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Project title: Nitrogen mineralization rate of biosolids and biosolids compost

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Introduction:

The disposal of biosolids is one of California's vexing environmental problems. Application on agricultural land represents the most beneficial use of this nitrogen-rich material. However, without a sound understanding of N mineralization behavior of the common biosolids products (dewatered, air-dried or composted) it is impossible to determine appropriate field application rate to supply the desired agronomic benefit without creating a nitrate pollution hazard. Information on N availability from biosolids under central California field conditions is extremely limited. This project was conducted to develop short- and long-term N availability estimates for representative biosolids products and, through field studies and laboratory assays, to examine the effects of soil type, cropping system, and loading rate on N mineralization dynamics.

Objectives:

a) Determine the short- and long-term N mineralization rates of dewatered, air-dried or composted biosolids.

b) Determine if short-term incubation assays are predictive of field mineralization rates.

Methods:

Field assays

A total of 104 microplots (large plastic pots of approximately 2.5 ft2 volume, containing approximately 90 kg of soil) were established in a field at UC Davis in early June, 2000. These microplots were filled with either a sandy loam or a clay loam soil from fields under standard row crop rotations. The organic matter content of these soils was 1.8 and 1.5%, and the total N content was 0.12 and 0.11% for the sandy loam and clay loam soils, respectively. These microplots were amended over a 3 year period (2000-2003) with various biosolids materials collected from waste treatment plants in several metropolitan areas of California (Table 1). Some microplots were amended only once (in 2000), others received repeat applications in 2001 and 2002 as well (Table 2). Air-dried and dewatered biosolids (samples A through D) were applied to the microplots on June 8, 2000, at a rate equivalent to a field application of 8 dry tons per acre. Due to the lower N content, and assumed slower mineralization rate, composts (samples E and F) were applied at a rate equivalent to 16 dry tons per acre. Immediately following

application the samples were manually incorporated into the soil to simulate disking in the field. The microplots were arranged in a completely randomized design in the field. There were four replicate microplots

To estimate the N availability dynamics of the various biosolids samples, sudan grass (*Sorghum vulgare* var. *sudanese,* cv. Piper) was grown in 76 of the microplots, and wheat (*Triticum aestivum*, cv. Yolo) in the remaining 28. Biosolids application, and plant sowing and harvest dates are given in Table 3.

In each year the biosolids samples were applied to the microplots and manually incorporated in June. Sudan grass was seeded a few days later. The wheat microplots remained fallow until seeding in November. An automated irrigation system was installed to maintain the soil between field capacity and approximately 70 centibar tension. A leaching port was installed in each microplot. In the first two cropping cycles for sudan grass and the first wheat crop, the leachate was collected and analyzed for mineral N concentration (NH3-N and N03 -N). In the second wheat and the third sudan crops, the leachate was returned to the microplots so that no biosolids N was lost from the cropping system.

Sudan was grown over a 4-5 month season, with two biomass harvests per season. The plants were clipped approximately 25 mm above the soil surface at the first harvest and allowed to regrow; at the second harvest, plants were clipped at the soil surface. The harvested biomass was oven dried, ground, and analyzed for total N concentration. At the **final harvest the soil profile of each microplot was sampled and analyzed for mineral N concentration. The sudan microplots were covered to prevent winter precipitation from leaching mineral N during the fallow season.**

Wheat was grown over the winter, with a single biomass harvest in the spring. A rain exclusion shelter was constructed over the wheat microplots to allow for control of soil moisture status during the winter; irrigation was applied as required to keep the wheat actively growing, with all leachate collected.

