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Influence of Compost-Treated Sewage Effluent Nutrient Integration on Nitrogen Dynamics in Arable Soil

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Abstract – **Availability of nitrogen (N) from compost is low as N derived from organic amendments mainly acts through the soil organic N pool. The mineral N content of compost is low due to nutrient losses during composting. This study examined the effects of combined application of compost and secondary treated sewage effluent on the dynamics of N and the influence of the treated sewage effluent on the mineralisation of organic matter in the soil.**

A laboratory incubation experiment (120 days at 25°C) was carried out using two soil types (sandy loam and clay loam), three N application rates (37.5, 75 and 150 kg total N ha-1) five nutrient supply combinations of greenwaste compost and treated sewage effluent (($150_{compost} + 0_{effluent}$), ($75_{compost} + 0_{effluent}$), ($37.5_{compost} + 37.5_{effluent}$), ($112.5_{compost} + 37.5_{effluent}$) and ($0_{compost} + 37.5_{effluent}$)) and a control with no amendment. Net N mineralisation (NMnet) was calculated as the difference in the concentration of mineral N between the treatments and the control. Mineral N data was fitted to the first order kinetic model to determine the influence of the nutrient combinations on the potentially mineralisable N. Repeated ANOVA was conducted on the data to determine significant differences of means. N mineralisation was significantly higher ($p < 0.05$) in clay loam soil due to relatively low clay content (29%) suggesting N fixation was not significant. NMnet was significantly influenced by the quantity of compost. Increasing the contribution of compost in clay loam reduced NMnet. Priming effects on native organic matter in clay loam increased NMnet significantly in ($0_{compost} + 37.5_{effluent}$) and ($37.5_{compost} + 37.5_{effluent}$) treatments. In sandy loam soil, during the first 30 days, addition of treated effluent resulted in N immobilisation in treatments with integrated nutrient supply and effluent only (($0_{compost} + 37.5_{effluent}$), ($37.5_{compost} + 37.5_{effluent}$) and ($112.5_{compost} + 37.5_{effluent}$)) suggesting rapid microbial biomass growth. Modelled potentially mineralisable N in clay loam soil was not significantly different ($p > 0.05$) amongst the treatments.

Our results suggest that the response to compost and effluent integration on N dynamics is soil specific. Increasing the quantity of compost in compost-effluent integration in clay loam with time resulted in reduced NMnet while in sandy loam, it improved net N mineralisation. Nutrient integration can provide a means through which less compost is applied at the same time taking advantage of the readily available nutrients in effluent.

Keywords – Compost, Nitrogen Dynamics, N Mineralisation, Nutrient Integration, Sewage Effluent.

I. INTRODUCTION

Compost application which is necessary to satisfy nitrogen (N) requirement of crops is becoming increasingly popular due to the escalating prices of inorganic fertiliser. Compost application enhances nutrient availability and organic matter status of the soil (Parkinson et al. 1999). However, just like other organic amendments, compost has low nutrient content as compared to inorganic fertilisers. Application of compost for crop production increases crop yields through the contribution of organic matter, improved soil structure and better moisture retention of the soil (Parkinson et al. 1999).

N derived from compost amendments mainly acts through the soil organic N pool (Gutser et al. 2005) as the mineral N content of compost is low due to nutrient losses during composting. Although various site-specific factors (e.g. compost maturity, composting conditions, climate, soil properties and soil management) may affect N-dynamics in compost amended soils, the short-term availability of N to plants is minimal since the majority (>90%) of total compost N is bound to the organic N-pool (Amlinger et al. 2003). Net N mineralisation of compost has been shown to be low, <15% of total N mineralised in 32 weeks (Hadas and Portnoy, 1994a) and <5% mineralised in 90 days (Benitez et al. 1998).

The gradual N release from the soil organic-N pool and the low mineralisation rates affect crop yield when compost alone is applied as a source of crop nutrients. The end result is that high crop yields are often associated with increased compost application rates. For example, after applying greenwaste compost at a rate of 50 t ha^{-1} annually for three years, Parkinson et al. (1999) found additional fresh weight yield response of maize of 31 t ha^{-1}, representing 75% increase relative to fields that were not amended with greenwaste compost. Similarly, high yields of 9.9 and 10.9 Mg ha^{-1} were obtained in treatments with high compost application rates of 33.6 and 44.8 Mg ha^{-1} respectively (Smiciklas et al. 2008). According to Sikora et al. (2001), excessive application of compost increases the levels of phosphorus and other ions in the soil hence combining compost with others sources of readily available nutrients e.g. inorganic fertilisers and effluent is often considered an appealing alternative.

The readily available nutrients in sewage effluent (predominately N and phosphorus) can be utilised to improve crop productivity. But after assessing nutrient dynamics in soils amended with treated effluent in an incubation experiment, Ramirez-Fuentes et al. (2002) concluded that despite increased concentration of organic C, total N, microbial biomass Carbon (C) and N the nutrients could not maintain and sustain crop production. Hence they recommended application of additional N to maintain the same level of crop yields.

Although the effect of inorganic fertiliser - compost nutrient integration has been explored (Sikora et al. (2001); Han et al. (2004)), the effect of secondary sewage effluent combination with compost is not yet well understood. The objective of the study was therefore to examine the effects of combined application of compost and secondary treated sewage effluent on the dynamics of N and the influence of the treated sewage effluent on the mineralisation of organic matter in the soil. This was achieved by comparing the interactive effects of various nutrient blends of compost and treated sewage effluent on two soil types.

II. MATERIALS AND METHODS

A. Soil, Compost and Treated Sewage Effluent

Sandy loam, clay loam and greenwaste compost were used for the incubation experiment. The soils and greenwaste compost were air dried and ground to pass through a 2 mm sieve. Particle size determination was done for sandy loam and clay loam soils. Greenwaste compost was sourced from MEC Recycling in Lincolnshire, UK and it was PAS 100 (Publicly Acceptable Specification) accredited. Secondary treated sewage effluent was collected from Cranfield University sewage treatment works. The initial analyses of the soils, treated sewage effluent and greenwaste compost are presented in Table 1 and Table 2.

