THE IMPACT OF SOIL AND MOISTURE ON NITROGEN MINERALISATION RATES IN BIOSOLIDS

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ABSTRACT

Nitrogen (N) based loading rates are commonly used to determine land application rates of biosolids, calculated to best target the agronomic N needs of the crop. The rate of N mineralisation following the amendment of soils with biosolids over a range of specific environmental conditions needs to be accurately quantified to prevent overloading the soil with N in excess of plant uptake. The N release characteristics of anaerobically digested dewatered biosolids cake (DBC), lime-amended biosolids (LAB) and alum sludge (AS), in comparison to urea as a source of readily available N, were investigated in a soil incubation study. The experimental design included two soil types and three moisture regimes (25%, 50% and 100% gravimetric water holding capacity (GWHC)). There was no significant effect of soil type on the proportion or rate of N mineralisation. Nitrogen mineralisation rate was greater for LAB and AS compared with DBC and lime amended biosolids which had been stockpiled (LABs) for 12 months. The rate of N mineralisation was also dependent on moisture and was generally greater at 50% GWHC compared to 25% GWHC, but at 100% GWHC losses of N were observed, especially from soil amended with LAB; this is attributed to denitrification. The proportion of mineralisable N (% organic N) at 50% GWHC was greater for LAB (72%) and AS (64%) in comparison with DBC (32%) and LABs (26%). These results are consistent with previous findings and demonstrate that the organic matter content of LAB and AS is of a lower stability than DBC and LABs. Plant available N in the first season following the land application of biosolids may be greater than current estimates of 20% and hence N mineralisation, volatilisation rate and denitrification losses for specific products under a range of environmental conditions needs further investigation.

INTRODUCTION

Biosolids typically contain 0.5-5% nitrogen (N) (LeBlanc et al., 2008), the majority of which is present as organic forms and must be mineralised before it is available for crop uptake (Figure 1). Typical mineralisable N values for biosolids reported in the recent literature range from 25-57% (Pierzynski and Gehl, 2005). The method of stabilisation used to produce the biosolids will affect the size of the mineralisable pool of N and availability of other nutrients (Smith et al., 1998a; Morris et al., 2003; Pu et al., 2008). The rate at which biosolids' organic N is mineralised is dependent on several factors including soil temperature (Smith et al., 1998a;b; Honeycutt et al., 2001), soil moisture (Rahman and Rashid, 2002), pH (Tester et al., 1977), and soil type (Tester et al., 1977; Smith et al., 1998a; Breedon et al., 2003).

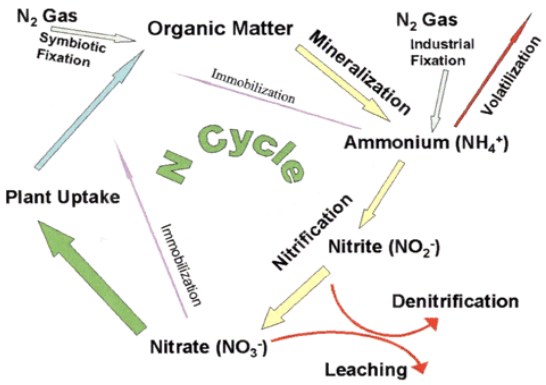

Figure 1: The soil nitrogen cycle, diagram reproduced from Sawyer (2001)

It is necessary that N loading rates of biosolids are managed appropriately to ensure benefits to crop growth are optimised, whilst reducing the risk of pollution though leaching or runoff of nutrients and gaseous losses of N by ammonia (NH_3) volatilisation or nitrous oxide (N_2O) emissions. Hence, plant available N (PAN) content following biosolids application should match crop requirements in the year of land application and in subsequent years the residual N should be taken into account prior to the application of additional fertiliser. In Australia, the rate of agricultural application of biosolids is generally determined by the 'Nitrogen Limited Biosolids Application Rate' or NLBAR, where the amount of PAN applied in the biosolids matches specific crop N requirement in the year of application. In Western Australia PAN assumes 50% volatilisation of the ammonium N (NH_4-N) content and 20% mineralisation of the organic N (org-N) content in the first growing season after application (DEP, WRC and DOH,

