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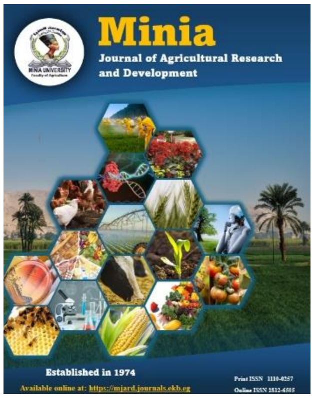

Nitrogen Forms and Heavy Metals Leachability Following Biosolids Application to Sandy Soil

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ABSTRACT

Leaching poses a significant concern in dry regions with sandy soils due to their inherent characteristics of low fertility, coarse texture, very low organic matter content, and limited water retention capacity. The aim of this research was to minimize environmental consequences of applying biosolids compost at high rates to sandy soils under arid conditions in terms of inorganic nitrogen and heavy metals pollution. This investigation used a pot experiment that was incubated at a constant temperature (25 ^{0}C) and comprised four application rates (0.0, 20, 40, and 60 t/ha) of compost, two methods of application (mulching and incorporating) and two intermittent irrigation intervals (3 and 6 days). Results of this experiment revealed that the nitrate concentration in soil leachate exceeded 50 mg/L, a value considered highly poisonous if it exists in drinking water. Ammonia concentrations exceeded 20 mg/L in the second leachate fraction but decreased to under detection limits in the last fifteen leachate fractions for all compost treatments. The suggested maximum contamination level for groundwater is 1.5 mg NH_4-N-1. NO_3-N concentrations in all soil leachate fractions were substantially above the acceptable threshold in drinking water for people (10 mg/L) but far below the recommended level in drinking water for cattle (100 mg/L). The findings provided strong evidence that the environment is well safeguarded in terms of heavy metal concentrations in the soil leachate. From this research, it may be stated that high loading rates of excellent quality compost to sandy soils is agronomically advantageous with little potential environmental harm if handled effectively.

Keywords: Biosolids Compost, Nitrate, Ammonia, heavy Metals.

INTRODUCTION

Population growth in Egypt is expected to reach 106 million by 2024, up from 50 million in the 1990s. According to **Abd El-Azeim et al. (2023)**, the population growth will need a 200% to 300% increase in food production to fulfill demand. Increased volumes of human waste will be produced by the growing population in addition to the rising need for food. Then,

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instead of just throwing trash in the closest stream or the Nile River, this will need to be disposed of in other ways. **Elgarahy et al. (2024)** state that in order to improve the productivity of sandy soil in Egypt, it is crucial to use as much of this human waste (biosolids) as possible as an organic fertilizer and soil conditioner.

Biosolids, also known as Sewage sludge, is the insoluble residue left behind after the treatment of wastewater following anaerobic or aerobic digestion. Biosolids are composed of organic matter that is 60% resistant to degradation, nitrogen (3%N), phosphorus (2% P_2O_5), and other macronutrients such as (0.5% K2O, 5% CaO, 1.5% MgO), an extensive variety of micronutrients, non-essential trace metals, organic pollutants, microorganisms, and parasitic organism eggs **(Sugurbekova, et al., 2023).** Raw sewage sludge, both primary and secondary, are odorous and pathogen rich. Tertiary treatment is applied to remove certain dissolved solids such as phosphorus, and often involves the additions of chemicals such as lime, Al and Fe, or organic polymers, to make the final product more stabilized, low pathogen levels and low odour potential **(Okoffo et al., 2020).** For every 10^6 Liters of wastewater treated, tertiary treatment yields around 1×10^4 L of tertiary sludge. Biosolids is organic matter (untreated sludge contains 70-80% dry weight of organic matter), and when added to soils, becomes part of the soil organic matter pool **(Dad et al., 2019).** Organic matter from biosolids can significantly change the physical, chemical and biological properties of soils. organic matter may change the content and transmission of water, air, and heat in the soil, as well as increase the structure (porosity, aggregation, and bulk density) and strength of the soil **(Cioca et al., 2021).**

Biosolids when put in soils offers macro-plant nutrients such as NPK; and micro-plant nutrients such as Fe, Cu, and Zn. Concentrations of plant nutrients in biosolids vary greatly, and NPK levels are around one-fifth of those found in standard chemical fertilizers **(Ge et al., 2019).** However, of all the N in any biosolids, organic N makes up the vast majority (between 50% and 90%). In contrast to N, organic P makes up just 10% to 30% of the total P in anaerobic biosolids **(Sen, 2023)**. The residual P exists as inorganic phosphates of Ca, Fe, and AL **(Sommers, 1977**It is important for the organic N and P combinations in biosolids to mineralize before they are absorbed by plants. According to **Oun et al. (2014)** and **Zhou et al. (2023)** local variables such as soil type, temperature, pH, water content, and other chemical and physical properties of the soil affect how quickly N and P in the soil mineralize. The reason why biosolids have a low potassium concentration is because most K compounds are soluble in water and end up in the aqueous fraction or sewage effluent during sludge dewatering **(Hue, 1995)**. The same process may also lead to the loss of some inorganic N, especially NH4+ that is concentrated during sludge digestion **(Kash et al., 2021; Marchuck et al., 2023)**.

Biosolids may have significant impacts on plant development and crop yield when used on soils due to its organic matter and mineral content **(Le and Price 2024).** However, biosolids may also have concentrations of heavy metals that are of environmental concern. Heavy metals can be either toxic or beneficial to humans, animals, and plants. Some of these are essential to plants, animals, and human (Zn, Cu, Fe, and B), others may be toxic (Cd, Cr, Pb, and Ni) or have no effect such as barium and antimony. **Sommers (1977)** reported the coefficient of variation for heavy metals in biosolids from eight U.S cities to be: Cd, 27 - 160%, Zn, 26 - 58%, Cu, 18 -167%, Ni, 12 - 144%, and Pb, 9-56%. Heavy metals are almost exclusively found in solid phases in biosolids; these phases' physicochemical shapes, and therefore their Phyto availability and mobility in soils, may be impacted by factors such as pH, the presence of ligands that form complexes, and the solubility of solid phase minerals **(Elgarahy et al., 2024; Abd El-Azeim and Haddad 2017; Abd El-Azeim et al., 2022).** The solid phase metals in biosolids and biosolids-treated soils have been separated by consecutive extraction processes **(Emmerich, et al., 1982)**, which demonstrated that large levels of heavy metals occurred in fractions containing organic matter. Biosolids, which are extensively applied to crops, may contain quite significant quantities of heavy metals. These heavy metals may stay in soils forever and be absorbed by crops in sufficient amounts to severely harm the health of consumers and/or crops themselves. When good biosolids are composted, the metal concentration is substantially diluted by the inclusion of bulking materials **(Liu et al., 2020)**.

Current ways of use/disposal of biosolids include land application, composting, drying, incineration, and landfilling. Although, all options have potential consequences, the practise of land application is the most widely used option. Consequently, there is still an issue with biosolids' final disposal; this is due to the fact that more will be produced and also because the public perception for biosolids agricultural use still inaccurate and considers biosolids products to be harmful in some way. Landfilling accounts for 50–75% of the biosolids disposal practices in various European nations. The remaining portion is disposed of in agricultural fields as a soil conditioner/fertilizer (25–35%) or in other recycling outlets, such as parks, land restoration, and landscaping **(EEA, 1998)**. National authorities promote agricultural use of composted biosolids or other digested biosolids as the best recycling method; incineration is regarded as the worst. Landfilling will be controlled if the removal of organic material is made necessary, since sea dumping is already forbidden.

Composting is considered as a cost-effective ecologically sound procedure for treatment of biosolids, even if they may include compounds, which offer potential harm to the environment or food chain. Composting is the biological breakdown of organic waste under regulated, aerobic circumstances into a humus-like stable product that may be sold as a soil conditioner and/or a slow-release fertilizer **(Epstein, 1997; Abo Shelbaya et al., 2021a and b)**. Biosolids composting aims at biologically stabilizing sludge as well as limiting pollution concerns in order to promote agricultural or other end use outlets using the nutritional or organic value of sludge. Biosolids compost, rich in organic nutrients, is regarded a good soil additive. Biosolids composted for agricultural end use is consequently of value to secondary markets. In the case of sludge treated by incineration, waste sludge may be composted as a pre-treatment to lower the water content, therefore boosting the efficiency of the burning process **(EEA,**

1998). Composting has various benefits in compared with other sludge treatment processes. Although expenses are high and the necessity for outlet market when sludge is composted, frequently underline and compel the need for sewage sludge disposal options. But, the health concerns such as disease risk, nutrient management, potentially hazardous metals, and organic pollutants in response to crop demand, supporting composting as a crucial and ecologically sound solution **(EEA, 1998; Abd El-Azeim et al., 2021)**.

The aim of this experiment was therefore set out to determine under more controlled conditions the effects of biosolids compost application rates and methods at different moisture conditions upon the fate of water-soluble forms of N and heavy metals in a coarse-textured sandy soil. Specifically, the objectives of this study were:

1- To quantify rate and pattern of nitrate, ammonia and total soluble N accumulation in the soil solution.
2- To determine the influence of moisture status on the potential of nitrate and ammonia leaching into ground water.
3- To determine nitrogen mineralization rate and calculating N budget.
4- To quantify amounts of available heavy metals accumulated in soil and amounts of water-soluble heavy metals in soil leachate.

2. MATERIALS AND METHODS

The factors investigated for substantial influence on the N forms and heavy metals in soil leachate were compost application rates (0.0, 20, 40, 60 t/ha), compost application methods (mulching and incorporating) and different moisture conditions on a three- and six-days' intervals basis. Before starting the experiment, a pilot trial was performed prior to the main pot experiment to observe temporal changes in moisture contents for biosolids compost treatments under high temperature. The pilot trial had the same combination of treatments as suggested for the main pot trial. Water content was estimated on a weight difference basis. Generally, throughout the measuring time (6 days), the soil moisture contents in the compost treatments were higher than the control. The highest moisture differences existed between the mulched-compost treatment at 60 t/ha of compost rate (Mul BS3) and the control. Intermediate values were obtained for the other compost treatments. In the light of the pilot experiment data, the influence of mulched applied compost was having a significant effect upon moisture content compared with incorporated compost. Also, the data suggest supplying water either every 3 or 6 days produce varied moisture conditions to which the pots are exposed. So that the main pot trial was watered with de-ionised water on a three- and six-day's intervals basis (W1 and W2 treatments) to maintain different moisture conditions.