Table 1. Characteristics of compost, sandy loam and clay loam soil used for incubation experiment

	Compost	**Sandy loam**	**Clay loam**
Extractable P (mg/kg)	367 (97)	39.7 (0.7)	21.52 (0.77)
Organic matter (%)	38 (1.16)	3.7(0.17)	4.8 (2.1)
Dry Matter (%)	58 (1.73)	85 (0.08)	88 (0.12)
TP (g/kg)	2.8 (0.19)	0.84 (0.03)	0.61 (0.01)
pH	7.8 (0.02)	6.8 (0.05)	7.6 (0.03)
NH_4^+ -N (mg/kg)	476 (42)	2.67 (0.23)	3.7 (0)
NO_3^- - N (mg/kg)	359 (34)	5.81 (0.19)	65.1 (1.14)
Total C (%)	21.5 (0.54)	1.29 (0.02)	1.68 (0.024)
Total N (%)	1.65 (0.03)	0.12 (0.002)	0.14 (0.002)
C/N ratio	13 (0.13)	10.8 (0.08)	11.9 (0.15)
Sand		77 (1.8)	42 (0.4)
Silt		11 (2.1)	29 (1.1
Clay		12 (0.2	29 (0.7)

Values in parenthesis are standard error of the means (SEM) and n = 3

Nutrient characterisation of the treated sewage effluent was done by employing reactive kits using spectroquant Merck® test kits. The treated sewage effluent was filtered before adding to respective cell tests and mixing with reagents for NH_4^+-N, NO_3^--N, K and PO_4^{3-}. For total N and K, treated sewage effluent was digested by heating at 120°C for 60 and 30 minutes respectively before adding to total N and K tests kits.

Table 2. Chemical and physical properties of the treated sewage effluent

	PO_4^{3-}	K	TN	NH_4^+ - N	NO_3^--N	P	Conductivity (uS cm^{-1})	pH
	-------------------------------		mg L^{-1}		--------------------------------			
Effluent	14.2 (0.1)	4.9 (0)	45.7 (4.3)	9.7 (0.1)	27.7 (0.4)	32.9 (1)	764 (0.3)	7 (0)

Numbers in parenthesis are SEM with n = 3

B. Incubation Experiment

The incubation experiment involved the use of triplicate samples in an incomplete randomised block design of sandy loam and clay loam soil. 300 g of soil was packed into 0.5 L incubation beakers with a bulk density of 1300 kg m^{-3}. The incubation beakers were covered with a perforated aluminium foil to allow gaseous exchange with the outside gases. The soil samples were incubated in the dark at 25°C for a period of 4 months. Moisture content of the incubated soil samples was maintained at field capacity by regular weighing and replacing the evaporated soil water with deionised water (Fonseca et al. 2007; Haer and Benbi 2003).

Field capacity was measured on a soil sample of known volume that was fully wetted and then allowed to sit under free drainage for two to three days). After free drainage had ceased, the water content of the sample was determined. Estimation of field capacity helped to decide on the maximum possible quantity of treated sewage effluent that could be combined with compost without exceeding the maximum water holding capacity of the soils. To supply similar amounts of N through treated sewage effluent for corresponding treatments in clay loam and sandy loam soil, an average of the two field capacities for the clay loam and sandy loam was used. This resulted in moisture content of 100 and 98% of water holding capacity for treatments in sandy loam and clay loam soils respectively. To minimise the evaporation losses of water from the incubated soil samples and also to regulate humidity, a water bath was placed at the bottom of the incubator.

Table 3. Nutrient supply combinations and application rates

Treatment combinations	Nutrient application rate (kg N ha^{-1})		Compost (ton ha^{-1})	Effluent (ml kg^{-1})
	Compost	Effluent		
$37.5_{compost} + 37.5_{effluent}$	37.5	37.5	2.3	396
$112.5_{compost} +37.5_{effluent}$	112.5	37.5	6.8	396
$0_{compost} + 37.5_{effluent}$	0	37.5	0	396
$75_{compost} + 0_{effluent}$	75	0	4.6	0
$150_{compost} +0_{effluent}$	150	0	9.1	0

Nutrient supply combinations were developed as treatments to supply 37.5, 75 and 150 kg total N ha^{-1} on sandy loam and clay loam soil by either compost, effluent or a combination of the two. Table 3 and 4 summarises the compost-effluent blends, quantity of effluent and greenwaste compost applied to supply 37.5, 75 and 150 kg total N ha^{-1}. Five treatments, nutrient integration ($37.5_{compost}$ + $37.5_{effluent}$) supplying 75 kg ha^{-1}, nutrient integration ($112.5_{compost}$ +$37.5_{effluent}$) supplying 150 kg ha^{-1}, treated sewage effluent ($0_{compost}$ + $37.5_{effluent}$) supplying 37.5 kg total N ha^{-1}, compost alone (($75_{compost}$ + $0_{effluent}$) and ($150_{compost}$ +$0_{effluent}$)) supplying 75 and 150 kg total N ha^{-1} respectively.

Soil samples were taken from the incubated soils at the start and once every 30 days for a period of 120 days. At each sampling time NH_4^+-N, NO_3^- - N and pH were analysed from the soil samples. Total N and total C were analysed at the start and end of the incubation. Mineral N was estimated as the sum of NO_3^--N and NH_4^+-N. NO_3^--N and NH_4^+-N were determined using the *Burkard Scientific* Segmented Flow Analyser - 2000. Sample extraction was done on 20 g fresh soil; 100 ml of 2 mol/l KCl solution was used to extract the sample before filtration using Whatman No.4 filter paper. Measurements of total N and total C in soil and compost were made on fine ground dried samples by catalytic tube combustion using the Vario EL III CHNOS elemental analyser while pH was determined in 1:5 soil/water extract.