2002); as based on predictions from research in temperate regions and overseas. Recent evidence by Bell et al. (2004) suggest that the rate and extent of N mineralisation is underestimated in the first six month after application in biosolids in sub-tropical conditions in Queensland, and hence has highlighted the need for site specific research within Australia. In response, Rigby et al. (2010) quantified the amount of PAN in biosolids-amended acidic sand relative to urea N in a dry temperate environment under field conditions and estimated that the proportion of org-N mineralised during the first growing season was 38% for DBC, 64% for AS and 65% for LAB, 2-3 times greater than the current value used in the NLBAR calculation. Further work was identified to explain the factors that determine the rate of N mineralisation in soils to ensure that NLBAR is appropriate over a range of soil types and environmental conditions. This paper describes a soil incubation experiment, established to investigate the effects of soil type, moisture and biosolids treatment type on the extent and rate of N mineralisation in biosolids-amended soil.

METHODS

Biosolids

The biosolids investigated in this study were representative of a range of biosolids produced in Western Australia: anaerobically digested dewatered biosolids cake (DBC) from Beenyup Wastewater Treatment Plant (WWTP), alum sludge (AS) from Kemerton WWTP, lime amended biosolids (LAB) from Subiaco WWTP and LAB that had been stockpiled for approximately 1 year (sLAB). The pH and N content of the biosolids is given in Table 1.

Table 1 Total N (TN), mineral N (min-N), organic N (org-N) and pH in DBC (mesophilic anaerobically digested dewatered biosolids cake), AS (alum sludge), LAB (lime amended biosolids) and LABs (stockpiled LAB)

	DBC	AS	LAB	sLAB
pH	8.1	6.9	12.5	7.7
TN(%)[a]	4.7	3.4	2.5	2.9
NH_4-N (mg kg^{-1})[a]	7200	88	970	350
NO_3-N (mg kg^{-1})[a]	11.0	31.0	26.0	<5.0
Min-N (mg kg^{-1})[a]	7211	119	996	355
Min-N (% TN)	15.3	0.35	4.0	1.2
Org-N (% TN)	84.7	99.7	96.0	98.8

[a]Dry solids (DS) basis

Dewatered biosolids cake (DBC) and AS had the greatest total nitrogen (TN) contents of 4.7% and 3.4%, respectively. Lower values of 2.5% and 2.9% were measured in LAB and LABs, respectively due to dilution of the TN content by addition of lime during the treatment process. Dewatered biosolids cake (DBC) had the greatest min-N component, equivalent to 15.3% TN, compared to <4% in the other biosolids products. This is because DBC had undergone anaerobic degradation of the organic matter (OM) during the treatment process, and subsequent conversion of org-N to NH_4-N. Alum sludge (AS) is digested aerobically, a less complete degradation process and LAB is raw undigested sewage sludge with lime added for stabilisation and to reduce the pathogen content.

Soils

Soil (0-15 cm) was collected from two locations in the agricultural region east of Perth, Western Australia; Ucarty (S31°19.159', E116°57.083') and Muresk (S31°43.051', E116°41.886'). Some properties of the <2 mm fraction in the surface soil (0-15 cm) were as follows: Ucarty: 96.5% sand, 2.0% silt, 1.5% clay; pH 5.8 (0.01M $CaCl_2$;1:5); 5 mS m^{-1} EC; 0.78% organic carbon (W/B); 0.06% TN and 87 mg kg^{-1} total P. Muresk: 90.5% sand, 6.0% silt, 3.5% clay; pH 7.1 (0.01M $CaCl_2$;1:5); 12 mS m^{-1} EC; 1.39% organic C; 0.12% TN and 220 mg kg^{-1} total P. All analyses were performed by the Chemistry Centre of Western Australia, which is accredited by the National Association of Testing Authorities (NATA). The soils differed in a number of physicochemical properties that may affect the rate of N mineralisation. The Muresk soil had a greater clay and silt content than the Ucarty soil, higher pH and greater organic C content.