2.1 EXPERIMENTAL MATERIALS AND DESIGN.

This investigation comprised a pot experiment done at a high temperature of 25^{o}C. It comprised four application rates (0.0, 20, 40, 60 t/ha) of biosolids compost, two methods of application (mulching and incorporating) and two intermittent wet and dry cycles (3- and 6-days intervals). Under these conditions, the fate and total recovery of nitrogen and heavy metals from biosolids compost applied to sandy soil were studied in the leachate following an incubation period of intermittent leaching and different moisture conditions in pots for 60 days.

2.1.1 EXPERIMENTAL MATERIALS

Sandy soil indicated in table 1 was gathered from the university research farm at Shosha. This sandy soil was selected since its range of physical and chemical qualities were comparable to most sandy soils that spread across Egypt.

Table (1). Physical and chemical properties of the investigated soil.

<table>
<tr><th colspan="2">Particle-Size Distribution %</th><th>Coarse sand
54.25</th><th>Fine sand
38.10</th><th colspan="2">Silt
3.95</th><th>Clay
3.70</th></tr>
<tr><td colspan="2">Texture grade</td><td colspan="5">Sand</td></tr>
<tr><td colspan="2">F.C %</td><td colspan="5">12.77</td></tr>
<tr><td colspan="2">PWP %</td><td colspan="5">3.34</td></tr>
<tr><td colspan="2">WHC %</td><td colspan="5">15.56</td></tr>
<tr><td colspan="2">A.V(F.C – PWP) %</td><td colspan="5">9.43</td></tr>
<tr><td colspan="2">A.V(WHC – PWP) %</td><td colspan="5">12.22</td></tr>
<tr><td colspan="2">Bulk Density g/cm^3</td><td colspan="5">1.64</td></tr>
<tr><td colspan="2">Particle Density g/cm^3</td><td colspan="5">2.59</td></tr>
<tr><td colspan="2">pH (1-2.5)</td><td colspan="5">7.56</td></tr>
<tr><td colspan="2">CEC (cmol$_c$ kg^{-1} soil)</td><td colspan="5">3.2</td></tr>
<tr><td colspan="2">O.M %*</td><td colspan="5">0.66</td></tr>
<tr><td colspan="2">EC dS m^{-1} at 25 ^{0}C</td><td colspan="5">0.70</td></tr>
<tr><td colspan="2">Total N %</td><td colspan="5">0.058</td></tr>
<tr><td colspan="2">Total P %</td><td colspan="5">0.019</td></tr>
<tr><td colspan="2">Total K %</td><td colspan="5">0.32</td></tr>
<tr><td colspan="2">$CaCO_3^-$ %</td><td colspan="5">8.54</td></tr>
<tr><td colspan="7">Heavy metals concentration (mg kg^{-1})</td></tr>
<tr><td>Zn</td><td>Cu</td><td>Ni</td><td>Pb</td><td>Cd</td><td colspan="2">Cr</td></tr>
<tr><td>24.22</td><td>56,32</td><td>43.54</td><td>24.34</td><td>2.12</td><td colspan="2">4.65</td></tr>
</table>

* Loss on ignition method.

Prior to the commencement of the incubation investigation, the soil was air dried, sieved to < 2.0 mm, and the moisture content was regulated at 15 % before the addition of biosolids compost mixtures. Sub-samples of the dried and sieved soil were utilized to determine the soil parameters using techniques of soil analysis **(Black, 1965)** and standard procedures by **(Avery and Bascombe, 1982; Page et al., 1982).**

Raw biosolids was obtained from New Minia city Sewage Station, industrial city, Minia governorate on October 2021. This raw biosolids were mixed with a bulk material of local agricultural plant residuals to provide carbon and increase pile porosity, then arrayed in a hierarchical pile for aerobic fermentation-composting. Biosolids compost specified in Table 2 was air dried, then crushed, blended and screened to < 5.0 mm, and then kept in unsealed plastic bags at 4 oC before addition to the experiments. Sub-samples of the dried, ground, and sieved biosolids compost were utilized to assess various physiochemical parameters such as moisture, heavy metals and total nutrients. Most of the procedures applied are of a standard laboratory practice derived from methods of soil analysis **(Black, 1965)** and **Avery and Bascombe, (1982)**; **Page et al., (1982)**. Biosolids composts were then applied to examined sandy soil alone at the rates of 0.0, 20, 40, 60-ton ha-1 on a dry weight by two techniques of application (mulching and incorporating).

Table (2). Some physical and chemical properties of the investigated biofertilizer.

Compost property	**Value**
Moisture weight %	22.8
pH	8.16
EC mS/cm at 25 ^{0}C	8.52
CEC meq/100g soil	55.6
Dry solids %	77.2
Total organic carbon % (D.M)	36.1
Total N %	2.22
C/N Ratio	16.26
Ammonia (mg kg^{-1})	451
Nitrate (mg kg^{-1})	57
Total P % (D.M)	0.50
N/P Ratio	4.44
Total K % (D.M)	0.90
Total Ca % (D.M)	1.68
Total Mg % (D.M)	0.67
Zn (mg kg^{-1})	66.86
Cu (mg kg^{-1})	200.3
Ni (mg kg^{-1})	120.2
Pb (mg kg^{-1})	56.55
Cd (mg kg^{-1})	3.20
Cr (mg kg^{-1})	11.33

2.1.2 Experimental design.

This study was performed with an incubation period of 60 days, at the facilities of faculty of Agriculture, Minia University, Egypt. Experimental pots were randomly incubated in a temperature-controlled propagating frame at 25 ^{o}C. Experiment was composed of four biosolid compost application rates, two application methods and two different moisture conditions. The BS (biosolids) application rates were 0.0, 20, 40, and 60 t ha^{-1} (BS_0, BS_1, BS_2 and BS_3 treatments, respectively). Compost was added on the surface as mulch (Mulching) and mixed thoroughly with the investigated sandy soil by hand (Incorporating). Deionised water was added to maintain different moisture conditions on a three- and six-day's intervals basis (W1 and W2 treatments).

Every three or six days, a two-volume application of deionized water would be applied. The first was the average amount of water required to fill each pot to its water holding capacity (WHC), and the second was 100 ml less the water that was left in the pot before water was applied. The weight differential between the wet and dry weights of the filled pots was used to compute the amount of water retained. The weight of the whole pot after water application and the cessation of free drainage was known as the wet weight, whereas the weight of the entire pot before water application was known as the dry weight.

2.2 Leachate sampling and analysis.

As the pots were being watered, 100 ml of the leachate fraction (Time series) from each leaching event was collected. Mercuric chloride (40 mg $HgCl_2$ / L) was then used to preserve the leachate fractions, with a final concentration of 1 mL of $HgCL_2$ per 100 effluent sample. Leachate fractions were then kept in storage at 4 ^oC **(Clark, 1983)**. Every duplicate was given a bulked sample, which was created by adding 5 ml to the time series effluent samples that were collected, maintained, and kept in the same manner as the time series. Using the Technicon Auto-Analyzer II **(Williams, et al., 1995)**, the time series and bulked samples were analysed for nitrate (NO_3-N) and ammonium (NH_4-N). The Autoclave technique was used to estimate the amount of total soluble nitrogen (TSN) in both samples **(Williams, et al., 1995)**. Unless otherwise noted, all N data in the research are reported in mg, with the N mass unit (mg) being used to compute the N budget.

After 12 days incubation half of the leachate fraction was collected and stored at 0.0 ^oC for heavy metals content determination according to **(ISO 11047, 1998).** The electrical conductivity (EC) and pH of all leachate fractions were measured. After the experiment ceased soil samples were taken and analysed for total heavy metal content by digestion in boiling aqua regia and the available heavy metals content by DTPA (diethylenetriaminepentaacetic acid) extraction method **(Lindsay, 1979)** using electrothermal atomic adsorption spectrometry. Other soil samples were taken and analysed for total nitrogen (TN) using Buchi equipment. Total N was determined using a modified version from Kjeldahl (digestion and distillation units) according to **Rowell, 1994.**

2.2.1 Nitrogen forms analyses.

Nitrogen analyses were carried out according to the standard methods derived from (Williams et al 1995; Rowell 1994, and MAFF, 1986). The N analyses involved the determination of NO_3^--N, NH_4^+-N, and total soluble N in the soil samples and leachate by automated continuous flow apparatus (Technicon Auto Analyser Π). Nitrate and ammonium are extracted from soil using aqueous salt solutions by potassium chloride as the extractant **(Black, 1965).** This method was used for all soil inorganic N and total soluble nitrogen (TSN) in extractions from the incubation trial and the leachate collected from the pot trial. Total N was determined using the BUCHI apparatus (digestion and distillation units) according to **Rowell, 1994; and MAFF 1986.**

2.2.2 Total and extractable heavy metals analyses by DTPA.

Electrothermal Atomic Absorption Spectrometry **(ISO 11047, 1998)** was used to assess the total heavy metal content of the compost and compost treated soils by digestion in boiling aqua regia, which was produced in compliance with **ISO 11466 (1995)**. Additionally, soil samples were crushed through a 2 mm stainless steel filter and allowed to air dry. Using DTPA, the extractable cations (Zn, Cu, Ni, Pb, Cd, and Cr) in the samples from the top 20 cm were identified. Using a combination of 0.1 M triethanolamine (TEA), 0.005 M diethylenetriaminepentaacetic acid (DTPA), and 0.01 M $CaCl_2$ at pH 7.3, the extractable cations were ascertained **(Lindsay and Norvell, 1978).**

2.3 Statistical analysis.

Experimental data were evaluated as a totally randomized design, with three replicates using the **(6.11, SAS Institute, 1996)** program. By Duncan's test, means of the experimental data were compared using Least Significant Differences (LSD) at the 0.05 probability level.

3. RESULTS AND DISCUSSIONS

This research was set out to design a management approach that employed biosolids compost as a soil conditioner and fertilizer to improve their agronomic advantages and reduce their environmental implications in terms of nitrate or heavy metals pollution when applied to recently recovered sandy soil. Under this research conditions, the fate of total recovered N and heavy metals from biosolids compost applied to sandy soil in pots were studied in the leachate following intermittent leaching cycles (3 and 6 days) for sixty-day period of incubation.

3.1 Results of soil moisture.

Moisture variations for compost treatments before to and after water application suggest that the experiment is exposed to variable moisture conditions (Table 3). Table 3 demonstrates that the compost treatments exhibited larger ranges of moisture values as the compost application rates rose following water application. This indicates that the beginning moisture conditions of the propagating pots were different at every watering event for all the treatments. However, prior to water application, moisture values declined as the watering period rose. Also, the findings of this experiment demonstrated that the maximum water content was observed for the highest compost rate and reduced as the compost application rates fell.

Table (3). Averages of water content prior to and after water application for the biosolids compost-amended pots.

