizers at all temperatures; within 2 weeks between 47% and 60% of organic N had been mineralized. Temperature had only modest effects, with 8-week N_{min} averaging 56% and 66% across fertilizers at 10 and 25 °C, respectively. Across temperatures, 8-week N_{min} averaged 60%, 61%, 62%, and 66% for feather meal, seabird guano, fish powder, and blood meal, respectively. Cost per unit of available N (mineralized N + initial inorganic N) varied widely among fertilizers, with feather meal the least and fish powder the most expensive.

Organic vegetable production is a rapidly expanding industry, particularly in California, where more than 37,000 acres of production was reported in 2003 [California Department of Food and Agriculture (CDFA), 2005]. Managing N fertility is problematic for many organic vegetable growers, particularly those producing high-N-demanding crops. Growing legume cover crops is generally the most economical way to provide plant-available N in organic systems (Gaskell et al., 2000). However, effective cover cropping presents a number of challenges. While legume cover crops have the potential to provide large quantities of N to a succeeding crop, the actual N contribution can vary widely, depending on field-specific conditions (cover crop species grown, length of growing season, etc.). Because cover crop production may require 3 months or more, opportunities for cash crop production can be constrained; this is particularly a concern for growers in the coastal valleys of central California, where very high land values and price premiums for winter-grown salad vegetables make it difficult to economically justify the production of an over-wintering cover crop. Even where an over-wintering cover crop is grown, spring weather can delay residue incorporation, disrupting spring planting schedules. As a result of these constraints, organic growers often use other methods to augment soil N supply.

Application of composted manure is a common practice in organic culture. However, at common application rates (usually <15 $Mg \cdot ha^{-1}$), the relatively slow rate of N mineralization from composts limits the effective N contribution (Hartz et al., 2000). Another limitation of composted manure is that significant quantities of phosphorus (P) may exist, and may present an environmental hazard if soil P is already elevated (Sharpley et al., 1994).

The use of "Chilean nitrate" [mined sodium nitrate ($NaNO_3$)] has historically been a common practice in organic fertility management to supplement in-season N availability. However, in many countries $NaNO_3$ use has been prohibited for organic production; currently in the U.S., $NaNO_3$ application is restricted to 20% of crop N requirement. In the absence of $NaNO_3$, the application of high-N waste products from agricultural and fishery industries is the most practical alternative for in-season N fertilization. While products like blood meal, feather meal, fishery waste, and seabird guano have been used for many years in organic farming, reliable data on their N mineralization characteristics are lacking. The objective of this study was to document the rate of net N mineralization from high-N organic fertilizers commonly used in organic vegetable production over a range of soil temperatures.

Materials and methods

Net mineralization of organic N from four high-N organic fertilizers was evaluated in a laboratory incubation experiment conducted at the University of California–Davis in 2004. Samples of blood meal, feather meal, pelletized seabird guano, and hydrolyzed fish powder were obtained from California vendors of organic amendments; all products evaluated were acceptable for use in certified organic production. These fertilizers were oven-dried, ground to pass a 1-mm screen, and analyzed for total N and C concentration using a combustion gas analyzer (Carlo Erba 1500; Fisons Instruments, Beverly, Mass.). Mineral N concentration [ammonium-nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N), in 2 N potassium chloride (KCl) extracts] was determined with a flow injection analyzer (Lachat Instruments, Milwaukee, Wis.). Total P and potassium (K) concentrations were determined by atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry (ICP-AES), respectively, following nitric acid/hydrogen peroxide microwave digestion (Sah and Miller, 1992).