Procedure

Soil was air-dried (<2mm) and thoroughly mixed and a total of 18 portions of each soil type was weighed to 1500 g. Six portions were brought to 25% Gravimetric Water Holding Capacity (GWHC) with deionised water, six were brought to 50% GWHC and six were brought to 100% GWHC (equivalent to soil moisture content of 5%, 10% and 15%, respectively in each soil type); within a range that could be expected in field soils over the growing season. The six treatments were: control (no amendment); urea and the four biosolids treatments. The four biosolids treatments were applied at approximately 1.0 NLBAR, the standard agronomic N loading rate used by the Water Corporation WA. The NLBAR was based on a crop N requirement of 70 kg ha^{-1}, approximately equivalent to 54 mg N kg^{-1} soil (assuming a bulk density of 1.3 g cm^{-3}). Urea was therefore applied at a comparable rate of 54 mg N kg^{-1} soil. The rates of application of DS and TN are given in Table 2. The biosolids and urea treatments were thoroughly mixed into the soil and then passed through a 2 mm sieve to enhance incorporation. Each treatment was weighed accurately into triplicate 80 g samples polythene bags for each removal time of the experiment. A gap was left in the seal of each bag to allow gas exchange Triplicate samples from

each treatment were immediately frozen at -19°C to preserve them prior to chemical analysis (Day 0 samples). The remaining samples were placed in the dark in an incubator set to 25°C. Triplicate samples for each of the 6 treatments were removed after 3, 10, 17, 28 and 45 days and frozen at -19°C. This time period was selected because in a number of similar incubation studies using a non-leached procedure conducted at a temperature between 25-30°C, the majority of the mineralisable pool of biosolids' N had been released between days 40-50 (Terry et al., 1981, Garau et al., 1996, Bernal et al., 1998, Smith et al. 1998a,b).

Chemical analysis: Nitrate-N (NO_3-N) and NH_4-N were extracted from moist soil samples in a 1 M KCl solution and measured by automated colorimetry, the results were expressed on a dry soil basis.

Treatment	Urea	DBC	AS	LAB	sLAB
DS (%)	N/a	18	13	28	87
Rate (g DS kg^{-1})	N/a	4.5	5	7.1	7.1
TN rate Mg kg^{-1})	54	211	170	178	206
Min-N rate (mg kg^{-1})	54	32.4	0.6	7.1	2.5

Table 2: Comparative rates of dry solids (DS) and nitrogen application for the N incubation study

Calculations and statistical analysis: The amount of N recovered as NO_3-N or NH_4-N at each time point in each treatment was calculated by subtracting the concentration of NO_3-N or NH_4-N in mg kg^{-1} in unamended control soil from the amended soil concentration, assuming that the difference was due to the soil amendment. This value was expressed as a percentage of the TN added in each biosolids or urea treatment. The net soil N mineralised in the control was calculated by subtracting the min-N present on day 0 from the min-N on each removal date. The net soil N mineralised in the urea treatment was calculated by subtracting the amount of min-N present in the control on day 0 plus the min-N added as urea from the min-N measured on each removal date. The net biosolids' N mineralised at each time point for each treatment was calculated by subtracting the total mineral N (NO_3-N + NH_4-N) in the control treatment from the total mineral N (NO_3-N + NH_4-N) in each biosolids treatment, this value was then expressed as a percentage of the organic N added in each biosolids treatment.

Two-way analysis of variance (ANOVA) was conducted in GENSTAT (Release 9.2, Lawes Agricultural Trust, Rothamstead Experimental Station, UK) for each combination of biosolids, moisture and soil type to determine the effects on the net mineralisable N recovered on day 48.

A non-linear regression model is frequently used to determine the total mineralisable N pool and the first order rate constant for N mineralisation (Smith et al., 1980, Bernal et al., 1986, Garau et al., 1986), such as the following formula:

$$N_m = N_o\,[1\text{-}\exp(\text{-}kt)]$$

Where N_m= quantity of N mineralised at a specific time (t); N_o= potentially mineralisable N and k = first order rate constant.

However, in our study, this model was not a good fit to the experimental data in the majority of cases, because this was a short-term experiment the treatments were still within or reaching the end of the linear phase of N mineralisation. Instead, linear regression models were fitted to the data:

$$N_m = kt + y0$$

Where N_m= quantity of N mineralised (mg kg^{-1}) at a specific time (t) and k = ~~first order~~ mineralisation rate ~~constant~~. This allowed determination of the rate of mineralisation (k) during the exponential phase for each moisture, soil and biosolids combination. Regression analysis was conducted using SigmaPlot 10.0, (Systat Software, Inc., Germamy).