Treatments		Water content %					
		Prior to water application.			After water application.		
		Average	S.D	C.V %	Average	S.D	C.V %
Mulching	W1 BS0	4.06	0.11	2.70	17.86	0.65	3.60
	W1 BS1	7.48	0.42	3.60	20.60	0.93	4.50
	W1 BS2	10.08	0.55	4.40	22.55	0.57	2.50
	W1 BS3	12.23	0.81	3.60	26.19	1.23	4.20
	W2 BS0	1.25	0.05	4.00	18.08	0.14	0.78
	W2 BS1	3.25	0.20	2.10	20.37	0.20	0.98
	W2 BS2	5.20	0.34	3.50	20.81	0.99	4.70
	W2 BS3	6.27	0.35	1.60	24.97	1.57	4.20
Incorporating	W1 BS0	4.06	0.11	2.70	17.86	0.65	3.60
	W1 BS1	7.03	0.41	4.90	19.59	0.43	2.10
	W1 BS2	8.08	0.19	2.20	21.31	1.15	4.30
	W1 BS3	10.30	0.44	4.30	24.43	0.67	2.70
	W2 BS0	1.25	0.05	4.00	18.08	0.41	0.78
	W2 BS1	2.30	0.30	1.30	20.48	0.74	3.60
	W2 BS2	3.99	0.24	3.10	22.28	0.90	4.10
	W2 BS3	4.90	0.18	3.80	25.05	0.60	2.30

- W1 and W2 refer to watering every 3 and 6 days, respectively.
- BS0, BS1, BS2, BS3 refer to 0.0, 20, 40, and 60 t ha^{-1} of biosolids compost addition, respectively.

For the watering time, moisture conditions also increased as the watering time decreased from 6 to 3 days. These indicate that the microorganisms responsible for N mineralization are subjected to varying moisture conditions. Therefore, the quantity of N mineralised from the applied compost was predicted to change as a consequence of varied moisture conditions.

3.2 Nitrate accumulation rate and leaching.

The accumulation rates of recovered NO_3-N in the effluent and bulk samples collected from sandy soils treated with different compost treatments after 3- or 6-days watering intervals are shown in table (4). The results revealed that the concentrations of NO_3-N were high but with no significant differences in all leachate fractions collected after 3-day watering intervals compared to 6 days. The concentrations of NO_3-N increased significantly as the application rate of compost increased. Therefore, the leaching of NO_3-N was increased in the case of different moisture condition and application rates. This is an indication of differential release of N from biosolids compost, which in turn was dependent on the different moisture conditions and compost application rate.

The peak concentrations of nitrate in leachate fraction were 53.51, 49.57, 47.27 and 43.16 mg/L for Inc W2 BS_3, Inc W1BS_3, Inc W1BS_2 and Mul W2 BS_2, respectively. The concentrations of nitrate for both the time series and bulked samples were raised when the moisture conditions rose by reducing watering intervals and the peak always appeared in the fourth leachate portion for varied treatments.

Table (4). The accumulation rate of various forms of N leached from sandy soil amended with biosolids compost in 20 leachate fractions.

Treatments			NO_3^--N		NH_4^+-N		TSN		SON	
App. Methods	Watering Time	App. Rate	series (mg)	bulked (mg)	series (mg)	bulked (mg)	Series (mg)	bulked (mg)	Series (mg)	Bulked (mg)
Mulching	***W1***	BS0	9.22 *a*	10.18 *a*	0.15 *a*	0.21 *a*	20.55 *a*	21.52 *a*	11.18	11.13
		BS1	19.35 *b*	21.35 *b*	0.86 *b*	1.00 *b*	99.16 *b*	101.2 *b*	78.95	78.85
		BS2	22.1 *bc*	22.6 *bc*	1.36 *c*	1.45 *c*	215.2 *c*	214.3 *c*	191.74	190.25
		BS3	25.36 *c*	26.15 *c*	3.18 *d*	3.02 *d*	292.5 *d*	282.5 *d*	263.96	253.33
	W2	BS0	6.66 *a*	7.12 *a*	0.11 *a*	0.13 *a*	11.23 *a*	11.52 *a*	4.46	4.27
		BS1	15.18 *b*	19.29 *b*	0.67 *b*	0.66 *b*	65.18 *b*	62.15 *b*	49.33	41.57
		BS2	20.25*c*	21.10 *c*	1.15 *bc*	1.25 *bc*	155.1 *c*	156.6 *c*	133.75	134.25
		BS3	22.35 *c*	22.05 *c*	2.17 *c*	2.21 *c*	182.3 *c*	180.9 *c*	157.83	156.64
Incorporating	***W1***	BS0	9.22 *a*	10.18 *a*	0.15 *a*	0.21 *a*	20.55 *a*	21.52 *a*	11.18	11.13
		BS1	25.83 *c*	23.90 *c*	2.15 *c*	2.31 *c*	101.1 *b*	100.9 *b*	73.12	74.69
		BS2	33.15 *d*	34.22 *d*	3.24 *d*	3.32 *d*	211.2 *c*	215.0 *c*	174.81	177.46
		BS3	41.22 *f*	42.68 *f*	5.50 *f*	5.56 f	281.6 *d*	282.1 *d*	234.88	233.86
	W2	BS0	6.66 *a*	7.12 *a*	0.11 *a*	0.13 *a*	11.23 *a*	11.52 *a*	4.46	4.27
		BS1	21.15 *b*	20.22 *b*	1.15 *b*	1.20 *b*	66.15 *b*	62.81 *b*	43.85	41.39
		BS2	24.61 *c*	25.09 *c*	2.17 *c*	2.31 *c*	151.1 *c*	153.1 *c*	124.32	125.70
		BS3	33.16 *d*	33.07 *d*	3.60 *d*	3.75 *d*	180.1 *c*	181.2 *c*	143.34	144.38

Means of three samples within columns and rows under one parameter followed by the same letter are not significantly different ($P \leq 0.05$*) as measured by the LSD method.

*NB. Soluble Organic Nitrogen (SON) = TSN – (NO_3-N + NH_4-N)

Among the different compost-moisture condition treatments, concentrations of NO_3-N were greater for incorporating compost into the sandy soil than mulching compost. The cumulative quantities of NO_3-N recovered in 2000 ml of leachate were significantly different among the four application rates and different methods of applications. The peak elution of NO_3-N leached followed the highest rate of incorporated-compost under the high moisture conditions (watering every 3 days). NO_3-N elution reached a peak on the fourth or fifth leachate and then declined to a very low level. It was speculated that immobilization was primarily responsible for this decline **(kosh et al., 2021; Marchuck et al., 2023)**. Figures 1 and 2 show that NO-N elution for all treatments persisted at a rather constant concentration from the sixth through the twentieth leachate. The concentrations of NH_4-N in the leachate rapidly decreased throughout this time, reaching zero. This indicates that there is a lag period between the release of TSN and the ensuing nitrification and hydrolysis.

The figures illustrate that no nitrate was present in the first leachate fraction from all treatments and the peak concentrations were observed in the fourth leachate after compost application to the sandy soil, i.e., 12 and 24 days for the 3 and 6 of watering time intervals, respectively. The NO_3-N decreased drastically by the fifth leachate. These results are in agreement with **(Algarahy et al., 2024).** This pattern of NO_3-N in the leachate fraction could be attributed to differences in edaphic soil conditions caused by compost method of application and different moisture conditions **(Oun et al., 2014; Zhou et al., 2023).**

Three conclusions may be drawn from this data. Firstly, the NO_3-N concentration in all leachate fractions improved as the application rate of compost increased and was significantly higher *($P \leq 0.05$)* from the incorporated-compost than from the mulched-compost. Secondly, In the leachate from both incorporated and mulched compost, nitrate was the predominant form of inorganic N. Increasing soil moisture content, as well as the rate and technique of applying compost, had a significant ($P < 0.05$) impact on the concentrations of NO_3-N in all leachate fractions. Thirdly, between all compost treatments, the NO_3-N concentrations in all soil leachate fractions were significantly higher than the **USEPA (1987)** recommended level for human drinking water (10 mg/l), but significantly lower than the Environmental Studies **Board (1973)** recommended level for livestock drinking water (100 mg/l).

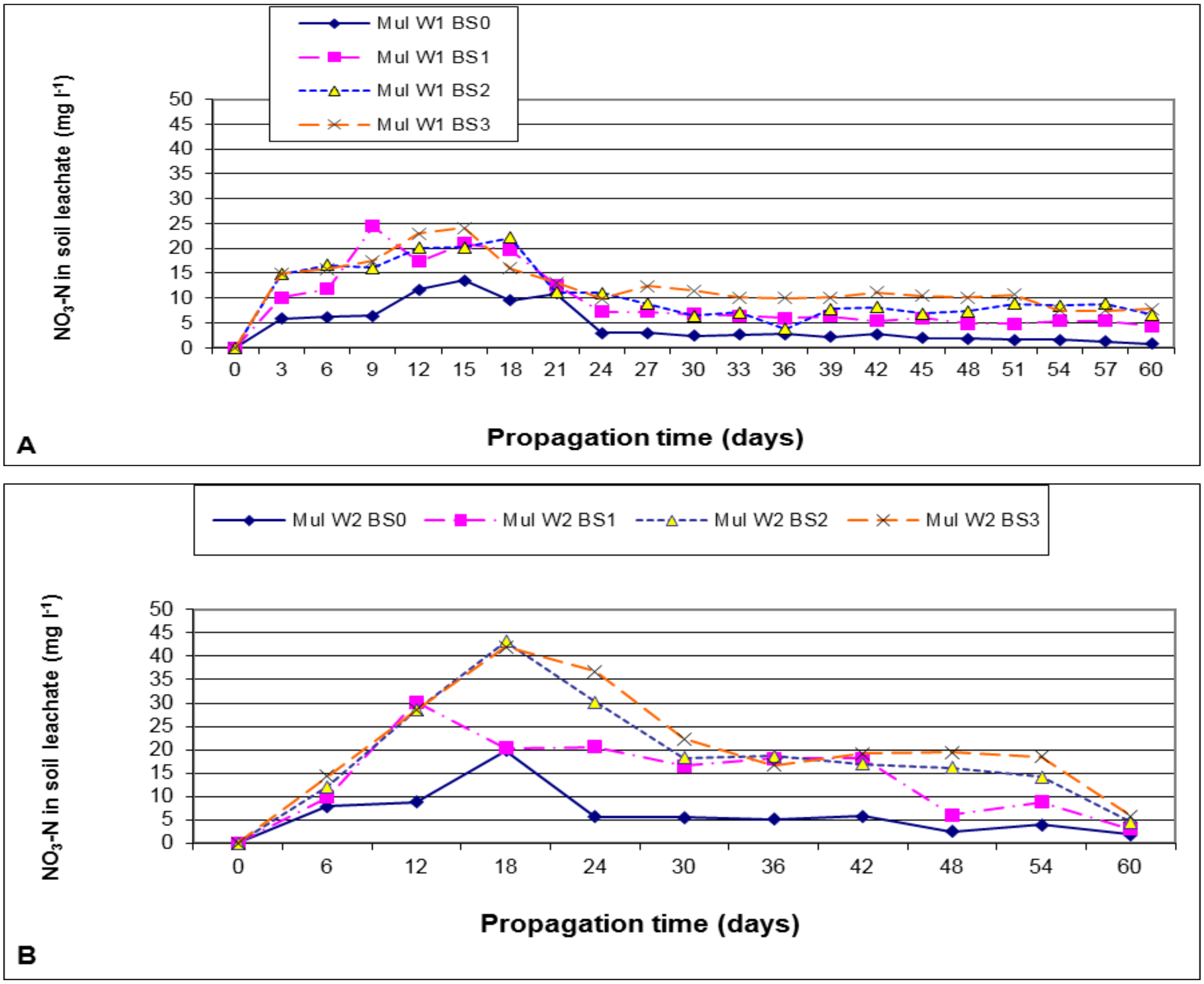


Fig (1). Elution curves of NO_3-N from sandy soil amended with biosolids compost as mulch.