A Sorrento sandy loam (mixed, thermic Calcic Entic Haploxerolls) from a field in long-term organic veg-

Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
29.5735	fl oz	mL	0.0338
3.7854	gal	L	0.2642
25.4000	inch(es)	mm	0.0394
0.4536	lb	kg	2.2046
1	ppm	$mg \cdot kg^{-1}$	1
6.8948	psi	kPa	0.1450
2.2417	ton/acre	$Mg \cdot ha^{-1}$	0.4461
(°F – 32) ÷ 1.8	°F	°C	(1.8 × °C) + 32

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etable production was collected and air-dried; soil was screened through a 5-mm sieve, and brought to equilibrium moisture (20% w:w) under 25 kPa pressure to simulate field capacity moisture content. The soil had 1.35% organic matter and a pH of 7.9. Initial mineral N concentration was 25 mg·kg^{-1}. The ground organic fertilizers were thoroughly mixed by hand into the moist soil at a rate of 0.3% of wet soil weight. That concentration of material was chosen based on prior research by Hadas and Rosenberg (1992), who used a 0.25% rate when evaluating a guano product; since the current study used lower incubation temperatures, a slightly higher incorporation rate was used.

Four replicate subsamples of moist, unamended soil, and of each fertilizer/soil blend, were extracted in 2 N KCl and analyzed for mineral N concentration as previously described. For each fertilizer/soil blend, and for unamended soil, the remaining material was divided among 64 centrifuge tubes, which were then placed in 1-L glass jars, four tubes per jar. To maintain constant moisture in the fertilizer/soil blends, 10 mL water was added to the bottom of each jar to maintain humidity in the airspace, and the jars were sealed. The jars were placed in climate-controlled rooms, one room maintained at each of these constant temperatures: 10, 15, 20, and 25 °C; four jars per fertilizer per soil blend were placed in each room. This temperature range was chosen to encompass the annual range of soil temperature typical of the coastal valleys of central California where most organic vegetable production takes place (Fox and Hatfield, 1983). After 1, 2, 4, and 8 weeks of incubation, one tube was removed from each jar in each temperature room, providing four replicate samples for each blend and for unamended soil at each temperature for each sampling date. On each sampling date the headspace of each jar was purged with air to maintain aerobic conditions; the maintenance of aerobic conditions was confirmed by monitoring carbon dioxide concentration in the headspace of selected jars using an infrared gas analyzer. On the last sampling date selected samples were weighed to document that soil moisture content had been maintained throughout the incubation period.

Samples were extracted with 2 N KCl and mineral N concentration was determined as previously described. The increase in mineral N concentration over time (compared to the change in unamended soil) represented N_{min} from the organic fertilizers.

Results and discussion

The organic fertilizers had total N concentration ranging from 11.7% to 15.8%, with all carbon : nitrogen (C:N) ratios <4.0 (Table 1). Only the seabird guano contained a significant quantity of inorganic N (0.8%, mostly in NH_4-N form). Phosphorus and K content varied from 0.1% to 2.6% and 0.1% to 1.1%, respectively.

N_{min} from the unamended soil over 8 weeks at 25 °C was 26 mg·kg^{-1}, or about 2% of initial organic N content (Fig. 1). This was in agreement with N_{min} estimates from other California soils in long-term vegetable rotations (Hartz et al., 2000; Krueskopf et al., 2002). N_{min} from soil organic matter approximately doubled with each 10 °C increase, in line with the typical respiratory quotient (Q_{10}) of microbially mediated processes. These results suggested that conditions conducive to mineralization were maintained throughout the experiment.

After 1 week of incubation the fish powder showed rapid N_{min} (~50% of organic N) at all temperatures (Table 2). The other fertilizers had N_{min} equivalent to the fish powder at 25 °C, but significantly slower mineralization at lower temperatures. After 2 weeks of incubation the fertilizers showed similar N_{min} patterns, with small but statistically significant differences among fertilizers present only at 10 °C. In all fertilizers the majority of N mineralized at 10 °C in the initial week of incubation remained in NH_4-N form, while at higher temperatures NO_3-N was predominant. This was consistent with the widely documented inhibitory effect of low temperature on nitrification (Tisdale et al., 1993). After 2 weeks, a substantial quantity of NH_4-N persisted only at 10 °C.