RESULTS AND DISCUSSION

Nitrogen transformations

Nitrogen recovered as NH_4-N and NO_3-N in each of the amended soils from days 0-45 is shown in Figure 2. Nitrogen transformations in the urea treatment demonstrated that there was a greater rate of nitrification in Muresk soil in comparison to Ucarty soil; this may be due to a more active microbial population in Muresk soil analogous to a greater organic matter content. In addition, the more acidic pH of Ucarty soil may have limited mineralisation rate which is optimal at a slightly alkaline pH (Day et al., 1978). In Ucarty soil, nitrification rates increased with increasing soil moisture content. In general there was full recovery of the added TN in urea treatments, however, by the end of the experiment there were lower recoveries observed at 100% GWHC. The final net recoveries of added TN as mineral N were 89%-101% in Ucarty soil and 66%-97% in Muresk soil. In the biosolids treatments a slower rate of nitrification was also observed in Ucarty soil, although rate of mineralisation and final recoveries of added N were similar in both soil types by day 45. Net mineralisation of org-N occurred in the majority of biosolids treatments between days 0-45, with the exception of LAB in both soils at 100% GWHC. Negative recoveries of NO_3-N were observed for DBC on day 3 and AS between days

3-10 in both soil types at 100% GWHC (Figure 2). Possible explanations for the negative recoveries of NO_3-N may be due to microbial immobilisation of N or denitrification. Denitrification is thought to be the most probable cause of negative recoveries of NO_3-N observed at 100% GSWC as it occurs under anaerobic soil conditions (Mendoza et al., 2006), and when there is greater water filled pore space (Maag and Vinther, 1996), and has been observed previously in soil incubation studies for biosolids types with low stability organic matter (Rigby and Smith, *unpublished data*). This is consistent with the negative recoveries of NO_3-N observed in LAB amended soil as LAB is raw sludge cake treated with lime to destroy pathogens, but does not undergo biological degradation of the organic matter content. For DBC the final recoveries of TN were 34-44% and 21-48% in Ucarty and Muresk soils, respectively. Final recoveries of TN in AS amended soil were 55-72% and 50-61% for Ucarty and Muresk soils, respectively. Final recoveries of TN in LAB amended soil were -12-50% in Ucarty and -57-84% in Muresk soil, and final recoveries of LABs were 20-24% and 22-27% in Ucarty and Muresk soils, respectively (Figure 2).

Rate and extent of N mineralisation

Net mineralisation of soil organic N in the control soil occurred in both soil types during the incubation period and is presented in Figure 3. Mineralisable N (N_m) values for each treatment on day 45, the mineralisation rate~~first order rate constant~~ (k) and R^2 and *P* values of the linear regression analysis for the rate of N mineralisation are presented in Table 3.

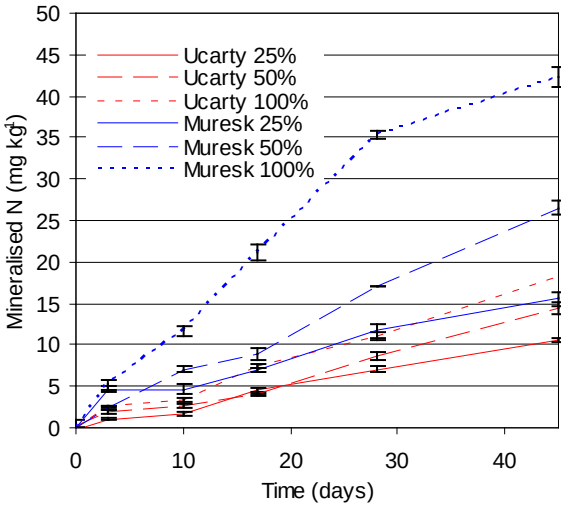

Figure 3: Nitrogen mineralised in control soils from days 0-45 in each soil type at three different soil moisture contents (25%, 50% and 100% GWHC).

For Control and Urea the N_m values represent the soil org-N mineralised, and for the biosolids treatments, they represent biosolids' org-N mineralised. The quantity of soil N mineralised was greater in Muresk soil in comparison to Ucarty soil, this may be because Muresk had a greater background TN content of 0.12% compared to 0.06% for UcartyMineralisation rate of soil org-N increased with increasing moisture status (Table 3). The k value (mineralisation rate) increased from 0.25 mg kg^{-1} d^{-1} at 25% GWHC to 0.39 mg kg^{-1} d^{-1} at 100% GWHC in Ucarty soil and tripled in Muresk soil from 0.31-0.97 mg kg^{-1} d^{-1}. An appreciable amount of soil org-N was mineralised in Muresk soil at 100% GWHC in the control soil, there was net

Table 3: Mineralisable N (N_m) for each biosolids treatment on day 45, ~~the first order rate constant~~mineralisation rate (k) and R^2 and P values from linear regression analysis to determine the relationship between mineralised N and time for each moisture, soil and biosolids combination.