A- 3 days intervals of watering time.

B- 6 days intervals of watering time.

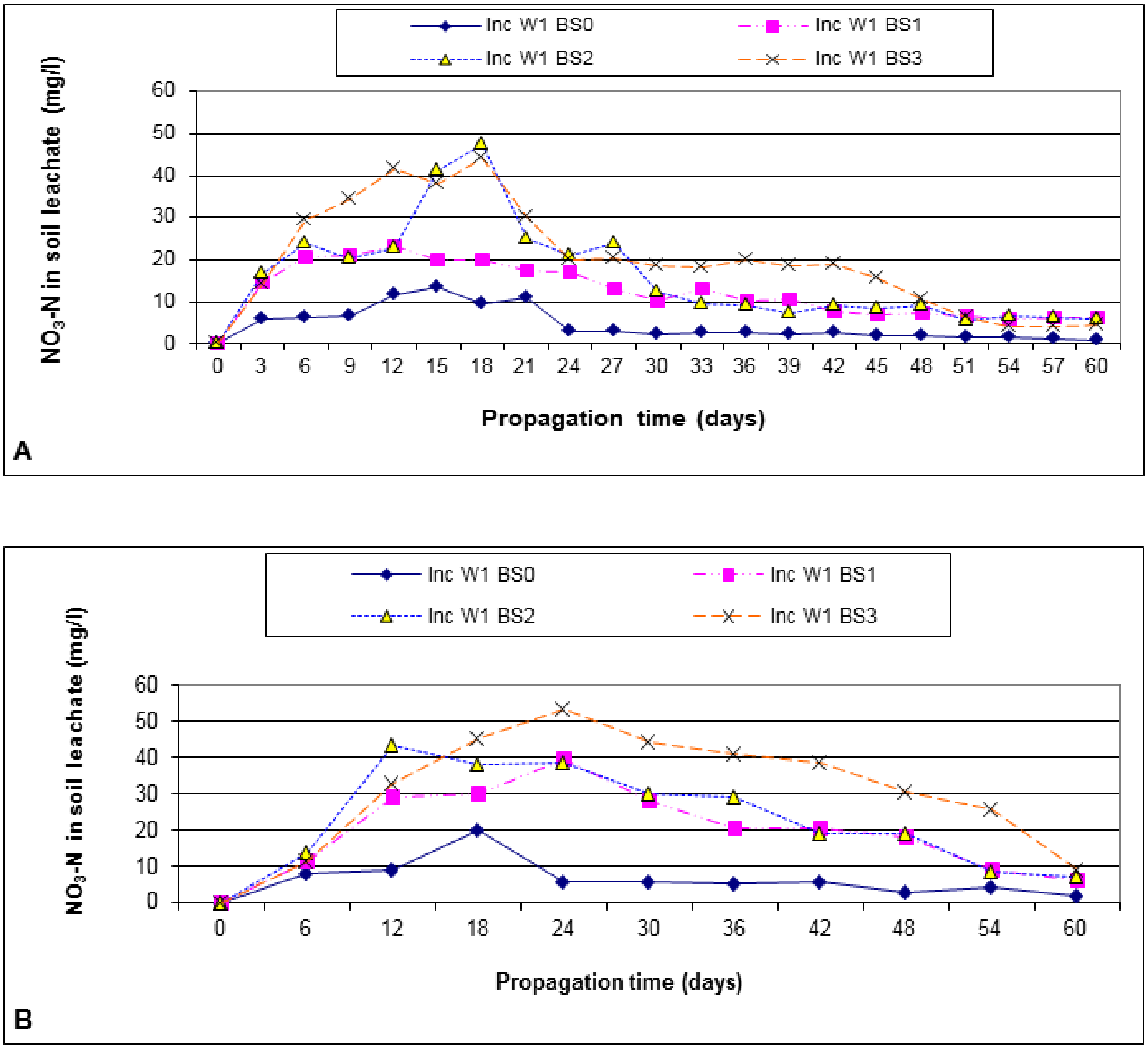


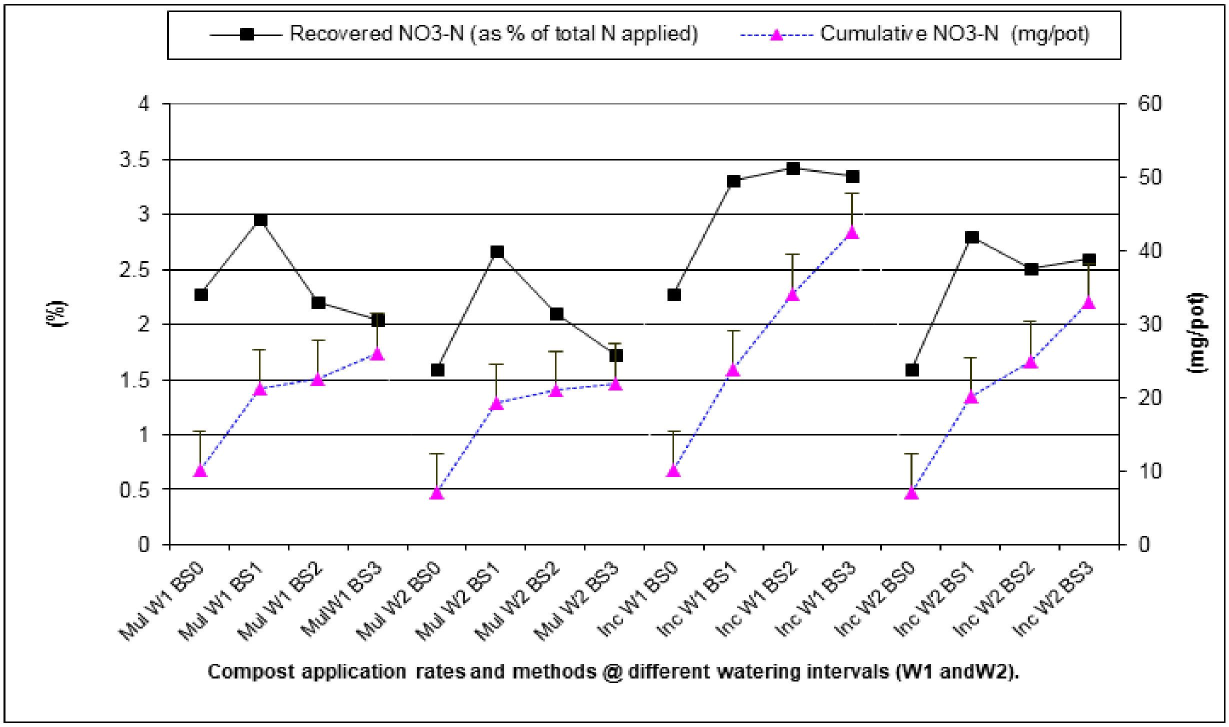
Fig (2). Elution curves of NO_3-N from sandy soil amended with biosolids compost as incorporation.

A- 3 days intervals of watering time.

B- 6 days intervals of watering time.

In the case of mulched-compost watered every three days at different application rates (0.0, 20, 40 and 60 t/ha), the total NO_3-N recovered in 20 leachate fractions were accounted for 2.28, 2.96, 2.21 and 2.05 % of the total N applied, respectively. Watered every six days, the total NO_3-N recovered in 20 leachate fractions accounted for 1.6, 2.67, 2.11, and 1.73% of the total N applied at the same application rates (Fig. 3). On the other hand, in the case of incorporated-compost watered every three days at the application rates of 0.0, 20, 40, and 60 t/ha, the total NO_3-N recovered in 20 leachate fractions accounted for 2.28, 3.31, 3.43, and 3.35% of the total N applied, respectively. But, watered every six days, the total NO_3-N recovered in 20 leachate fractions were accounted for 1.6, 2.8, 2.51, and 2.59% of the total N applied at the same application rates (Fig. 3).

The results revealed that the concentrations of NO_3 -N were highly significant at all application rates for incorporated-compost compared to mulched-compost. The cumulative recoveries of NO_3-N in 20 leachate fractions were 41.22 mg/total leachate (2000 ml), in the situation of the greatest incorporated-compost rate under high moisture condition (watering every 3 days). However, the cumulative recoveries of NO_3-N were 25.36 in the case of the same rate of mulched-compost under high moisture conditionThis nitrate has the potential for leaching into groundwater or be absorbed by plants. According to **Zhou et al. (2023),** the concentration of NO_3-N in soil solution from soil supplemented with MSW and sludge treatment surpassed 50 mg/l. According to **Algarahy et al. (2024)**, temperature influences the rate at which nutrients are released from sewage sludge, and it is also influenced by other elements including pH, soil moisture content, total soluble salts, and microbial activity.