Apparent biosolids N availability was calculated for the Sudan and wheat assays by the following formula:

[(crop biomass N) + (mineral N in leachate) + (mineral N in soil profile at end of season)]

minus those quantities from unamended (control) microplots. This amount of N was expressed as a percentage of total N (organic and mineral forms) initially present in the biosolids materials. For the sudan microplots receiving annual biosolids applications, the apparent N availability from the samples applied in 2001 were estimated by comparison to the microplots that received the same biosolids sample in 2000. The apparent N availability of 2002 biosolids samples were calculated by subtracting the residual contribution of the appropriate 2000 biosolid sample as well as the estimated residual contribution of the 2001 sample; the estimated contribution of the 2001 sample was calculated as the same percentage of N availability of the appropriate biosolids type (air-dried, dewatered, or composted) observed in 2001 from the 2000 samples.

Laboratory assays

A parallel laboratory study was conducted in which the rate of net N mineralization of organic N in the biosolids samples was estimated from aerobic incubation of biosolids-amended soil under constant temperature and moisture. The

sandy loam soil used in the microplot studies was moisture equilibrated in a pressure apparatus at 25 centibars tension (approximately field capacity). Dried, ground biosolids were thoroughly blended with this moist soil at 0.4% by dry weight. After sampling for initial mineral N concentration, these soil/biosolids blends were placed in sealed glass jars and incubated at 25°C (77°F); there were 4 replicate jars per biosolids blend, and 4 jars of unamended soil. At 4, 8, 12, and 16 weeks the air in the headspace of the jars was sampled and analyzed for CO_2 concentration. The jars were then vented and the soil blends sampled; mineral N was determined in 2 N KCl extracts of those soil samples. Any change in mineral N from that in unamended soil represented net N mineralization or immobilization of N from the biosolids.

Additionally, dried, ground biosolids samples were subjected to a laboratory procedure reputed to be an index of N mineralization potential. Triplicate samples of each biosolids material used either in 2000 or 2001 were heated in 2 N KCl solution for 4 hours at 100°C; the NH_4-N concentration of the heated samples, and of matching samples held at room temperature, was determined. The increase in NH_4-N induced by the heating was compared to the results of the field and laboratory incubation experiments to see if this relatively quick assay was predictive of N mineralization potential.

Results:

Biosolids sample characteristics

The biosolids samples evaluated varied substantially within types, and dramatically among types (Table 1). Air-dried samples were 80-95% solids, while the dewatered material was only 13-26% solids. The moisture content of the composts was highly variable. On a dry weight basis, air-dried material ranged from 4.6 - 6.6% total N, with dewatered samples somewhat lower (3.9 - 4.8% N). All composts were blends of biosolids and municipal yard and landscape waste, but individual samples differed substantially in N content; the samples could be categorized as low N (< I%, samples F and K), or high N (> 2%, samples E, J, and 0). Carbon content varied from 26 - 37%, with the exception of sample K, which appeared to be comprised mainly of woody wastes. The C/N ratio of all air-dried and dewatered samples was < 8, while the composts ranged as high as 49.

Fresh extracts prepared in 2 N KCl before oven drying showed substantially higher mineral N concentration (NH_4-N and $N0_3$-N) than after drying. This difference was particularly striking in the dewatered samples, in which 30-50% of total N content was in NH_4- form in the fresh material. The steep decrease in NH_4-N may be due in part to some volatilization loss, but undoubtedly also reflects some incorporation into microbial biomass during drying process, which took several days with these samples. Once dry, mineral N generally constituted only 5 - 8% of total N. Given that the mineral N content of biosolids was highly variable, and likely to change on application to field soil (by volatilization and incorporation into microbial biomass), the data on N availability presented in this report is based on the total N content of the original dried sample.

Field assays

The three types of biosolids materials (air-dried, dewatered, and composted) behaved quite differently in the sudan assay (Table 4). In the first season after application, dewatered biosolids (samples C, D, I, and M) showed apparent N availability

of 22-34% of initial N content, while air-dried biosolids (same , B, G, and L) were less active, ranging from 19-24%. Although all compost sa les ere made from municipal yard and landscape wastes and biosolids, there ere e two distinct types of compost performed quite differently. Samples E, J, and O ontained more than 2% N, with C/N ratios of 12-13. By contrast, sample F had very low N (0.9%), and high C/N ratio (49). Sample F was nearly N neutral, with only 2-3% N availability; the more N-rich composts averaged 6%.