[a]Biosolids type followed by soil moisture status (% GWHC), [b]n=3, [c]n=1, N.S. not significant, *** P=0.0001, **P<0.01, *P<0.05

cumulative mineralisation of approximately 40 mg/kg, which is comparable to the quantity of biosolids' org-N mineralised. In the calculation of the proportion of TN recovered in each biosolids treatment, the min-N in the control soil was subtracted, on the assumption that the addition of biosolids did not influence mineralisation of native soil N. It may be that there is some suppression of mineralisation of native soil org-N following soil amendment, in which case the lower recovery in biosolids treatments in Muresk soil at 100% may be in part to do with less mineralisation of soil org-N in the amended soils. However, it is unlikely that this is the main factor because in the urea treatments there was full recovery of N in Muresk soil at 100% GWHC until day 17 (Figure 2), indicating equivalent mineralisation of native N to the control treatment of <20 mg kg^{-1} (Figure 3) whereas negative recoveries of min-N were observed on day 3 in DBC, AS and LAB-amended soils.

In the majority of cases linear models were a good fit to the data, however for LAB at 25% GWHC in Ucarty soil there was no significant linear relationship (P>0.05) because the majority of the mineralised N was released between day 0 and day 3 (Figure 2) and for DBC 100% GWHC in Muresk soil the linear regression was not significant (P>0.05), this may be due to net losses of min-N on day 3 and slow net release of N, which is potentially due to denitrification losses. In general, the mineralisation rate of biosolids N was greater at 50% GWHC in comparison to 25% GWHC in Ucarty, but this pattern was not observed in Muresk soil in LAB and AS treatments. However, Figure 2 shows that there was greater mineral N recovery in soil at 50% GWHC compared to 25% GWHC for these treatments in Muresk soil at the early stages of the incubation, but net mineralisation rate at 50% GWHC was reduced from day 15. This may indicate that there were also denitrification losses in these treatments. Further investigation is required to measure denitification losses in biosolids amended soil, and to determine the effects of soil and moisture type. The rate of mineralisation was not increased at 100% GWHC in either soil types in biosolids-amended soil. This is in contrast to the increase in mineralisation rate of soil org-N observed in the control treatments and may be due to the net losses of min-N observed in this soil type. Biosolids type had a clear effect on mineralisation rate with greater k values observed in both soil types for LAB and AS compared with DBC and LABs (Table 4). This may be because these less stabilised sources of organic matter have a larger mineralisable N pool and is consistent with the findings of a field investigation by Rigby et al. (2010) where plant tissue in AS and LAB treatments had a high N concentration at the start of the growing season.

There was a significant effect of biosolids type (P<0.0001) on the proportion of org-N that was mineralised by day 45 over all moisture conditions, overall mean N_m values were 28% TN for DBC (range 11-40%), 56% for alum sludge (range 46-71%), 29% for LAB (range -58-84%) and 23% for LABs (range 20-27%). The range in values highlight clearly the effect of rainfall and soil