(Fig. 3). Total recovered and cumulative leaching of NO_3-N from sandy soil amended with biosolids compost as mulch and incorporating under different moisture conditions. Vertical bars represent a fixed value (L.S.D value) for the application method of compost *($P < 0.05$).*

There are two main reasons to be concerned about soil NO_3-N. First, as noted by **Zhou et al. (2023)**, the amount of NO_3-N in the rooting zone serves as an indicator of N requirements. Secondly, high concentrations of NO_3-N in the soil profile are susceptible to leaching, which could lead to contamination of surface and groundwater and consequent effects on human and animal health. Moreover, denitrification of NO_3-N has the potential to produce N_2O and weaken the ozone layer **(Zhou et al., 2023; Algarahy et al., 2024).** Nitrate-N concentrations in leachate beneath incorporated-applied compost were generally higher than the mulched-applied compost, despite the fact that the application rates of compost were the same. The potential impact of incorporated-compost on leachate NO_3 -N concentration was higher in comparison to mulched-compost for two reasons. Incorporated compost immediately induced intimate contact with the sandy soil where its content of ammonia is readily hydrolysed to NH_3, nitrified rather than adsorbed, and then becomes more subjected to leaching than to volatilisation. In contrast, mulched compost remains on the surface and its content of ammonia and organically bound N is subject to volatilisation. Consequently, more NO_3-N was available for plant uptake or leaching from incorporated-applied compost than from the mulched-applied compost.

The other possibility is that the high rate of soluble organic nitrogen (SON) in the case of mulched-applied compost may explain the substantial difference in nitrate observed between mulched and incorporated compost. In the situation of mulched-applied compost, a significant fraction of nitrate may have been immobilized again into the soluble organic N fraction of compost or incorporated into the soil organic N during movement of leached mineralised N from the mulching layer of compost into the underlying sandy soil. This possibility of immobilization or incorporation of some mineral N in the soluble organic N or in the soil organic matter is supported by the high difference in the C/N ratio of the compost mulching layer and the sandy soil underneath. Another factor is the soil moisture content.

Following every watering event, the mulching layer of compost becomes saturated and, short bursts of intense denitrification occur. Denitrification rates generally increase with increasing soil moisture content **(Ryden, 1983; Goodroad and Keeney, 1984).** These results are in agreement with **Clay et al., 1993; Farrel, et al., 1996.** The results of this study indicated that increases in soil moisture content up to the saturation point may increase the rate of denitrification in the compost mulching layer. The observations that incorporated-compost have higher NO_3-N leaching losses than mulched-compost under these conditions; emphasize the importance of method of application, the application rate and the compost N content, soil moisture and temperature.

3.3 Ammonia accumulation rate and leaching.

The NH_4 -N and NO_3 -N values obtained from the time series samples were usually comparable to the values obtained from the bulked samples (Table 4). Table 4 indicates that the NO_3-N levels for both the time series and bulked samples were higher than the NH_4-N values. The research provides evidence of the occurrence of nitrification. The NH4-N concentrations in different leachate fractions were below 11mg/L for all treatments, except for the (Inc W2 BS_3) treatment. The NH_4-N concentration in the (Inc W2 BS_3) treatment reached its highest point at 23.98 mg NH_4-N per litter in the second fraction, and then declined to 0.0 mg/L in the remaining fifteen fractions for all treatments. The cumulative quantities of NH_4 -N recovered in 2000 ml of leachate were accounted for 0.003, 0.11, 0.13 and 0.25 % of total N applied of MulW1BS0, MulW1BS1, MulW1BS2 and MulW1BS3, respectively.

Among the different compost-moisture condition treatments, concentrations of NH_4 -N were greater for incorporating compost into the sandy soil than for mulching. The cumulative quantities of NH_4 -N recovered in 2000 ml of leachate were significantly different among the four application rates and different methods of application (Table 4). In all treatment, NH_4-N concentrations increased sharply in the second leachate, remained steady constant concentrations until the fourth leachate, and then declined to nil in the rest of twenty leachate fractions (Figures 4 and 5). In general, ammonia N concentrations in all leachate fractions from all treatments were below the detection limit (0.1 mg/L) after 15 days of propagation.

The reduction in leaching of NH_4 -N may be attributed to the loss of NH_3^+ via volatilization or the conversion of NH_4^+ into $NO3^-$ during the nitrification process. Concentrations of NH_4-N were much lower in the leachate fractions from mulched-compost at all application rates compared with incorporated-compost. This demonstrates that when compost is incorporated into sandy soil, its content of ammonium N is rapidly nitrified under these conditions of moisture content and high temperature (25°C).

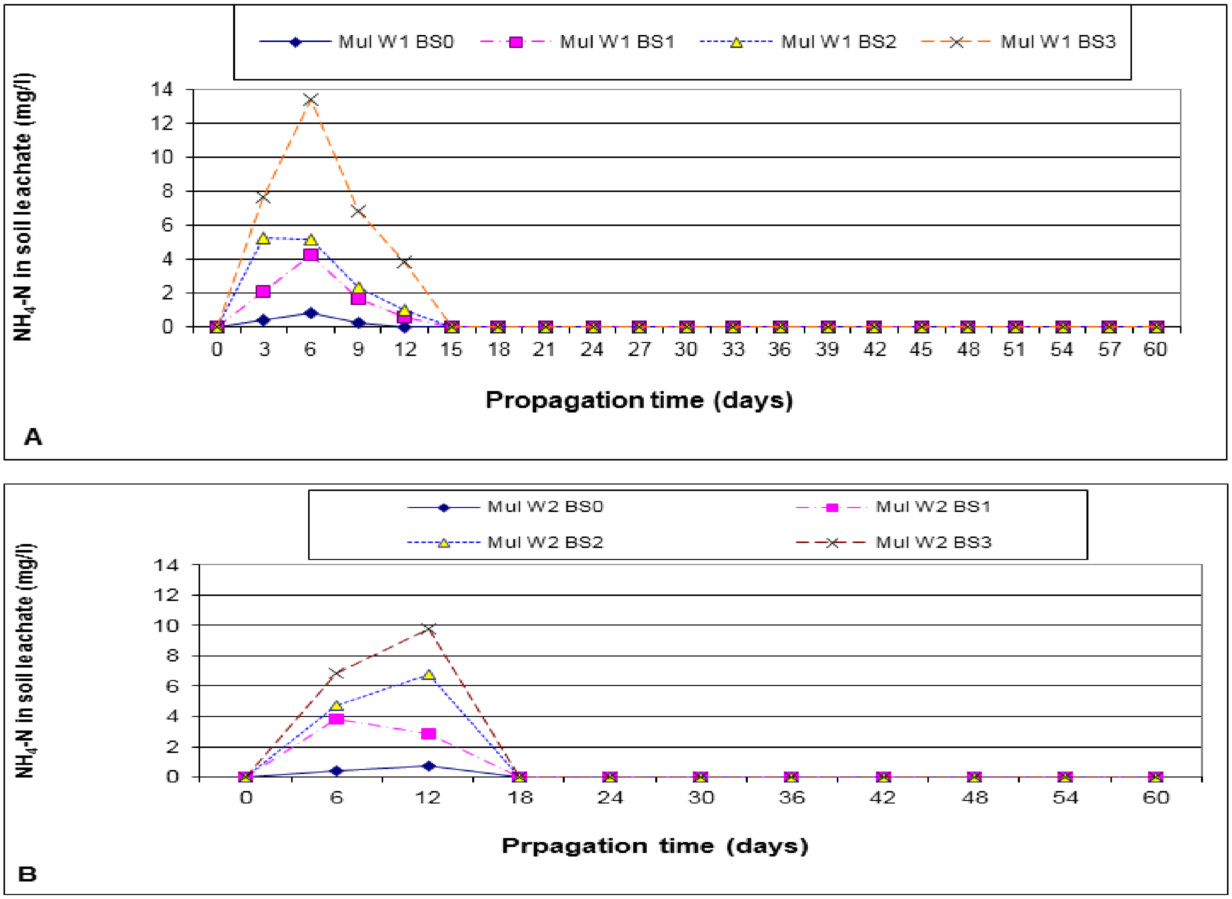


Fig (4). Elution curves of NH_4-N from sandy soil amended with biosolids compost as mulch.

A- 3 days intervals of watering time.

B- 6 days intervals of watering time.