Table 4. Quantity of compost and treated sewage effluent applied in each treatment

Treatment (kg N ha^{-1})	**Compost (mg beaker^{-1})**	**Treated sewage effluent (ml beaker^{-1})**
$0_{compost} + 37.5_{effluent}$	0	119
$37.5_{compost} + 37.5_{effluent}$	354	119
$112.5_{compost} +37.5_{effluent}$	1046	119
$75_{compost} + 0_{effluent}$	700	0
$150_{compost} +0_{effluent}$	1400	0

C. Calculations

At each time interval, net N mineralisation as a result of the integration of compost and sewage effluent was calculated based on the accumulation of mineral N in the soil. Net N mineralised was calculated as the difference in the concentration of mineral N between the treatments and the control (Han et al. 2004). Net N mineralisation is presented per unit of total N applied (Eq. (1)).

$$\mathrm{NM}_{\mathrm{net}}\left[\mathrm{kg\ inorganic\ N\ kg^{-1}\ applied\ N}\right]=\frac{Mineral\ N_{amended\ soil} - Mineral\ N_{control}}{Total\ N_{applied}} \qquad (1)$$

To model N dynamics, the first order equation with one mineralisation pool proposed by Stanford and Smith (1972) as cited in Cordovil et al. (2005) was fitted to the mineral N data to estimate the mineralisable N from each treatment (Eq. (2)).

$$N_m = N_0\left(1-\exp\left[-kt\right]\right) \qquad (2)$$

This model was chosen so as to estimate the potentially mineralisable N as a result of the various nutrient amendment combinations. In the first order model, N_m represent the accumulated mineralised N at time *t*, while *k* is the mineralisation rate constant and the amount of potentially mineralisable N is given by N_0.

D. Statistical analysis

Repeated ANOVA (General Linear Models) in Statistica 9.0 was conducted on the data to determine significant difference of variances. Significant treatments were separated using least significant difference of 0.05 using Fishers LSD. Model fitting was done in Statistica 9.0 using non-linear least squares estimation and T-test was used to compare the N_o for the treatments.

III. RESULTS

A. Nitrogen Mineralisation

Net N mineralisation was higher ($p < 0.05$) in clay loam soil as compared to sandy loam. Net N mineralisation was affected by the addition of secondary treated sewage effluent as well as the characteristics of the soils used. A significant increase in net N mineralisation in clay loam soil was observed for the ($0_{compost} + 37.5_{effluent}$) treatment (Fig. 1). Net N mineralisation increased from 0.9 kg inorganic N kg^{-1} applied N at the start to 2.5 kg inorganic N kg^{-1} applied N after 60 days. After 90 days, net N mineralisation reduced from 2.5 to 1.9 and 1.6 kg inorganic N kg^{-1} applied N on day 90 and 120 respectively. The initial mineralisation for this treatment was higher ($p < 0.05$) than for the rest of the treatments.

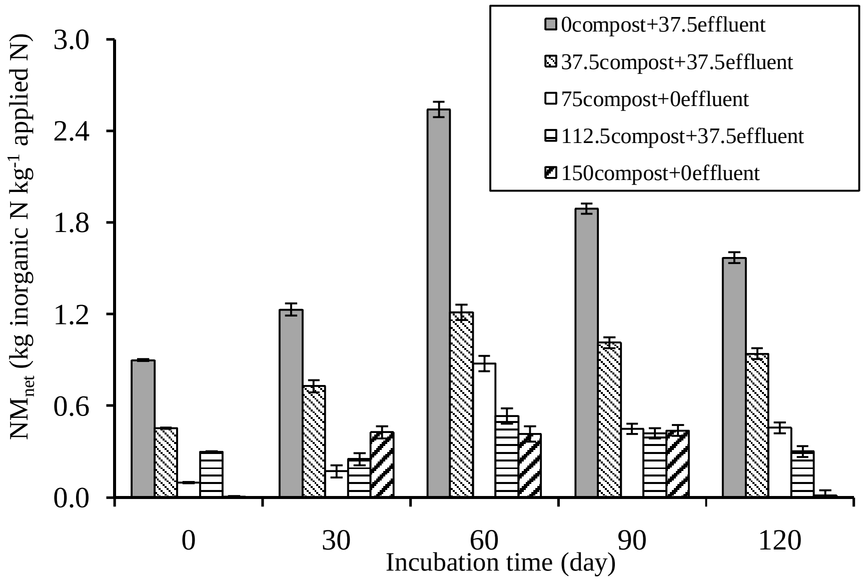


Fig. 1. Net N mineralisation (NM_{net}) in clay loam soil with various combinations of compost and treated sewage effluent ($p = 0.00$). The values are the means of triplicates and vertical lines indicate standard error of the means (SEM)

High net N mineralisation was observed in treatments with either treated effluent alone or treated effluent with compost apart from the treatment ($112.5_{compost} + 37.5_{effluent}$). Increasing the contribution of compost in a treatment resulted in a decrease in N mineralisation. On day 60, while net N mineralisation was higher ($p < 0.05$) for the treatment ($0_{compost} + 37.5_{effluent}$), for the ($37.5_{compost} + 37.5_{effluent}$) and ($112.5_{compost} + 37.5_{effluent}$) treatments it was 1.21 and 0.53 kg inorganic N kg^{-1} applied N respectively. On day 90, it was 1.01 and 0.42 kg inorganic N kg^{-1} applied N for the ($37.5_{compost} + 37.5_{effluent}$) and ($112.5_{compost} + 37.5_{effluent}$) treatments respectively.

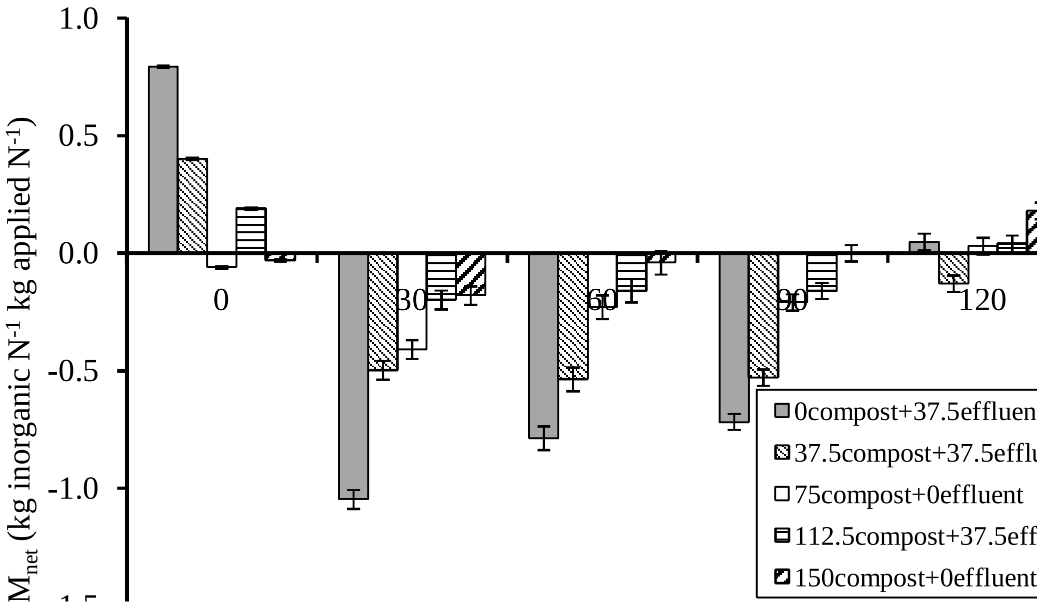


Fig. 2. Net N mineralisation (NM_{net}) in sandy loam soil with various combinations of compost and treated sewage effluent ($p = 0.00$). The values are the means of triplicates and vertical lines indicate SEM