Beyond 2 weeks of incubation the rate of additional mineralization slowed for all fertilizers. After 8 weeks all products had equivalent N_{min} at

Table 1. Initial carbon (C), nitrogen (N), phosphorus (P), and potassium (K) concentrations of the organic fertilizers.

Material	C (%)	Total N (%)	Inorganic N (%)	P (%)	K (%)	C:N (ratio)
Fish powder	47.0	13.7	0.2	0.6	1.1	3.4
Blood meal	49.0	15.8	<0.1	0.1	0.1	3.1
Feather meal	49.0	14.2	<0.1	0.2	0.1	3.5
Sea bird guano	39.0	11.7	0.8	2.6	0.9	3.3

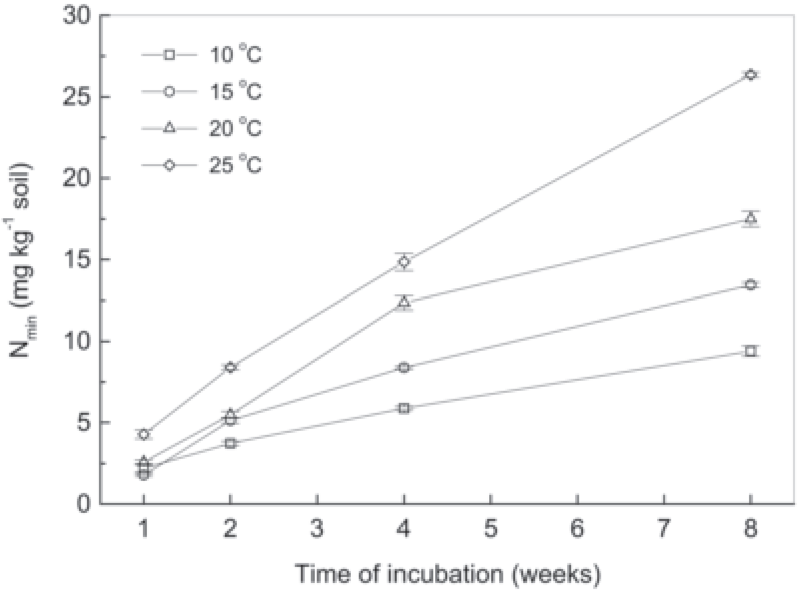

Fig. 1. Effect of temperature and time of incubation on net nitrogen mineralization (N_{min}) from unamended soil. Bars indicate standard error of measurement; 1 mg·kg^{-1} = 1 ppm.

Table 2. Net nitrogen (N) mineralization (N_{min}) from organic fertilizers, as influenced by temperature and time of incubation.

Time of incubation (weeks)	Fertilizer	N_{min} (% of organic N)							
		10 °C^{z}		15 °C		20 °C		25 °C	
		Total^{y}	as NH_4-N	Total	as NH_4-N	Total	as NH_4-N	Total	as NH_4-N
1	Fish powder	51 a^{x}	44	51 a	37	51 a	21	48	6
	Blood meal	18 c	12	41 b	28	48 ab	20	51	1
	Feather meal	30 b	21	42 b	23	47 ab	5	50	<1
	Seabird guano	29 b	21	42 b	20	43 b	3	46	<1
									NS
2	Fish powder	51 a	37	56	1	57	1	57	<1
	Blood meal	47 b	31	52	1	60	1	60	<1
	Feather meal	48 ab	27	49	<1	56	<1	57	<1
	Seabird guano	48 b	24	52	<1	52	<1	58	<1
					NS		NS		NS
4	Fish powder	54	8	55	<1	58	<1	60 b	<1
	Blood meal	52	1	60	<1	63	<1	67 a	<1
	Feather meal	51	<1	56	<1	61	<1	64 ab	<1
	Seabird guano	55	<1	61	<1	59	<1	60 b	<1
		NS		NS		NS			
8	Fish powder	56	<1	61	<1	65	<1	64 b	<1
	Blood meal	60	<1	64	<1	70	<1	70 a	<1
	Feather meal	55	<1	59	<1	64	<1	63 b	<1
	Seabird guano	54	<1	64	<1	60	<1	67 a	<1
		NS		NS		NS			

^{z}(1.8 × °C) + 32 = °F.