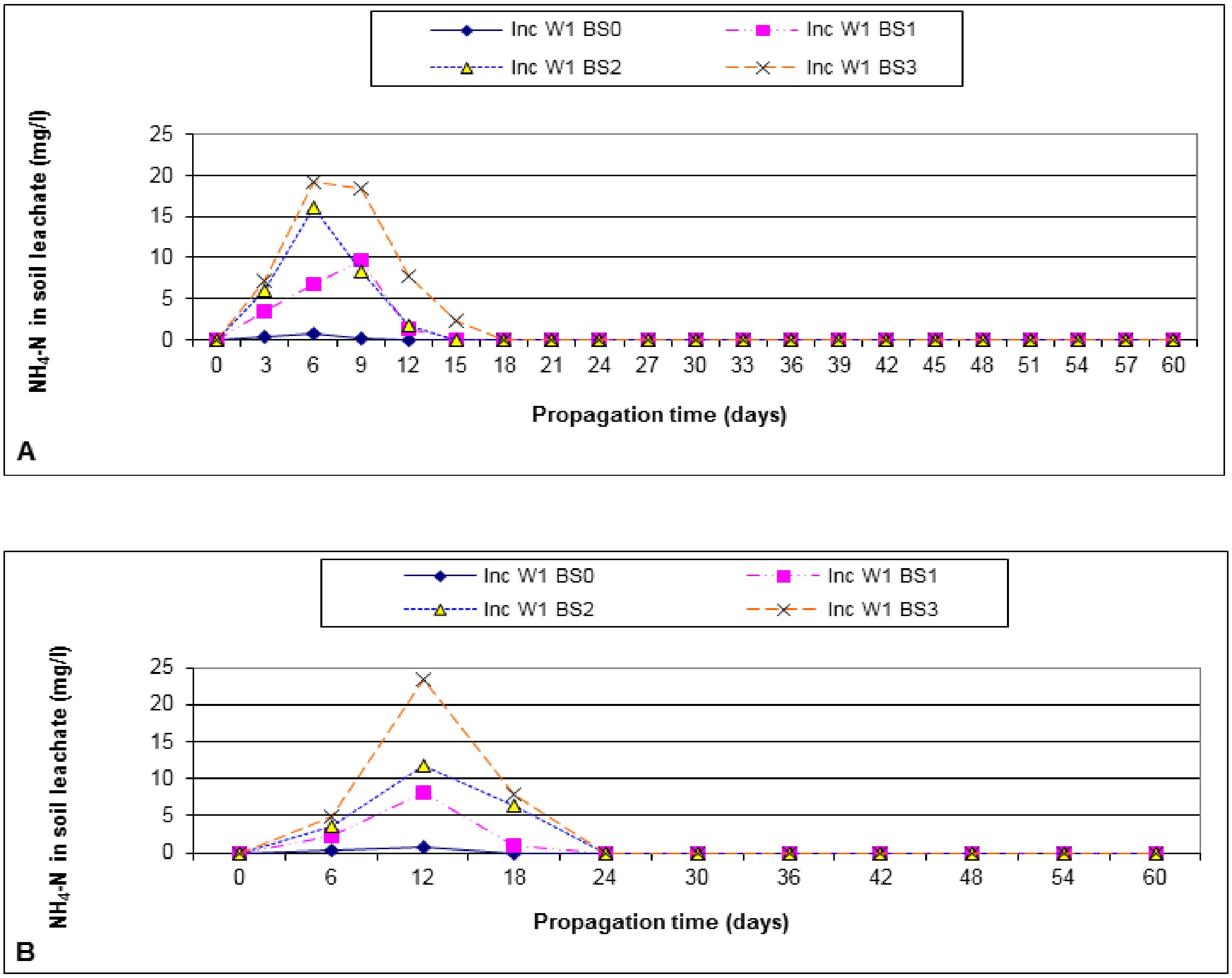
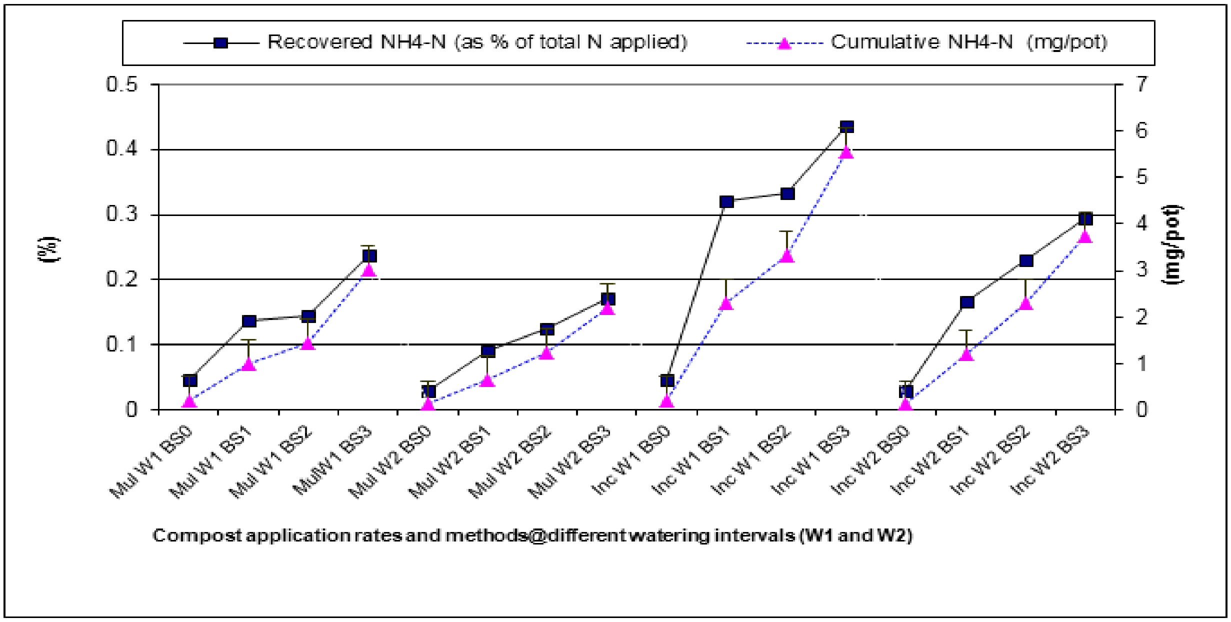


Fig (5). Elution curves of NH_4-N from sandy soil amended with biosolids compost as mulch.

A- 3 days intervals of watering time.
B- 6 days intervals of watering time.

At present, there is no critical limit concerning concentration of NH_4-N for the drinking water standard. According to **Stoffela et al. (1997)**, the maximum contamination limit (MCL) for groundwater is 1.5 mg NH_4-N L^{-1}. Although it may produce NH_3 at an alkaline pH, ammonia in water resources is not inherently hazardous. It is possible to create ammonia gas, which might harm a number of fish species **(Rostango and Sosebee, 2001)**. If converted to NH_3, concentrations as low as 0.02 mg NH_4 -N L^{-1} may raise the possibility of fish suffocation. Ammonia at concentrations of 0.1 mg/L may produce taste and smell issues, even though there are no standards for NH_4-N for cattle drinking water **(Rostango, and Sosebee, 2001).**



(Fig. 6). Total recovered and cumulative leaching of NH_4-N from sandy soil amended with biosolids compost as mulch and incorporating under different moisture conditions. Vertical bars represent a fixed value (L.S.D value) for the application method of compost *($P < 0.05$)*.

This figure illustrates that the total amounts of ammonia N accumulated in all soil leachate fractions from all the compost treatments never exceeded 7 mg/pot and the recovered amounts of ammonia is not considered a significant source of N in this study. Rather, ammonium fixation, nitrification, and volatilisation were the primary factors responsible for the low levels of ammonia determined in this study.

3.4 Total soluble N accumulation rate and leaching.

The accumulation rates of recovered total soluble N in the effluent and bulk samples collected from sandy soils treated with different compost application rates and methods after 3- or 6-days watering intervals are shown in table (4). The results revealed that no soluble N was existent in the first leachate fractions from all treatments and the peak concentrations were viewed in the fourth leachate, i.e., 12 days after compost application to the sandy soil. The total soluble N decreased drastically by the fifth leachate. Additional TSN released after 12 days diminished rather than augmented and reach a plateau for the rest of propagation time. Similar trends with no significant difference in TSN release were noted for both mulched and incorporated compost.

Among the different compost-moisture condition treatments, concentrations of total soluble N were nearly the same for incorporated or mulched compost in the sandy soil. The cumulative quantities of total soluble N recovered in 2000 ml of leachate were significantly different among the four application rates and different moisture conditions. Total soluble N elution reached a peak in the fourth or fifth leachate and continued at a fairly steady concentration after the sixth through to the twentieth leachate (Figures 7 and 8) for all treatments.

The concentrations of TSN (organic N + inorganic N) reached a maximum after 12 days of propagation in the case of watering every 3 days and after 18 days of propagation in the case of watering every 6 days and then declined gradually (Figures, 7 and 8). The exact reason for this decline is not clear, but some loss of mineral N (NO_3 -N + NH_4 -N) whether by volatilisation or denitrification is probable.

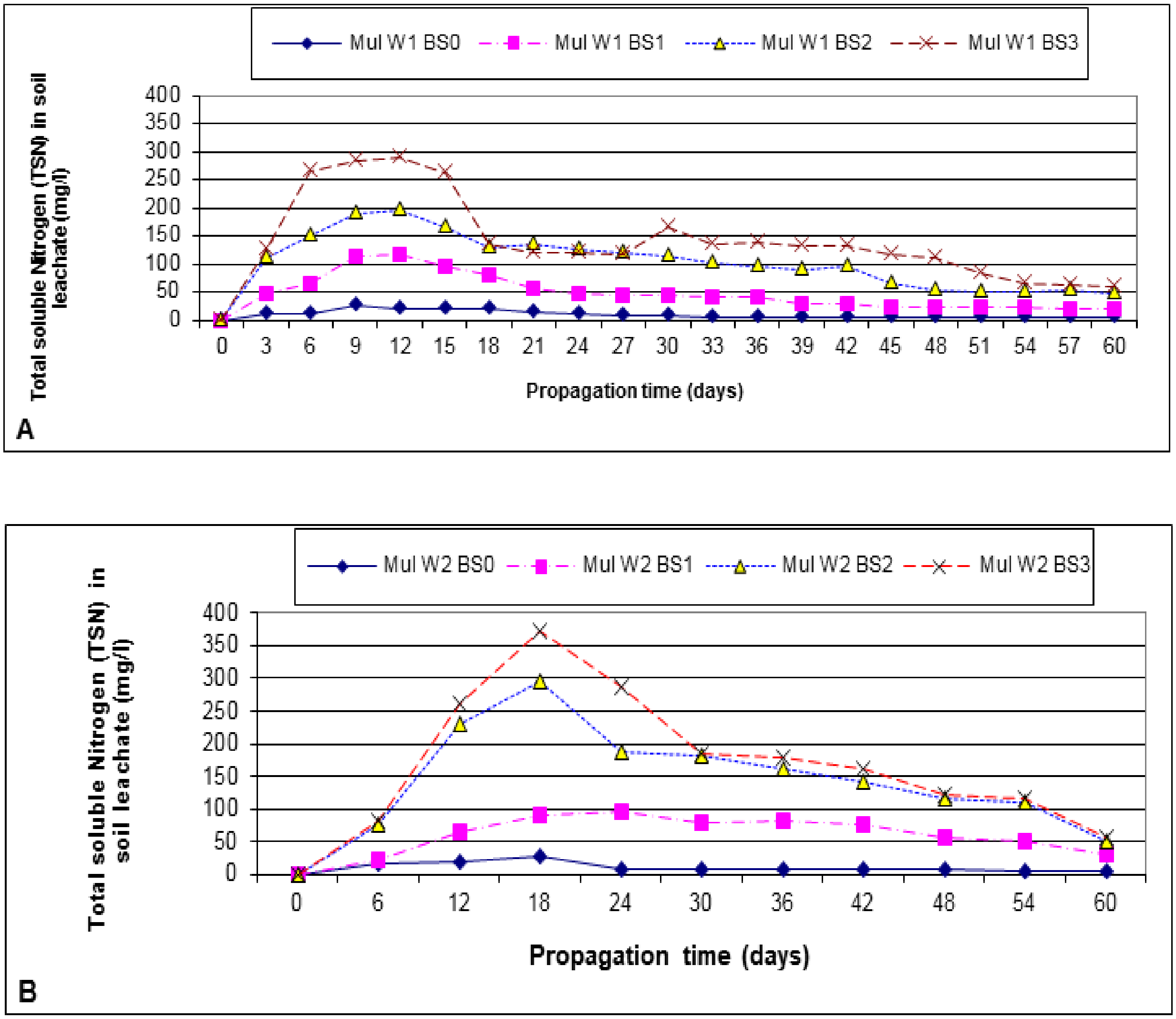


Fig (7). Elution curves of TSN from sandy soil amended with biosolids compost as mulch.

A- 3 days intervals of watering time.

B- 6 days intervals of watering time.