Treatment[a]	Nm (%) (±S.E.)[b]	N_m (mg/kg) (±S.E.)	k (d^{-1})	R^2	*P*
Ucarty Soil					
Control 25		10(±0)	0.25	0.96	***
Control 50		14(±1)	0.31	0.93	***
Control 100		18[c]	0.39	0.97	***
Urea 25		0(±1)	0.38	0.27	*
Urea 50		-6(±1)	0.24	0.3	N.S.
Urea 100		-6(±0)	-0.03	0.01	N.S
DBC 25	29(± 3)	51(±2)	0.88	0.96	***
DBC 50	33(±4)	58(±3)	1.05	0.91	***
DBC 100	22(±1)	40(±1)	0.82	0.76	***
AS 25	55(±3)	92(±2)	1.66	0.96	***
AS 50	71(±7)	121(±4)	2.24	0.95	***
AS 100	47(±1)	80(±0)	1.67	0.9	***
LAB 25	48(±10)	82(±6)	0.78	0.16	N.S.
LAB 50	61(±6)	105(±4)	1.38	0.38	*
LAB 100	-17(±2)	-30(±1)	-1.73	0.4	**
LABs 25	19(±2)	39(±1)	0.61	0.91	***
LABs 50	26(±1)	52(±1)	0.93	0.93	***
LABs 100	23(±4)	47(±3)	0.87	0.87	***
Muresk soil					
Control 25		16(±1)	0.31	0.88	***
Control 50		27(±1)	0.58	0.98	***
Control 100		42(±1)	0.97	0.95	***
Urea 25		-8(±1)	-0.60	0.01	N.S.
Urea 50		-8(±2)	-0.13	0.09	N.S.
Urea 100		-12(±5)	-0.27	0.3	N.S.
DBC 25	39(±2)	70(±3)	0.84	0.75	***
DBC 50	31(±1)	55(±1)	1.09	0.66	***
DBC 100	11(±3)	19(±5)	0.29	0.12	N.S.
AS 25	59(±1)	101(±1)	1.67	0.94	***
AS 50	56(±1)	94(±2)	1.10	0.81	***
AS 100	46(±2)	78(±3)	1.47	0.65	***
LAB 25	62[c]	10[c]	2.01	0.58	**
LAB 50	84(±1)	143(±1)	1.90	0.72	***
LAB 100	-58(±2)	-100(±4)	-2.67	0.73	***
LABs 25	27(±0)	54(±0)	0.82	0.82	***
LABs 50	26(±0)	52(±0)	0.78	0.78	***
LABs100	20(±0)	40(±1)	0.75	0.75	***

moisture on potential mineralisation rates in a dryland rainfed cropping system compared to high rainfall or irrigated farming systems. There was no significant overall effect of soil type on $N_{m.}$ between the two soils investigated. However at 25% GWHC there was significantly less net N mineralised in Ucarty compared to Muresk, and there was significantly more net N mineralised in Ucarty at 100% GWHC. There was a significant effect of soil moisture (P<0.0001) (N_m) with the greatest N_m at 50% GWHC, followed by 25% GWHC and negative values observed in some cases at 100% GWHC. This is likely to be due to the greater rate of mineralisation observed at 50% GWHC and is an indication that mineralisation at 25% GWHC was incomplete at day 45. Other studies (Terry et al., 1981, Garau et al., 1996, Bernal et al., 1998, Smith et al. 1998a,b) have indicated that at approximately 50% GWHC and temperature of 25-30^{o}C the majority of mineralisable N was released by days 40-50. At 50% GWHC N_m in Muresk soil was 31% org-N for DBC, 56% for AS, 84% for LAB and 26% for LABs. In Ucarty soil at 50% GWHC, N_m was 33% org-N for DBC, 71% for AS, 61% for LAB and 26% for LABs. The lower value of 26% for LABs compared to 61-84% mineralisable N for LAB demonstrates that that the fertiliser N value of the LAB is reduced during storage. This is because the organic matter has become degraded over time, converting the mineralisable N pool to NH_4-N, which is then vulnerable to NH_3 volatilisation losses.

General discussion

The mineralisation of org-N in biosolids calculated from this experiment was appreciably higher than the estimate of 20% that is currently used to determine N loading rates (i.e. NLBAR calculations), with mean values for DBC, AS, LAB and LABs of 32% (range 31-33%), 64% (range 56-71%) 72% (range 61-84%) and 26%, respectively, at 50% GWHC. These values are consistent with the estimated mineralisable N of 38% for DBC and 65% for both AS and LAB in a field investigation conducted by Rigby et al. (2010) at the Ucarty site over a 7 month growing season (280 mm rainfall) (Figure 4).

Elsewhere in Australia, studies by Pu et al. (2008) in Queensland demonstrate that the N mineralisation rate of anaerobic and aerobic biosolids is 43-59%, higher than than the DBC used in this study, and may reflect the effect of the higher temperatures encountered in the sub-tropical conditions An estimated 34% of org-N was mineralised from DBC in silty clay in a field trial with turf in New South Wales (Eldridge et al., 2008) similar to the value of approximately 35% obtained for DBC in this experiment and by Rigby et al. (2010). Lime amended biosolids (LAB) had not undergone a biological digestion process, as it was raw sewage sludge treated with lime to raise the pH and to destroy pathogens, whereas AS had undergone aerobic digestion. The differences in treatment process may explain the greater PAN of these two materials in comparison to DBC, which had been digested anaerobically and therefore had a more stable organic N fraction, and was mineralised to a lesser extent when added to the soil. A greater fraction of mineralisable organic N in aerobically digested biosolids as compared to anaerobically digested biosolids has been reported elsewhere (Morris et al., 2003; Pu et al., 2008). These results and ours indicate that it is not appropriate to use the same estimate of the available fraction of organic N for biosolids undergoing different treatment processes.