As expected, the apparent N release from the 2000 samples slowed in the subsequent growing seasons, averaging 9% and 7% of initial N in 2001 for the air-dried and dewatered samples, respectively; in 2002 both types averaged 3% of initial N. Compost sample E showed declining N availability, while sample F caused N immobilization (reduced N availability) in both succeeding seasons, apparently due to the continuing breakdown of the high C/N ratio material.

These results marginally underestimate the N release from the biosolids samples in the first season after application because they do not include N contained in root biomass. Root systems typically contain no more than 10-15% of total plant biomass, so apparent N recovery is understated by no more than 3-4% of initial N. However, leaving the root biomass in the microplots improved the estimates of residual N availability in subsequent seasons.

Soil type had no consistent influence on N release from the biosolids samples. First year apparent N availability averaged 21 and 22% for air-dried samples, 28 and 31 % for dewatered samples, and 6 and 7% from composts in the sandy loam and clay loam microplots, respectively. N availability from the soils themselves averaged 3, 3 and 2% on initial total N in 2000, 2001, and 2002, respectively.

There are several potential mechanisms of N loss from field plots (volatilization and denitrification) that were not specifically measured in this study. To approximate these losses soil samples were collected at the termination of the 2002 Sudan crop, dried, ground, and analyzed for total N. More than 60% of total N applied in microplots receiving the air-dried and dewatered samples, and more than 80% of total N applied from compost, was still present. This suggests that N loss through denitrification and volatilization were modest over the 3 year period, and that the estimates of apparent N availability were reasonably accurate.

In the wheat assay, apparent N recovery in the season after application was somewhat less than that achieved in the sudan assay (Table 5). This difference was likely related to the cooler soil temperature during the wheat growing season, compared to the period of the year the sudan was in production. Again, soil type had minimal influence on apparent N recovery. In the second cropping season the residual influence of the 2000 biosolids application was again slightly lower than in the sudan assay. Over the two growing seasons the air-dried and the dewatered samples performed similarly, while the composted sample mineralized N more slowly. The failure of the dewatered samples to mineralize more quickly than the air-dried material was undoubtedly due to the fact that the biosolids application to the microplots occurred several months before the seeding of the wheat (a management sequence that may be similar to actual field practice); the `freshness' aspect of the dewatered material was lost, as it would have dried completely in the prolonged dry, high temperature summer conditions.

Laboratory assays

Net N mineralization (Nmin) from dewatered samples in the incubation assay ranged from 20 - 30 % of initial N (Table 6), very similar to the behavior of these samples in the sudan field assay. Air-dried samples varied more, from 19 - 41% of initial N, somewhat more than in the sudan assay. Air-dried samples G and L had much higher N content (6.2 and 6.6%, respectively) than any other samples evaluated in this study, and they had by far the highest Nmin• Combining data from air-dried and dewatered samples, Nmin was significantly correlated with initial N content [% Nmin = (6.9 x % initial N concentration) - 7 , r= 0.81]. Initial C content was strongly correlated with Nmin [% N,nin = (2.1 x % initial C concentration) -40, r=0.87]. Percent of initial C mineralized was also correlated with % Nmin (r = 0.75).

As in the field assays, the two categories of compost behaved differently. The relatively high N samples (E and J) averaged 11 % Nmin ; the reason for the lower rate observed for sample 0 was not clear. Of the samples with low initial N content, sample F was essentially N neutral, while sample K showed strong net N immobilization. The low amount of C mineralization from sample F suggests that its carbon was substantially less labile than that in sample K, and accounts for the lack of short-term N immobilization in this sample. As the sudan assay suggested, however, this sample had the potential for long-term immobilization, as one would infer from its high C/N ratio. The rate of Nmin over the incubation period showed a relatively uniform increase (or decrease) over time for all categories of materials tested (Fig. 1).