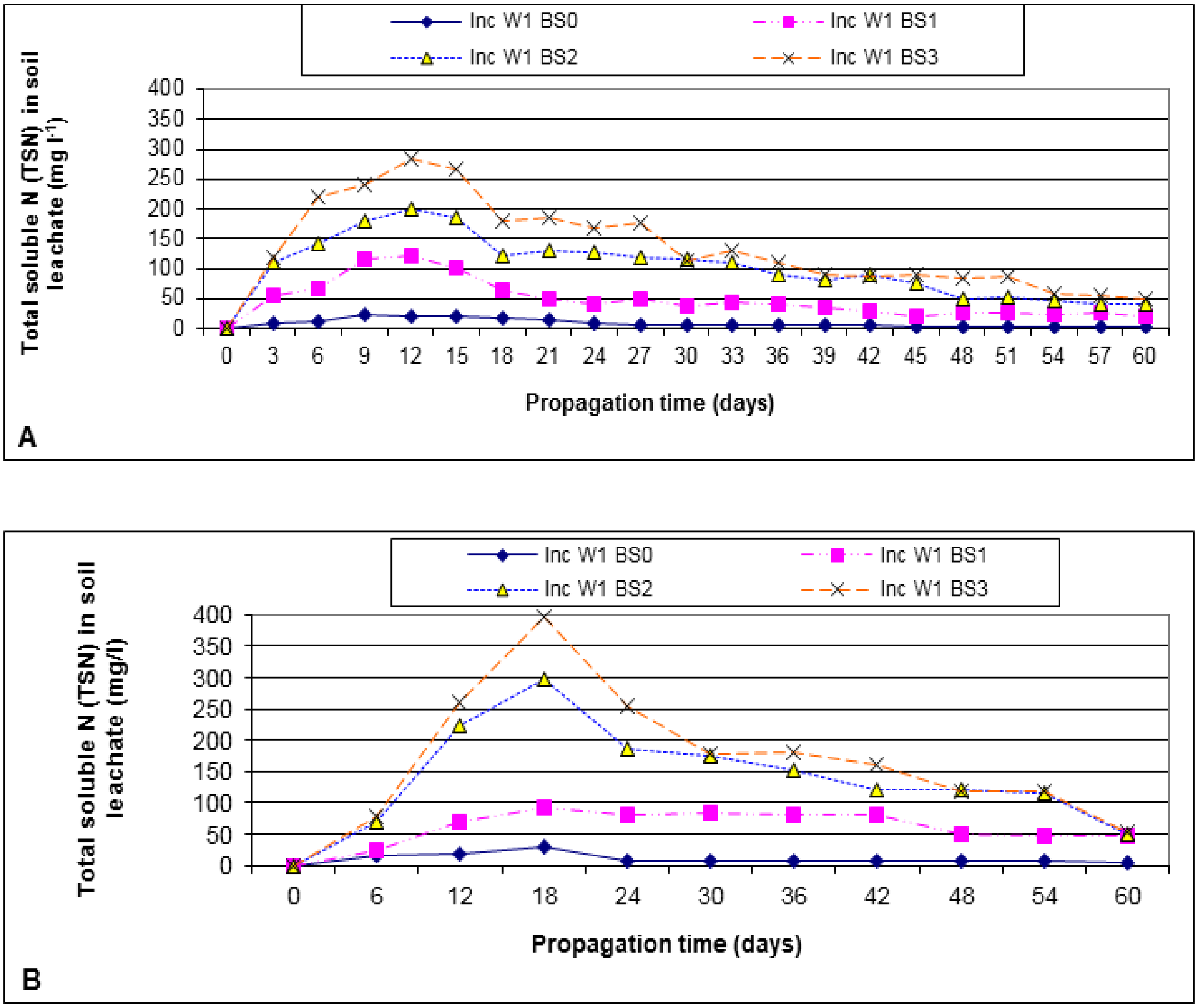


Fig (8). Elution curves of TSN from sandy soil amended with biosolids compost as incorporating.

A- 3 days intervals of watering time.

B- 6 days intervals of watering time.

These figures illustrate that total soluble N release (organic + inorganic) from biosolids compost in compost-mulched pots at all treatments was similar to the compost-incorporated pots. For example, the cumulative rate of TSN for compost-mulched pots ranged from 11.52 to 282 mg/pot compared with 21.52 to 282.1 mg/pot for compost-incorporated pots.

Although, total soluble N release from incorporated and mulched-compost was similar regardless of application rates and moisture conditions, inorganic N release was significantly greater in pots with incorporated-compost than those with mulched. It is interesting that unlike inorganic N, soluble organic N (SON) tended to be significantly ($P \leq 0.05$) greater in pots with mulched-applied compost than with incorporated. Results showed that soluble organic N (SON) was significantly affected by compost application method and moisture conditions. This soluble organic N is not readily available, but it can be a significant source of plant available N over post-application time **(Algarahy et al., 2024).** There is a distinct possibility that some ammonia might have been lost through NH_3 volatilisation from the compost-mulching layer under high temperature and pH conditions.

3.5 Net N mineralization and N budget.

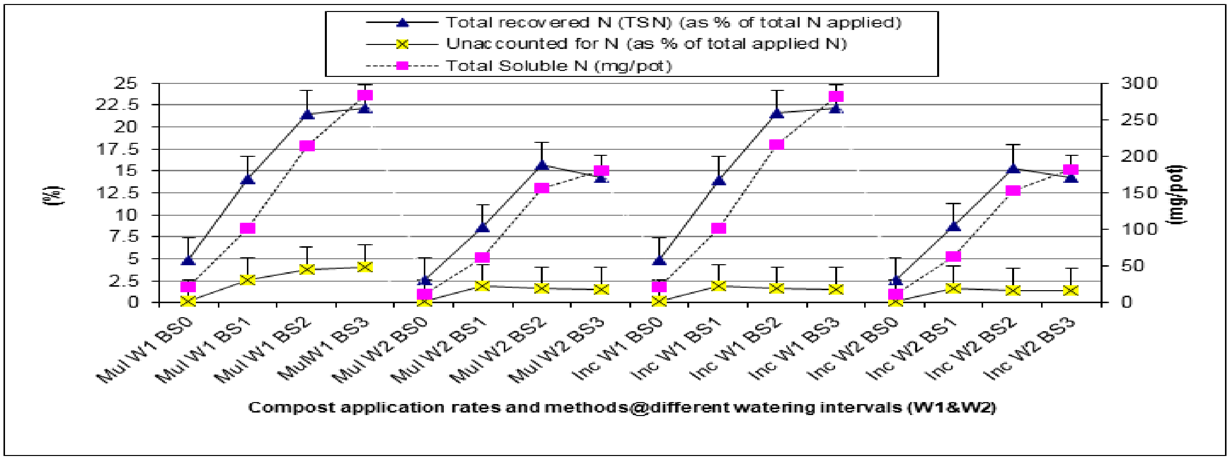
Table 5, shows the N-budgets for the submitted biosolids compost under various moisture conditions. Table 5 includes the values of TN applied from the start, TN retained at the end, N recovered in effluent (TSN in bulked samples), and variances between them representing the unaccounted-for N, which was assumed to be lost in the form of gaseous N compounds. The TSN is composed of all the N forms soluble in water including for instance NH_4^+-N, NO_3^--N, NO_2-N, amino acids, amides, nitrides, di-poly-amino compounds, and amino alcohols **(Brady, 1990).** Therefore, the TSN values are the suitable values for calculating N budget.

Table 5. Nitrogen budget for different combinations of compost application rates and methods under different moisture conditions.

Treatments			TN (mg/pot)		N recovered		Unaccounted-for N	
App. Method	Watering Time	App. Rate	At the start	At the end	(mg/pot)	(%)	(mg/pot)	(%)
Mulching	W1	BS0	445	422.91	21.52 a	4.83	0.57	0.13
		BS1	721.06	601.28	101.2 b	14.03	18.58	2.57
		BS2	997.12	745.15	214.3 c	21.49	37.67	3.77
		BS3	1273.18	939.19	282.5 c	22.18	51.49	4.04
	W2	BS0	445	432.91	11.52 a	2.58	0.57	0.13
		BS1	721.06	641.51	62.15 b	8.61	17.4	1.88
		BS2	997.12	809.95	156.6 c	15.7	30.57	1.61
		BS3	1273.18	1061.15	180.9 c	14.21	31.13	1.57
Incorporating	W1	BS0	445	422.91	21.52 a	4.83	0.57	0.13
		BS1	721.06	606.61	100.9 b	13.99	13.55	1.88
		BS2	997.12	766.05	215.0 c	21.56	16.07	1.61
		BS3	1273.18	971.02	282.1 c	22.15	20.06	1.57
	W2	BS0	445	432.91	11.52 a	2.58	0.57	0.13
		BS1	721.06	646.15	62.81 b	8.71	12.1	1.67
		BS2	997.12	828.28	153.1 c	15.35	13.72	1.37
		BS3	1273.18	1074.66	181.2 c	14.23	17.32	1.36

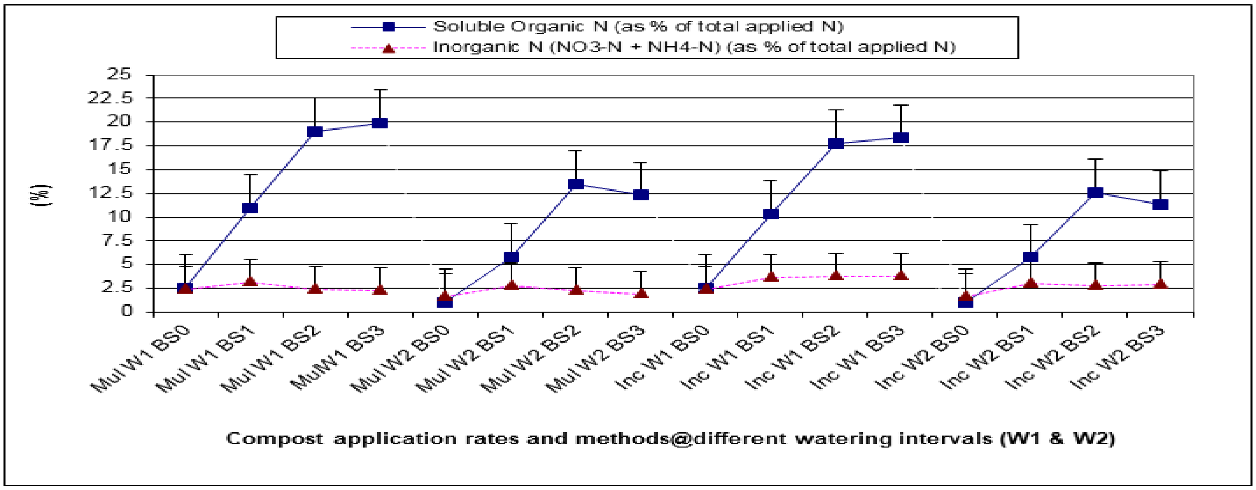
*Means of three samples of N recovered (mg/pot) within a column followed by the same letter are not significantly different ($P \leq 0.05$) as measured by the LSD method.