In sandy loam soil (Fig. 2), the pattern of net N mineralisation between 0 and 30 days showed rapid decline for all treatments. The highest decline was observed for the treatment ($0_{compost}$ + $37.5_{effluent}$) to -1.1 kg inorganic N kg^{-1} applied N after 30 days. The decline started to reduce thereafter to the end of the incubation.

At the start of the incubation, net N mineralisation was 0.8, 0.4 and 0.2 kg inorganic N kg^{-1} applied N for the (($0_{compost}$ + $37.5_{effluent}$), ($37.5_{compost}$ + $37.5_{effluent}$) and ($112.5_{compost}$ + $37.5_{effluent}$)) treatments respectively. The presence of compost N in nutrient integration treatments in sandy loam helped to increase net N mineralisation (see Fig. 2). Increasing compost contribution as in treatment ($112.5_{compost}$ + $37.5_{effluent}$) resulted in an increase of net N mineralisation. On day 30 and 60, net N mineralisation was -0.5 and -0.54 kg inorganic N kg^{-1} applied N for the ($37.5_{compost}$ + $37.5_{effluent}$) treatment while for ($112.5_{compost}$ + $37.5_{effluent}$) treatment it was -0.2 and -0.16 kg inorganic N kg^{-1} applied N respectively.

B. NO_3^- -N and NH_4^+-N Concentration

The overall effect of nutrient integration on NO_3^--N and NH_4^+-N concentration on treatments in clay loam soil revealed accumulation and increase of NO_3^--N with time while NH_4^+-N declined sharply in all treatments in sandy loam and clay loam. The decline of NH_4^+-N in all treatments in clay loam was generally accompanied by a corresponding increase of NO_3^--N, indicating that NH_4^+-N released from organic matter mineralisation was nitrified into NO_3^--N. However, the contribution of NH_4^+ -N in both soils was only significant up to day 30 after which its concentration was untraceable in all treatments (Fig. 3 a & b). At the start of the experiment for the ($112.5_{compost}$ + $37.5_{effluent}$), ($0_{compost}$ + $37.5_{effluent}$) and ($37.5_{compost}$ + $37.5_{effluent}$) treatments, NH_4^+-N concentration was 30%, 23% and 35% of the inorganic N respectively before it became undetectable.

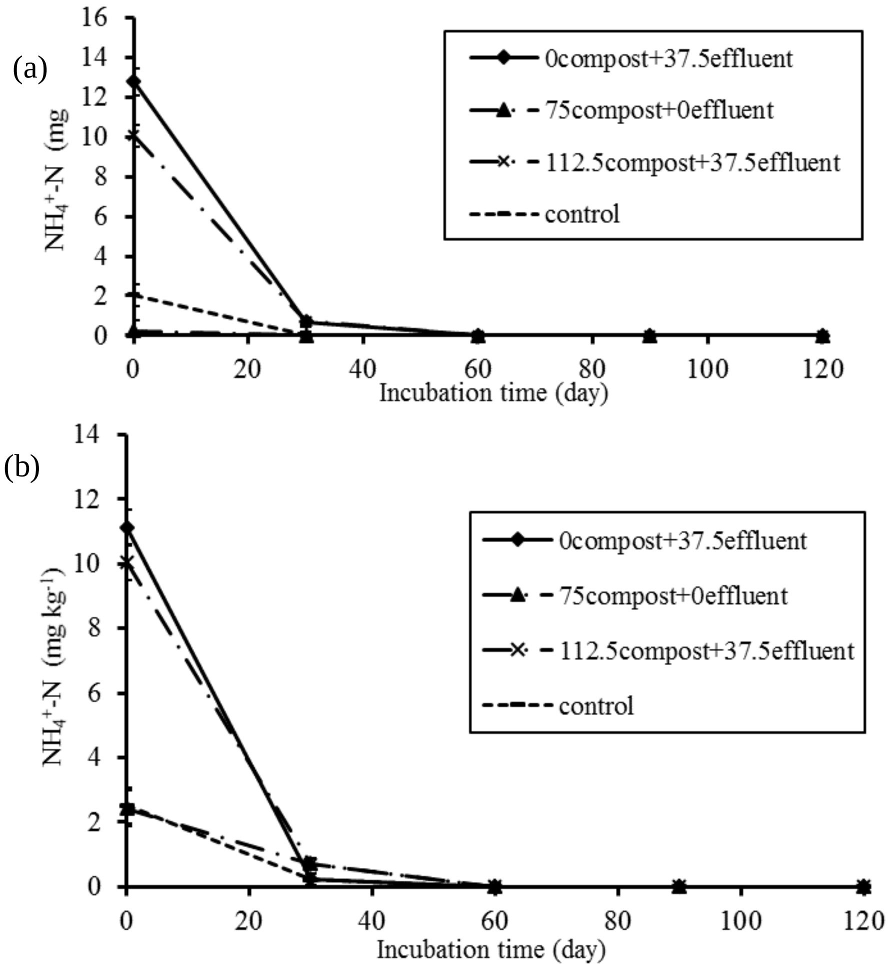


Fig. 3. NH_4^+-N dynamics in (a) sandy loam (b) clay loam soil with various combinations of compost and effluent ($p = 0.01$). The values are the means of triplicates and vertical lines indicate SEM

NO_3^--N increased significantly from 25 to 99 mg kg^{-1} (Fig. 4b) in the first 30 days for the ($112.5_{compost}$ + $37.5_{effluent}$) treatment in clay loam, after which the increase was at a reduced rate to 125 and 130 mg kg^{-1} soil on day 60 and 90 respectively. On day 120, NO_3^--N reduced to 121 mg kg^{-1}. A similar trend was observed for all treatments with a contribution of effluent N (($112.5_{compost}$ + $37.5_{effluent}$), ($37.5_{compost}$ + $37.5_{effluent}$) and ($0_{compost}$ + $37.5_{effluent}$)). The changes in NO_3^--N were significant with time ($p < 0.05$).