In the hot KCl assay the increase in NH4-N induced by the 4 hr of heating at 100°C appeared to be unrelated to apparent N availability in the field assay or organic N mineralization rate in the laboratory incubation (Table 7). The relatively high amount of NH4-N generated with heating in the dewatered and composted samples suggests that the assay may simply be estimating some fraction of microbial biomass N rather than N availability per se. Even within the categories of biosolids materials, this assay did not appear to be predictive of N mineralization behavior.

Discussion:

This project demonstrated that N release from air-dried and dewatered biosolids was reasonably consistent across numerous sources and samples. In the growing season after late spring application, approximately 20-25% (air-dried material) or 25-30% (dewatered material) of total N applied would be expected to become available for crop uptake under Sacramento Valley conditions. Given this predictability, the use of laboratory assays to characterize materials is unlikely to significantly improve prediction of N,nin, with the possible exception of % total N of the material. It is possible, however, that biosolids outside the range of initial N content evaluated in this study may perform differently.

The behavior of composted biosolids was less predictable. Low N biosolids / yard waste composts are at best N neutral, and may have long-term immobilization characteristics that make them problematic for use in production agriculture. This is particularly true if applied at high rates. In the worst case scenario, an application of 16 dry tons / acre of sample K would immobilize almost 100 lb N / acre, based on the incubation assay. Use of these composts as surface mulches may be appropriate, but as soil-incorporated amendments the disadvantages may outweigh any benefits.

Composts with a higher N content (> 2%) behaved similarly to manure-based composts of equivalent N content, with N recovery ranging from 3-13% of initial N. These composts have no obvious agronomic drawbacks, but their contribution to crop N fertility is modest. Since the composting process stabilizes the N (and to a degree the carbon) content, biosolids composts should have more significant long-term effects on soil organic matter content (and presumably soil tilth) than straight biosolids application.

The cumulative effects of multiple biosolids applications were significantly increased soil C and N content, and progressively enhanced crop fertility. Crop N availability in the third year of the study (after 3 annual applications of 8 dry tons / acre) was the equivalent of approximately 330 lb N / acre in microplots receiving either air-dried or dewatered biosolids, and approximately 70 lb N / acre for microplots receiving high N biosolids compost. The decline in N availability over time was reasonably consistent within biosolids categories, allowing the effects of cumulative applications to be predicted with acceptable accuracy. The trend for declining Nmin over time for all biosolids types suggested that after 3 years the rate of mineralization of remaining organic N was similar to that of native soil organic N, perhaps 1-3% per crop season. For sites receiving annual biosolids application, application rates must decline over time to prevent mineral N accumulation in the soil, and associated pollution potential.

Based on the results of this study, the following outlines a procedure for estimating the maximum biosolids application to crop land:

Step 1: Estimate N fertilizer requirement of the crop on this soil type; estimates for fields receiving repeated biosolids application (> 2 years) should take into account the enhanced organic matter content.

Step 2: Soil sample the top 1-3 feet of soil (depending on the rooting depth of the crop) before biosolids application, and determine the residual N03-N content; assuming a crop recovery efficiency of 50-75%, multiply residual N03-N amount by 0.50 - 0.75 to calculate the potential contribution toward crop N requirement.

Step 3: If air-dried or dewatered biosolids had been applied the previous year, assume this season's contribution from that application to be 5-10% of the initial N content; assume the contribution from a high N content biosolids compost to be no more than 5%.

Step 4: Subtract the estimated contribution from soil residual N (step 2) and prior biosolids application (step 3) from estimated fertilizer need (step 1); this is the estimated amount of N necessary to apply for the current crop season.

Step 5: Using estimates of 20-25% (air-dried), 25-30% (dewatered) or 5-10% (high N compost) of total N content available in the season of application, calculate the maximum amount of biosolids N appropriate to apply.