^{y}Total includes both ammonium-nitrogen (NH_4-N) and nitrate-nitrogen (NO_3-N).

^{x}Means within columns within incubation times separated using Duncan's multiple range test, $P < 0.05$.

lower temperatures, with blood meal and seabird guano showing slightly higher N_{min} at 25 °C. Significant fertilizer × temperature interaction after 1 and 4 weeks of incubation precluded the comparison of overall fertilizer or temperature effects on those dates; at 2 and 8 weeks no interaction was observed. Across temperatures, all fertilizers had equivalent N_{min} after 2 weeks, with blood meal having a slight advantage after 8 weeks (Fig. 2). Across fertilizers, small but consistent temperature effects were observed, with N_{min} ranging among temperatures from 48% to 58%, and 56% to 66%, after 2 and 8 weeks, respectively.

Total N availability (mineralized organic N + initial inorganic N) was highest in the seabird guano, due to its higher initial inorganic N (Table 3). The cost per kilogram of total N varied widely among the fertilizers, with feather meal the least and fish powder the most expensive. The costs listed were gathered in 2004 from the California vendors who supplied the fertilizers; cost of similar products may vary substantially by geographical region based on N content, degree of processing, and proximity to the product source. Cost of available N correspondingly varied among fertilizers, from \$7.30/kg to \$43.10/kg at 25 °C. Lower soil temperature moderately increased the unit cost of the organic fertilizers, but did not change the relative ranking among products. By comparison, $NaNO_3$ is currently about \$3.00/kg N, and as a soluble fertilizer the N is readily available, regardless of soil temperature.

N mineralization dynamics documented in this study were similar to those observed by Hadas and Kautsky (1994) and Hadas and Rosenberg (1992), who evaluated feather meal and seabird guano, respectively. In an 8 week soil incubation at 30 °C they reported N_{min} of ~65% for feather meal, and 80% for seabird guano. Soil type had little effect on N_{min} in either study. In both reports the vast majority of mineralization was observed in the initial 2 weeks of incubation, as was the case in the present study.

We found the pattern of N mineralization from soil organic matter (relatively consistent mineralization over time, with significant temperature effects) to be in clear contrast to that observed for the organic fertilizers. The rapid mineralization from the organic fertilizers in the first 2 weeks of incubation undoubtedly came primarily from enzymatic hydrolysis of urea and simple proteins; while these processes are temperature dependent (Loll and Bollag, 1983; Moyo et al., 1989), even at low soil temperature these highly labile forms of organic N were apparently exhausted within 2 weeks. The much slower rate of mineralization from the organic fertilizers after week 2 more closely paralleled that from soil organic matter, suggesting microbially mediated degradation of more complex organic N forms. The practical significance of these observations is that substantial N availability can be obtained from high-N organic fertilizers even at low soil temperature. However, given the slow rate of nitrification at low temperature, the mineralized N may remain in NH_4-N form for a significant period.

Relative N availability was similar among the fertilizers, but their cost varied widely. While P and K content have some value, both can be supplied more economically with preplant application of lower cost products; in-season application of high-N organic fertilizers will therefore be based almost exclusively on N availability. The relatively high P content of the seabird guano would