The interaction of time and soil type was significantly different ($p < 0.05$) for both soils in terms of NO$_3^-$-N. On average, there was an increase of NO$_3^-$-N with time with the greatest increment observed in clay loam soils. During the first 30 days, the rate of NO$_3^-$-N accumulation in clay loam soil was 2.8 mg NO$_3^-$-N kg^{-1} day^{-1} while for sandy loam it was 0.1 mg NO$_3^-$-N kg^{-1} N day^{-1}. However, between day 30 and 60 the rate reduced to 0.6 mg NO$_3^-$-N day^{-1} for clay loam while for the sandy loam, it increased to 0.23 mg NO$_3^-$-N day^{-1}.

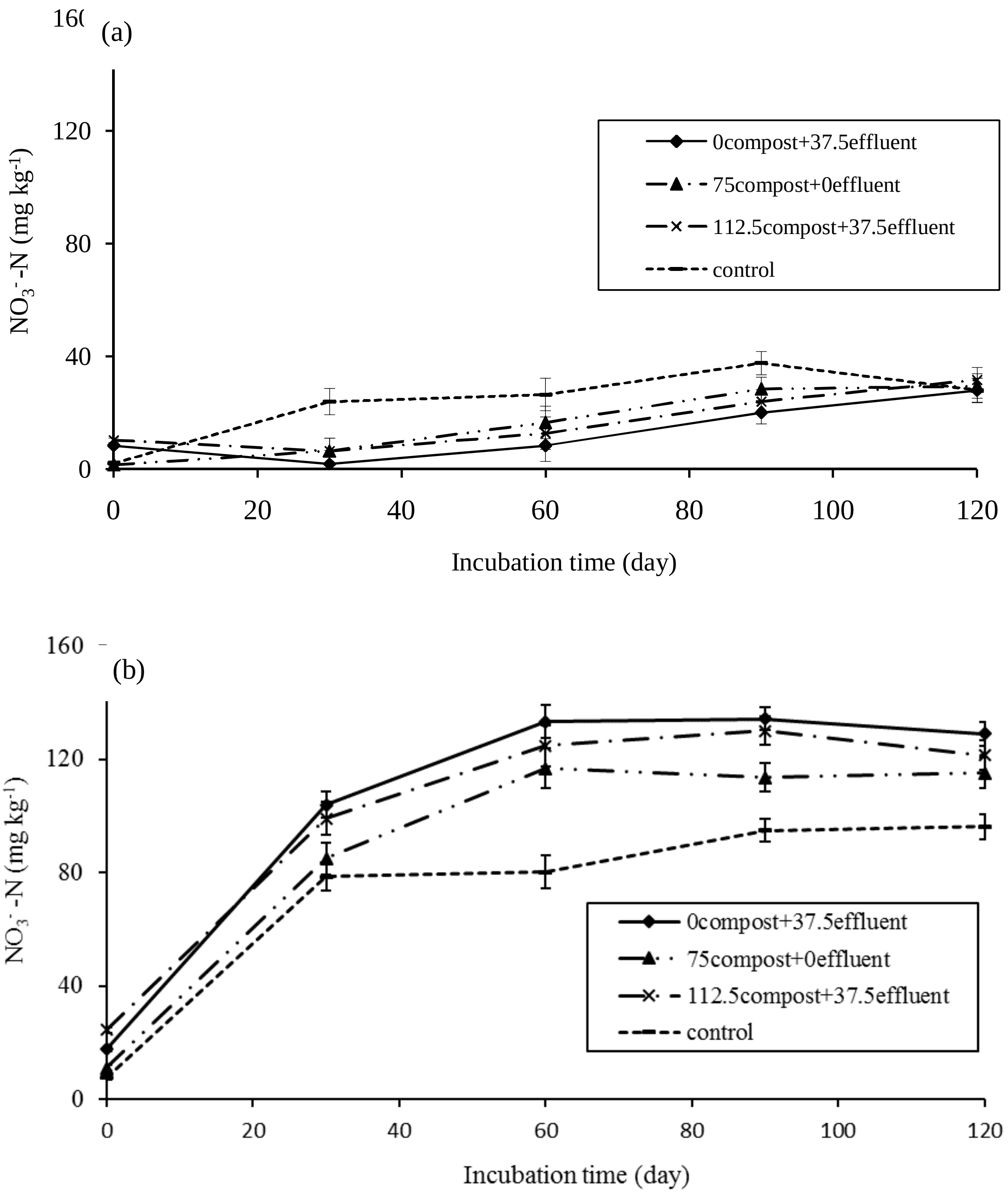


Fig. 4. NO$_3^-$-N dynamics in (a) sandy loam (b) clay loam soil with various combinations of compost and effluent (p = 0.00). The values are the means of triplicates and vertical lines indicate SEM.

During the first 30 days, there was a NO$_3^-$-N decline in treatments with effluent N in sandy loam soil ((0$_{\text{compost}}$ + 37.5$_{\text{effluent}}$), (37.5$_{\text{compost}}$ + 37.5$_{\text{effluent}}$) and (112.5$_{\text{compost}}$ + 37.5$_{\text{effluent}}$)). NO$_3^-$-N declined from 8.3 to 2.5 mg kg^{-1} for the treatment (37.5$_{\text{compost}}$ + 37.5$_{\text{effluent}}$) while for the (112.5$_{\text{compost}}$ + 37.5$_{\text{effluent}}$) and (0$_{\text{compost}}$ + 37.5$_{\text{effluent}}$) treatments, the decline was from 10.6 to 2.1 mg kg^{-1} soil and 8.3 to 1.8 mg kg^{-1} soil respectively (Fig. 4a). However, NO$_3^-$-N in the control treatment in between 30 to 90 days was significantly high ($p < 0.05$) than in treatments with nutrient integration and effluent alone.