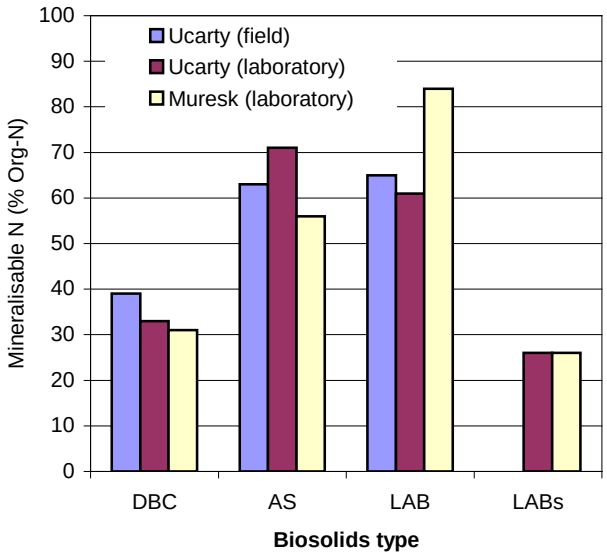

Figure 4: The proportion of mineralisable N in dewatered biosolids cake (DBC), alum sludge (AS), lime amended biosolids (LAB) and stockpiled LAB (LABs) in each soil type at 50% GWHC compared to the estimated mineralisable N calculated by Rigby et al. (2010) from a field investigation at the Ucarty site.

The rate at which mineral N becomes available, is dependent on environmental factors such as soil temperature and moisture (Smith et al., 1998a;b; Honeycutt et al., 2001; Rahman and Rashid, 2002). Our results indicated that increasing moisture from 25-50% GWHC increased the rate of N mineralisation, but even at the low soil moisture status (25% GWHC) biosolids were a rapid release source of N, <60% of the org-N was mineralised within 10 days. However, N release dynamics from biosolids may behave differently under moisture limited field conditions where particle size is larger and the biosolids are not so well incorporated into the soil, this is an area, which requires further investigation. The field experiment conducted by Rigby et al. (2010) was irrigated to compensate for low rainfall at the start of the growing season, however, under normal growing conditions a dry start to the season may result in PAN limiting crop growth in biosolids-amended soil.

The recommended N loading rates for biosolids based on mineralisation rates of ~20% needs to be reviewed to account for higher concentrations of PAN than previously assumed. The risk of nitrate leaching due overloading of biosolids is an area which requires further investigation. This would reduce the potential for pollution of waterways and improve the use of biosolids as a replacement for inorganic fertiliser N.

CONCLUSION

Mineralisation of organic N from biosolids in a laboratory incubation study was 2-3 times greater than the currently assumed field value of 20% and was greater for biosolids which had not been treated to stabilise their organic matter content. Therefore, current N loading rates for for biosolids should be reviewed further against crop N uptake and N budgets in comparable field studies to ensure N is not being inadvertently overloaded in these farming sytems. This will maximise the economic benefit and reduce the loss of nitrate by leaching and the risk of pollution. Nitrogen mineralisation rate was dependent on biosolids type and was greater for lime amended biosolids (LAB) and alum sludge (AS) compared to dewatered biosolids cake (DBC) and lime amended biosolids which had been stockpiled (LABs). Mineralisation rate of soil org-N N increased with increasing soil moisture capacity and was greater in the soil with the greater org-N content. Mineralisation rate was generally greater at 50% GWHC compared to 25% GWHC, but at 100% GWHC losses of N were observed, especially from soil amended with LAB; this is attributed to denitrification. Mineralisation rates may vary under field conditions due to differences in biosolids particle size and extent of incorporation and soil moisture conditons and temperatures. Nitrogen based loading rates for land application of biosolids should consider the rate of N mineralisation at the start of the growing season to ensure adequate supply of N for early plant growth.. Further research is also required to investigate gaseous losses of N from biosolids-treated soil through ammonia volatilisation and denitrification.