Given the potential errors inherent in estimating the N mineralization dynamics of organic materials, and the potential problem of matching the timing of crop N uptake with N mineralization, a prudent grower may apply a modest amount of mineral fertilizer and a smaller amount of biosolids. In-season monitoring of crop and / or soil N03-N status by tissue or soil testing would be advisable to ensure adequate N supply.

Project evaluation:

This project was successful in developing an understanding of the N mineralization behavior of the common biosolids materials under Sacramento Valley conditions. The agreement between the field and laboratory assays, and the relatively consistent results obtained from numerous samples within each biosolids category, suggest that the results are sound and widely applicable. Unlike most CDFA-FREP projects, this project was strictly research-oriented, with no outreach component included.

Characteristics of biosolids samples, 2000-2002.

	Initial % dry weight[z]	Mineral N in sh sample (PPM)[y]	is after oven drying -N (PPM	NO_3-N (PPM)
d^gU^1Ww				
ZO				
-d bc				
0				
bb^b				
air-dew				10
dew				6
com				9
com				108
-d CC)C)C -dCC)C)				
air-dew				
dew				
com				

[z] calculated as (dry wt / wet wt)*100

[y] calculated on a dry weight basis

Table 2. Bioassay crop / soil texture / biosolids sample combinations evaluated.

Bioassay	Soil	Number of		**Biosolids sample applied**	
crop	type	**microplots**	2000	2001	2002
Sudan	**Sandy loam**	**4**	A	**none**	**none**
		4	**B**	**none**	**none**
		4	C	**none**	**none**
		4	D	**none**	**none**
		4	E	**none**	**none**
		4	F	**none**	**none**
		4	**B**	G	L
		4	D	I	M
		4	F	J	O
		6	**none**	**none**	**none**
	Clay loam	4	**B**	**none**	**none**
		4	D	**none**	**none**
		4	F	**none**	**none**
		4	**B**	G	L
		4	D	I	M
		4	F	J	O
		6	**none**	**none**	**none**
Wheat	Sandy loam	4	A	**none**	**none**
		4	C	**none**	**none**
		4	E	**none**	**none**
		4	**none**	**none**	**none**
	Clay loam	**4**	A	**none**	**none**
		4	C	**none**	**none**
		4	E	**none**	**none**
		4	**none**	**none**	**none**

Table 3. Biosolids application, and crop planting and harvesting dates, field assays.

	Year	**Sudan assay**		Wheat assay
Biosolids application date	2000	**8 June**		**8 June**
Planting date		**14 June**		9 Nov.
Harvest date(s)		24 Aug., 25 Oct.		22 May, 2001
Biosolids application date **Planting date**	2001	27 June 10 July		28 Nov.
Harvest date(s)		7 Sept.,	8 Nov.	17 May, 2002
Biosolids application date	2002	12 June		
Planting date		17 June		
Harvest dates		6 Aug.,	7 Nov.	

Table 4. Apparent N availability from biosolids samples in the sudan grass bioassays.

Soil	Biosolids sample	Year applied	Type	Biosolids N availability (% of initial N)Z 2000	2001	2002
Sandy loam	A	2000	air-dried	21 + 1	13 + 2	5 + 4
	B	2000	air-dried	20 ± 2	8+ 2	3+ 2
	C	2000	dewatered	29 ± 4	7+ 1	2+ 1
	D	2000	dewatered	30 ± 2	5+ 3	5+ 1
	E	2000	composted	13 + 1	6+ 2	1 + 2
	F	2000	composted	3 ± 8	-7 + 3	-4 + 3
	none			4+ 1	3+ 1	2+ 1
Clay loam	B	2000	air-dried	19 ± 1	6 ± 1	2 ± 1
	D	2000	dewatered	30 + 1	8+ 1	3+ 1
	F	2000	composted	2 ± 2	-4 + 3	-5 + 1
	none			2+1	2+1	1 +1
Sandy loam	G	2001	air-dried		24 + 2	
	I	2001	dewatered		22 + 6	
	J	2001	composted		5 + 2	
Clay loam	G	2001	air-dried		22 ± 2	
	I	2001	dewatered		34 ± 3	
	J	2001	composted		9 + 3	
Sandy loam	L	2002	air-dried			20 ± 2 '
	M	2002	dewatered			32 ± 4 y
	O	2002	composed			3 ± 2 Y
Clay loam	L	2002	air-dried			24 ± 3 y
	M	2002	dewatered			29 + 3 y
	O	2002	composted			9 + 1 Y