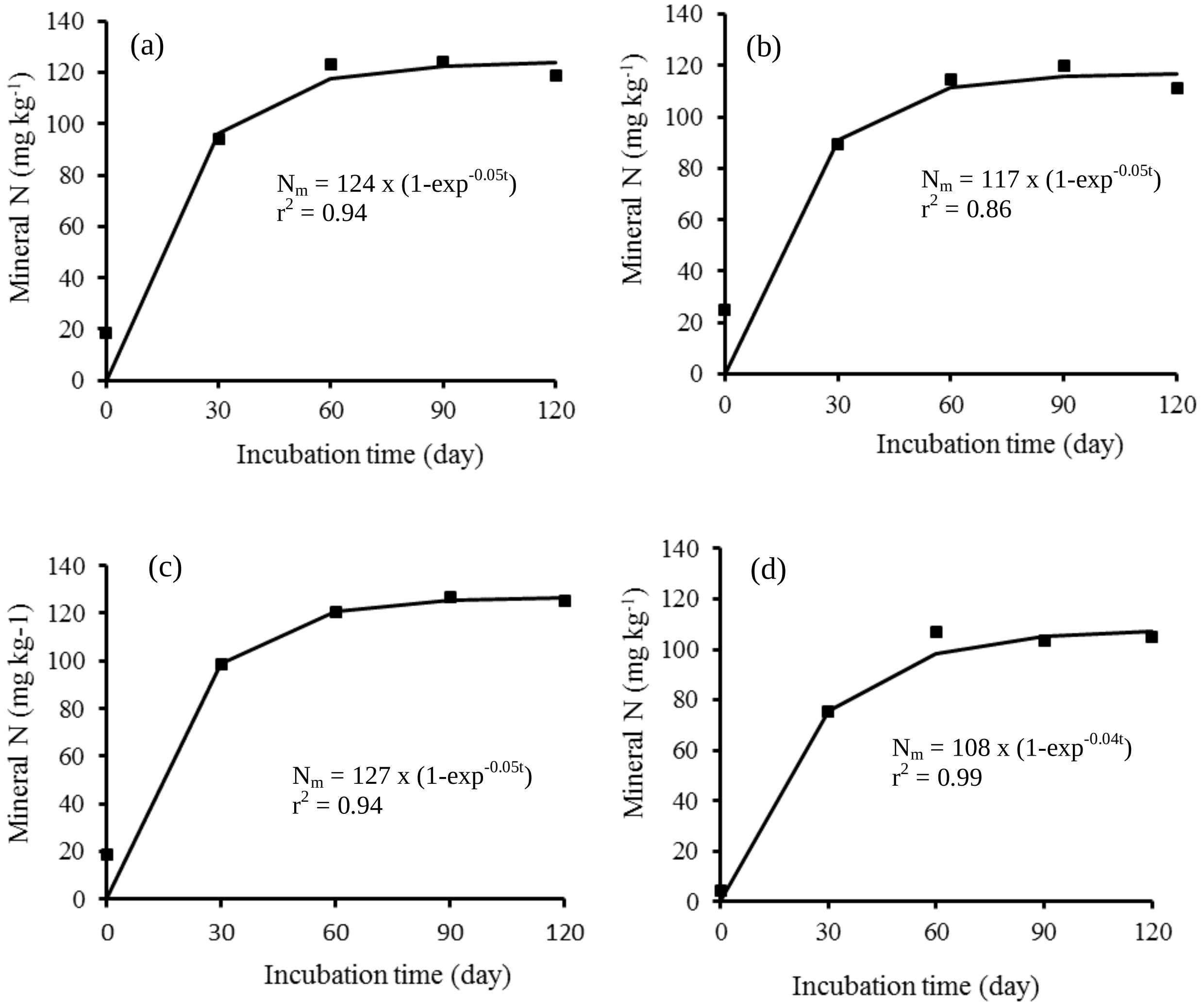
C. Impact of Compost and Effluent Nutrient Combinations on Potential Mineralisable N

The mineral N data was fitted to the one pool model of Stanford and Smith (1972) to determine the influence of the nutrient combinations on the potentially mineralisable N. This model has been successfully used by other authors to describe potentially mineralisable N in soils amended with organic materials. According to Cordovil et al. (2005), the value of potentially mineralisable N (N_o) varies with factors such as moisture, aeration, temperature, nature and amount of organic matter, nature and amount of crop residues left in the soil, and other physical, chemical and biological factors.

The one pool model assumes a mineralisation pattern showing an initial rapid mineralisation followed by a slower linear release of N (Stanford and Smith 1972). This probably explains why the mineral N (N_{min}) data for treatments in sandy loam soil could not be fitted to the model. The N_{min} data for treatments in sandy loam followed the pattern that was described by Chae and Tabatabae (1986) as showing an initial immobilisation of N, followed by N mineralisation. However with satisfactory results, the one pool model was fitted to treatments in clay loam. This was because the pattern of N mineralisation for these treatments in clay loam followed the pattern as described above by Stanford and Smith (1972).

The results of the model fitting for treatments in clay loam soil are presented in Fig. 5. Increasing the quantity of compost as in treatments ($37.5_{compost} + 37.5_{effluent}$) and ($112.5_{compost} + 37.5_{effluent}$) resulted in a lower N_o of 124 and 117 mg kg^{-1} respectively (see Fig. 5). In treatments with effluent ($0_{compost} + 37.5_{effluent}$) and compost alone ($75_{compost} + 0_{effluent}$), the value of N_o was 127 and 108 mg kg^{-1} respectively (see Fig. 5 c & d). Though not significantly different ($p > 0.05$), the readily available N from treated sewage effluent likely influenced the potentially mineralisable N for the ($0_{compost} + 37.5_{effluent}$) treatment.

For the treatment ($150_{compost} + 0_{effluent}$), the one pool model could only be fitted to results of the first 90 days (see Fig. 5e). The reasons are unclear, but we can associate this to the variability of N dynamics that occurred after 90 days. However, the N_0 determined (122 mg kg^{-1} soil) was higher than for the ($75_{compost} + 0_{effluent}$) treatment. Increasing the compost application rate from 75 to 150 kg N ha^{-1} in treatments supplying compost N alone did not significantly increase the N_0.