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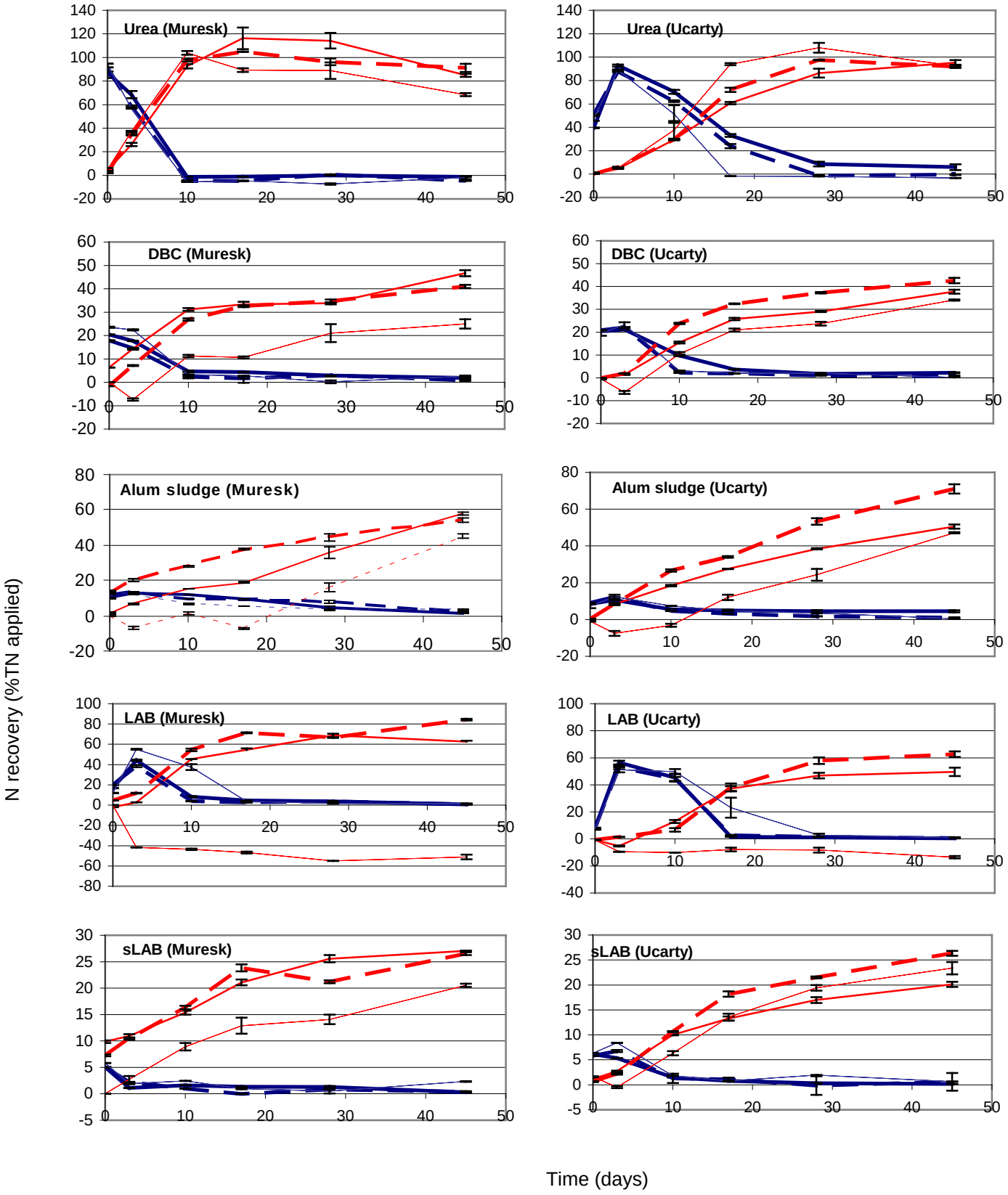

Figure 2: Nitrogen recoveries as NO_3-N (——) and NH_4-N (——) as a proportion of TN added at 25% GWHC (solid line), 50% GWHC (broken line) and 100% GWHC (dotted line)