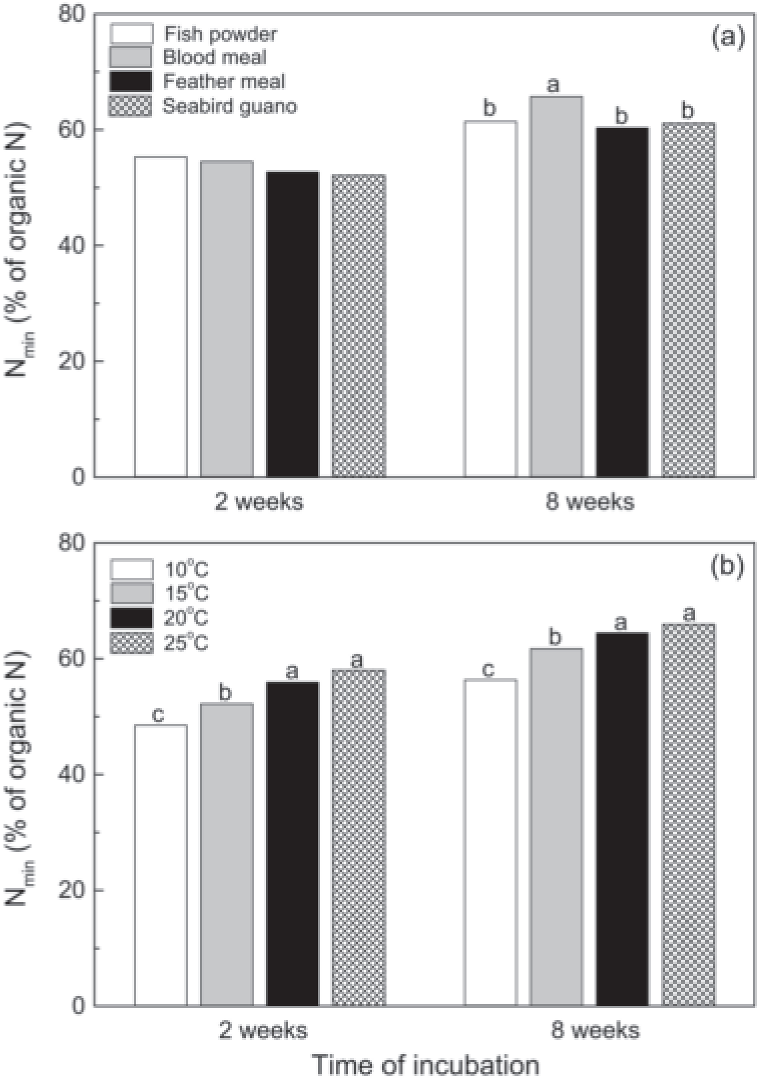

Fig. 2. Net nitrogen mineralization (N_{min}) from organic fertilizers across temperatures (a), and temperature effects on N_{min} across fertilizers (b), after 2 and 8 weeks of incubation. Mean separation within dates by Duncan's multiple range test, $P < 0.05$; (1.8 × °C) + 32 = °F.

Table 3. Organic fertilizer nitrogen (N) availability and relative cost per kilogram, based on net N mineralization during 8 weeks of incubation.

	Product cost	N availability^z (%)		$/kg available N^y	
Material	($/kg total N)	10 °C^x	25 °C	10 °C	25 °C
Fish powder	28.00	57	65	49.10	43.10
Blood meal	6.80	60	70	11.30	9.70
Feather meal	4.60	55	63	8.40	7.30
Sea bird guano	6.60	61	74	10.80	8.90

[z] Mineralized N + initial inorganic N, expressed as a percentage of initial total N.
[y] $1.00/kg = $0.4536/lb.
[x] (1.8 × °C) + 32 = °F.

actually make that product undesirable for use in fields with elevated soil P.

All the organic fertilizers were considerably more expensive than $NaNO_3$, historically the product of choice for in-season N fertilization. However, in the U.S., organic rules restrict $NaNO_3$ use to 20% of crop N requirement; also, in recent years some influential retailers in the U.S. have declined to purchase organic produce grown with $NaNO_3$, further limiting its use. Europe and Japan prohibit $NaNO_3$ use in organic farming entirely, and ban import of organic produce grown with $NaNO_3$.

Where in-season N application is necessary, we conclude that high-N organic fertilizers can be effectively used, even under cool soil conditions. As a practical matter, the high cost of these products requires that they be used sparingly. When it is compatible with other cultural considerations, the use of soil-building practices like cover cropping will supply N less expensively.

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