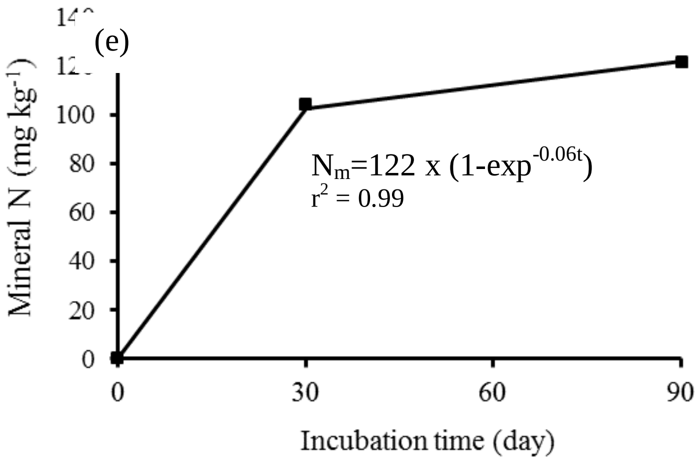


Fig. 5. Net N mineralisation from treatments in clay loam soil:
(a) $37.5_{compost} + 37.5_{effluent}$; (b) $112.5_{compost} + 37.5_{effluent}$; (c) $0_{compost} + 37.5_{effluent}$,
(d) $75_{compost} + 0_{effluent}$; (e) $150_{compost} + 0_{effluent}$. Key: _____, model; • observed value. $N_m = N_{min}$ accumulated at time, t.

The mineralisation constants (*k*), that denote the quantity of mineralisable N released in a day (Serna and Pomares 1992) for the nutrient integration treatments (($37.5_{compost} + 37.5_{effluent}$) and ($112.5_{compost} + 37.5_{effluent}$)) was high ($p > 0.05$) than for treatments with compost N alone. In fact, the *k* for the nutrient integration treatments were greater than 0.013 day^{-1} reported by Eghball (2000) for composted beef cattle feed-lot manure, 0.007 – 0.016 day^{-1} by Dossa et al. (2009) for organic N in the soil, 0.003 – 0.006 day^{-1} (Mungai and Motavalli 2006) for green waste manure.

The mineralisation constants (*k*) obtained for the treatments from the one pool model were not significantly different and close to each other with an average of 0.0509 day^{-1}. Similarly Ribeiro et al. (2010) found no significant differences when they compared mixtures of compost, hen manure and fertiliser. Since there is an inverse relationship between N_0 and *k* (Wang et al. 2003a), Cabrera et al. (2005) suggested using a constant *k* to model the N_0. When this approach was used, the models were significantly different and N_0 decreased with increasing compost contribution. The pattern established was ($0_{compost} + 37.5_{effluent}$) > ($37.5_{compost} + 37.5_{effluent}$) > ($112.5_{compost} + 37.5_{effluent}$). In treatments with compost alone ($75_{compost} + 0_{effluent}$) and ($150_{compost} + 0_{effluent}$), N_0 was 105 and 111 mg kg^{-1} respectively

IV. DISCUSSION

The results from the study indicated that N mineralisation was high in clay loam soil and in treatments that had compost-sewage effluent amendments and sewage effluent alone. The high net N mineralisation in treatments ($0_{compost} + 37.5_{effluent}$), ($37.5_{compost} + 37.5_{effluent}$) and ($112.5_{compost} + 37.5_{effluent}$) could have been influenced by the predominance of effluent – N in mineral form (Fonseca et al. 2007) and low C/N ratio of the treated sewage effluent.

According to Kuzyakov (2000), the release of mineral N without a lag phase is common after the addition of readily available organic substances, because the microbial community do not need time to adapt to the added substances. This was observed in treatments with nutrient integration and effluent as a single source of nutrients. Increasing the contribution of compost in a nutrient supply combination resulted in reduced net N mineralisation. The treatment ($37.5_{compost} + 37.5_{effluent}$) registered significantly higher net N mineralisation as compared to ($112.5_{compost} + 37.5_{effluent}$) despite the former having a low N application rate of 75 kg N ha^{-1} (see Fig. 1).

It is worth noting that NM_{net} for the treatment ($0_{compost} + 37.5_{effluent}$) in clay loam from day 30 to the end of the incubation was significantly higher (see Fig. 1). The observed NM_{net} released from the amendment (effluent) was higher than the applied total N. For example on day 120, NM_{net} was 1.57 kg inorganic N kg^{-1} applied N. Azeez and Van Averbeke (2010) observed up to 400% of total N mineralised when they amended sandy clay loam soil with goat manure while Eneji et al. (2002) found 155% of the added N mineralized in urea amended soils. Similarly, Abbasi and Khizar (2012), reported N mineralisation that was larger than the applied total N. All these authors attributed the extra mineralisation to the release of initially immobilised N due to death of the microbes and also from the microbial cell metabolism.

Priming of soil's native organic matter could have also been a source of the extra mineralisation for the treatments ($0_{compost} + 37.5_{effluent}$) and ($37.5_{compost} + 37.5_{effluent}$). According to Diaz et al. (2008), it is possible that some of the N attributed to the N sources could have originated from the soil organic matter if there was any priming effect caused by the addition of readily available N. The readily available N in secondary treated effluent may have influenced priming of organic matter in clay loam soil. Although this cannot be substantiated in this study, priming effects have been described as being small, short time and occurring immediately or shortly after addition of specific substance to the soil (Kuzyakov et al. 2000; Fontaine et al. 2003)

Nitrogen immobilisation is often associated with the usage of mineral N by the microbial community; actually other authors have interpreted negative N mineralisation as N immobilisation (Burgos et al. 2006) by microbial biomass. However, negative mineralisation does not necessarily relate to N immobilisation by soil microbes because of a possibility of high denitrification losses (Calderón et al. 2005). According to Smith et al. (1998), gaseous losses of N by denitrification or volatilisation can potentially cause large errors in estimates of N availability of organic amendments determined by laboratory incubation, depending upon the experimental conditions.

Using an average field capacity as a basis for determining the quantity of effluent to add to the sandy loam and clay loam may also have influenced N mineralisation. This approach probably resulted into wetter soils in sandy loam. According to Myers et al. (1982) in soils wetter than or close to field capacity, there is either considerable depression of mineralisation or a net loss of mineral N. Guntiñas et al. (2012) found that the optimal moisture content for N mineralisation was 80% of the field capacity but mineralisation at 100% of field capacity was only slightly lower than that obtained at 80% while Rowel (1994) suggested that losses of N by denitrification are minimised when the soil is maintained at approximately 60% of field capacity.