+ plus or minus standard error

(crop biomass N + leachate N + residual soil mineral N), minus those quantities from microplots of unamended soil

' calculated by deducting the measured residual contribution of the 2000 sample, and the estimated contribution of the 2001 sample

Table 5. Apparent N availability from biosolids samples in the wheat bioassays.

			Apparent biosolids N availability (% of initial N)'	
Soil	Biosolids sample	Type of material	2000-01	2001-02
Sandy loam	A	air-dried	18 ± 5	4 ± 2
	C	dewatered	15 + 7	9 ± 6
	E	composted	7+ 1	4+ 5
Clay loam	A	air-dried	16 ± 1	3 ± 1
	C	dewatered	21 + 2	3 + 1
	E	composted	10 ± 2	3 ± 2

+ plus or minus standard error

(crop biomass N + leachate N + residual soil mineral N), minus those quantities from microplots of unamended soil

Table 6. N and C mineralization from biosolids in 16 week laboratory incubation.

Sample type	**Sample**	Total N (%)	Total C (%)	% N **mineralization**	% C **mineralization**
Air-dried	A	5.7	33	25 + 1	20 ± 1
	B	4.6	26	19 + 4	25+3
	G	6.2	37	39+ 1	31+2
	L	6.6	36	41+1	47+ 1
Dewatered	C	3.9	30	25 ± 4	**18+2**
	D	4.8	32	22+2	24+3
	H	4.7	32	24+2	22+3
	I	4.6	32	28 + 3	21+1
	M	4.8	33	30+2	**28+1**
	N	4.2	30	20+ 1	25+2
Composted	E	2.2	27	14 ± 1	**18+2**
	F	0.9	44	1 + 1	8+1
	J	2.3	27	8+5	14+1
	K	0.9	33	-33 + 3	19+1
	O	2.4	30	1 +1	13+1

± plus or minus standard error

Table 7. NH4-N **generation** by heating **biosolids materials in KC1 solution.**

Sample type	Sample	Initial total N (%)	Increase in NH4-N with heating (PPM)	NH4-N increase as % of initial NH4-N	NH4-N increase as % of total N
air-dried	A	5.7	350	5.8	0.6
	B	4.6	140	5.8	0.3
	G	6.2	360	8.5	0.6
dewatered	C	3.9	480	19.5	1.6
	D	4.8	480	4.6	0.4
	H	4.7	1050	21.0	2.2
	I	4.6	1040	19.4	2.3
composted	E	2.2	270	15.2	1.2
	F	0.9	270	64.6	0.3
	J	2.3	720	53.5	3.1
	K	0.9	160	63.2	2.0

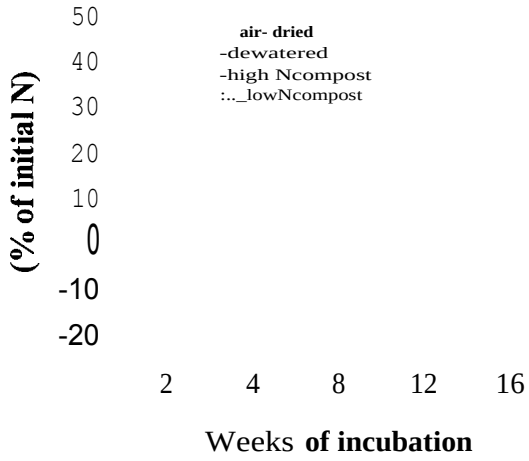

Fig. 1. Net N mineralization dynamics over time in the laboratory incubation assay; average of biosolids samples within categories.