In our case negative NM_{net} from treatments in sandy loam soil signified not only N immobilisation in the treatments but also that N mineralisation was substantial in the control without any amendment as compared to the treatments. This lower rate of net N mineralisation in the presence of compost and/or sewage effluent could be partly due to N assimilation by the growing microbial biomass that was stimulated by compost, effluent and soil organic C. When either effluent and/or compost are added, the adaptation of the soil microbial community is disrupted and a new equilibrated state is required to enhance N mineralisation. In the control in sandy loam soil, soil microbial community are well adapted to a certain environment and respond accordingly to result in N mineralisation. Above all, the low C/N ratio of the sandy loam soil (10.8) guaranteed N mineralisation from the control. A C/N ratio of 15 is a critical limit separating soil groups with higher or lower N release (Springob and Kirchmann, 2003).

Availability and access to substrate by microbes influences nitrification. However availability of substrate can be limited by protection of N from microbial attack through sorption or fixation of organic N and NH_4^+ -N by soil clay minerals (Wang et al. 2003b). Treatments with nutrient integration of compost and treated sewage effluent provided enough substrate to microbes and the replenishment of moisture regularly during the incubation period helped to undermine the protective mechanisms of clay minerals hence large amounts of organic N became available for mineralisation and subsequent nitrification. Above all, C availability is an important factor controlling N cycling in soil. According to Hart at al., (1994), microbial demand for N declines as C availability declines hence more NH_4^+-N become available to autotrophic nitrifiers leading to NH_4^+-N conversion to NO_3^--N. Initially, total C was significantly higher in clay loam soil than sandy loam. At the end of the incubation, a significant reduction of total C was observed in sandy loam (from 1.23% to 1.18%) while a decline in total C in clay loam was not significantly different (p = 0.16). The significant decline of total C in sandy loam was from treatments with compost alone (($75_{compost} + 0_{effluent}$) and ($150_{compost} + 0_{effluent}$)) while no significant differences were observed for treatments in clay loam.

Apart from C/N ratio, temperature and moisture content, soil texture is another important factor that influences the rate and percentage of the total N mineralised. The loss of N through denitrification is higher in fine textured soils than coarse-textured soil, in fact according Parfitt and Salt (2001), net N mineralisation follows the order: sand > clay > silt, however N mineralisation rates in our study, suggested the opposite. Mineralisation rates were significantly higher in clay loam soils ($p < 0.05$) than sandy loam soils. The relatively low clay content in the clay loam soil (29%) and the experimental conditions suggested that fixation in the clay loam soil was not significant hence high N mineralisation. Pare and Gregorich (1999) found lower N mineralisation in soil that had high clay content of 54% after amending the soil with alfalfa residues.

In sandy loam soil, net N mineralisation at the start was significantly high in treatments with effluent N contribution. This indicated that effluent N made a significant contribution to the net N mineralisation at the start of the incubation. After 30 days, the disappearance of the initially high NH_4^+ -N (in the greenwaste compost) may have also influenced the negative mineralisation (Calderón et al. 2005). Burgos et al. (2006) also noted markedly reduced NH_4^+-N until 6 weeks after which NH_4^+ -N content was zero. Disappearance of NH_4^+ -N has been attributed by Hadas and Portnoy (1994b) and Han et al. (2004) to the assimilation of N by growing microbial biomass stimulated by the organic and inorganic N amendments. According to Fonseca et al. (2007) loss of NH_4^+ -N is strongly linked to microbial N immobilisation as it is the most preferred microbial inorganic N.

The influence of compost-effluent nutrient integration on N dynamics and N mineralisation has been soil specific. This could be explained by the initial differences in fertility of the two soils (see Table 1). In clay loam soil, the influence of the treated sewage effluent resulted into inorganic N accumulation in the soil. Treated sewage effluent had a pronounced effect on treatments in clay loam while in sandy loam its effects resulted in N immobilisation at the start of the incubation.

The immobilisation that took place in treatments with effluent N at the start affected inorganic N accumulation in sandy loam soil. This immobilisation was likely as a result of an increase in the reproductive rates of microbes after the addition of readily available N and soluble organic matter through the sewage effluent. According to Abbasi and Khizar (2012), the increase in microbial reproductive rates results into a competition for nutrients and subsequent trapping of nutrients (immobilisation). This phenomenon was more pronounced in sandy loam which was also low in fertility as compared to the clay loam.

This means that even the native N in the sandy loam could not provide enough substrate for the microbial population after applying the sewage effluent. The extent and the duration of N immobilisation in sandy loam soil ((0$_{compost}$ + 37.5$_{effluent}$), (37.5$_{compost}$ + 37.5$_{effluent}$) and (112.5$_{compost}$ + 37.5$_{effluent}$)) can potentially present serious problems on crop growth due to limited availability of inorganic N. However, the increase in N mineralisation after 30 days guarantees continuous supply of inorganic N for plant growth.

V. CONCLUSION

The analysis of the data has shown that the response to compost and effluent integration on N dynamics is soil specific. Different patterns of N dynamics have been shown as a soil response to the different combinations of compost and treated sewage effluent: an initial rapid net N mineralisation followed by a slower release of N for clay loam soil and an initial period of immobilisation followed by a continuous N mineralisation period for sandy loam soil.

In clay loam, increasing the quantity of compost in nutrient blending resulted in a reduced net N mineralisation. At the end of the incubation, (37.5$_{compost}$ + 37.5$_{effluent}$) treatment registered net N mineralisation of 0.9 kg inorganic N kg^{-1} applied N while (75$_{compost}$ + 0$_{effluent}$) and (112.5$_{compost}$ + 37.5$_{effluent}$) treatments had 0.5 and 0.3 kg inorganic N kg^{-1} applied N respectively. While in sandy loam with time, increasing the quantity of compost improved net N mineralisation. However, N mineralisation was higher in clay loam soil as compared to sandy loam soil but in sandy loam soil moisture content likely influenced N mineralisation.

The extent and duration of N immobilisation in sandy loam under compost-effluent blending could potentially produce serious risks of N deficiency to plants. This can affect plant growth for a period of at least one month after addition of the amendments. However, nutrient integration can provide a means through which less compost is applied at the same time taking advantage of the readily available nutrients in effluent.

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