Table 5 and figure 9 show that the total N recovered (organic + inorganic) of biosolids compost in compost-mulched pots at all treatments were similar to the compost-incorporated pots. For example, the total recovered N for compost-mulched pots watered every three days ranged from 4.83% to 22.18% compared with 4.83 to 22.15% for compost-incorporated pots. However, the total recovered N for compost-mulched pots watered every six days ranged from 2.58% to 14.21% compared with 2.58 to 14.23% for compost-incorporated pots.



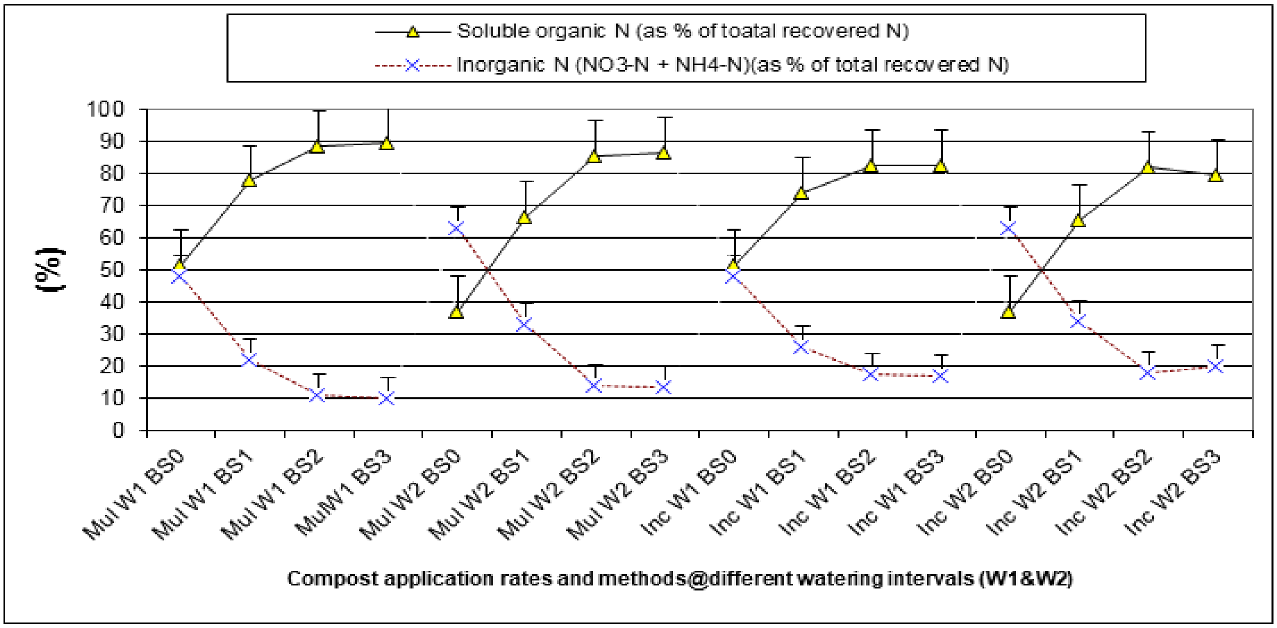
(Fig. 9). Total recovered and unaccounted-for N from sandy soil amended with biosolids compost as mulch and incorporating under different moisture conditions. Vertical bars represent a fixed value (L.S.D value) for the application method of compost *($P < 0.05$)*.

Although, total recovered N from incorporated and mulched-compost was similar, inorganic N recovered was significantly greater in pots with incorporated-compost than those with mulched. Most of the total recovered N in the soil leachate was found as soluble organic N (SON) (Fig. 10). Mulched compost resulted in significantly greater soluble organic N fractions in soil leachate compared with incorporated compost. **Algarahy et al. (2024)** state that the soluble organic N pool is the primary source of N supplies to the mineral N pool and a representation of the N reserves in the soil.



(Fig. 10). Total soluble organic and inorganic N as a percentage of total applied N from sandy soil amended with biosolids compost as mulch and incorporating under different moisture conditions. Vertical bars represent a fixed value (L.S.D value) for the application method of compost *($P < 0.05$)*.

The lower inorganic N recoveries from mulched-compost in the soil leachate suggest that the mulched-compost underwent higher volatilisation and/or denitrification than incorporated. This was further supported by high amount of unaccounted-for N in the case of mulched compost, where it was in the range of 0.13 to 4.04% of the total N applied. The unaccounted-for N expressed, as a percent of the total applied N was significantly larger from the mulched-compost pots than from incorporated. The results revealed that 0.13 to 4.04% of the total applied N to this sandy soil as mulch under these conditions is unaccounted-for and presumably lost via volatilisation and/or denitrification. The unaccounted-for N was in the range of 0.13 to 1.57% of the total applied N to this sandy soil as incorporating. The inorganic N recovered in soil leachate followed different trend from the soluble organic N recovered, where the inorganic N decreased as the application rate of compost increased (Fig. 11). The reverse was true for the soluble N recovered, where it increased as the compost application rate increased. This figure also illustrates that 70 to 90% of the total recovered N was found in the form of soluble organic N.



(Fig. 11). Total soluble organic and inorganic N as a percentage of total recovered N from sandy soil amended with biosolids compost as mulch and incorporating under different moisture conditions. Vertical bars represent a fixed value (L.S.D value) for the application method of compost *($P < 0.05$).*

This investigation indicated that the rapid N release from biosolids compost used during the initial leaching events. The total N recovery from compost as mulch after completion of 20 leaching and dry cycles accounted for 22.18 % of the total N applied. There was a lag phase for the release of N forms during the successive leaching events. At high application rates, the NO_3-N concentrations enhanced above 10 mg/L in soil leachate. Thus, this study indicates that leaching of NO_3^- should be looked when compost application rates and frequencies are determined, particularly on sandy soil with coarse structure and low water holding capacity. Under the circumstances of this investigation, the hypothesis that nitrate and ammonia are not to leach through such soil profile must be rejected.

3.6 Available heavy metals content of the soil and leachate.

After 12 days propagation time, a very small portion of heavy metals were readily water soluble and would be removed only in early leachates when biosolids compost is applied to land (Table 6), except for Cd. In all soil leachate fractions, the amounts of Cd were below the detection limits of the technique. Following a 12-day propagation period, the leachate fractions from all the compost-modified pots exhibited heavy metal concentrations that were below the detection limits of the technique. These findings concur with those of **Silviera and Sommers (1977)** as well as **Dowdy et al. (1991)**. Certain metal fractions, such as those that are water-soluble and exchangeable, are often thought to be immediately accessible to plants **(Brady, 1990; Liu et al., 2020; Algarahy et al., 2024)**, while other fractions could be unavailable or only slowly available. According to the findings, the water-soluble form of heavy metals is present in very tiny and negligible amounts and is likely more plant accessible and leaching-prone than the other soil fractions **(Alloway, 2013; Liu et al., 2020; Algarahy et al., 2024)**.

Table (6). Heavy metals content (mg/L) of leachate after 12 days incubation of compost-treated and untreated sandy soil.

Treatments			**Zn2+**	Cu $^{2+}$	Ni $^{2+}$	Pb $^{2+}$	Cr $^{2+}$
Application Methods	Watering Time	Application Rate					
Mulching	W1	BS0	0.04 *a*	0.009 *a*	0.11 *a*	0.01 *a*	0.006 *a*
		BS1	0.24 *b*	0.025 *a*	0.37 *c*	0.05 *b*	0.04 *b*
		BS2	0.19 *b*	0.022 *a*	0.30 *bc*	0.05 *b*	0.04 *b*
		BS3	0.11 *a*	0.020 *a*	0.21 *ab*	0.03 *ab*	0.03 *b*
	W2	BS0	0.09 *a*	0.011 *a*	0.10 *a*	0.01 *a*	0.007 *a*
		BS1	0.25 *c*	0.028 *a*	0.31 *b*	0.04 *b*	0.05 *b*
		BS2	0.20 *bc*	0.023 *a*	0.27 *b*	0.04 *b*	0.04 *b*
		BS3	0.14 *ab*	0.023 *a*	0.16 *ab*	0.02 *ab*	0.03 *b*
Incorporating	W1	BS0	0.04 *a*	0.009 *a*	0.11 *a*	0.01 *a*	0.006 *a*
		BS1	0.23 *b*	0.023 *a*	0.30 *b*	0.04 *b*	0.03 *b*
		BS2	0.15 a*b*	0.020 *a*	0.26 *b*	0.04 *b*	0.01 *a*
		BS3	0.11 *ab*	0.017 *a*	0.16 *ab*	0.02 *ab*	0.01 *a*
	W2	BS0	0.09 *a*	0.011 *a*	0.10 *a*	0.01 *a*	0.007 *a*
		BS1	0.25 *b*	0.028 *a*	0.27 *b*	0.04 *b*	0.03 *b*
		BS2	0.19 a*b*	0.022 *a*	0.25 *b*	0.05 *b*	0.02 *b*
		BS3	0.13 *ab*	0.016 *a*	0.18 *ab*	0.03 *ab*	0.01 *ab*

**Means of three samples within a column followed by the same letter are not significantly different (*P≤0.05*) as measured by the LSD method.*

Concentrations of heavy metals in soil leachate fractions were significantly affected by compost rate and method, but not by different watering intervals (3 or 6 days). The results from the pots watered every 3 days were nearly the same as those for the pots watered every 6 days. These results suggest that it was not neither the volume of water applied nor the moisture content that existed in the compost-amended pots that controlled the movement of compost-borne heavy metals, but rather the compost application rate and method influence upon the soil characteristics such as pH, soluble salts, and organic matter. For the highest rate of compost application (60 t/ha), concentrations of heavy metals in soil leachate fractions were insignificantly ($P \leq 0.05$) higher from compost-amended pots than from the control. For the lowest rate of compost application (20 t/ha) concentrations of heavy metals in soil leachate fractions were significantly ($P \leq 0.05$) higher from compost-amended pots than from the control. There was no significant difference between compost application rates at different moisture conditions.

High concentration of heavy metals in the soil leachate fractions leached from the pots amended with the lowest compost application rate probably resulted from unstable organic complexes they form with soluble organic matter present in compost. Also, concentrations of heavy metals in soil leachate fractions were insignificantly higher in mulched-compost pots than in incorporated-compost. The higher concentrations of SON in soil leachate fractions leached from mulched-applied compost than from incorporated-compost, may explain the difference between the two methods of application. In general, increases in dissolved heavy metals followed the trend MulBS1, IncBS1, MulBS2, IncBS2, MulBS3 and IncBS3 with no significant difference for all the compost treatments. In addition, the results revealed that there are consistent and significant increases in DTPA-extractable heavy metals in compost treated pots compared to control (Table 7). The extractable concentrations of heavy metal were unproportionally affected as the compost application rate increased, since no significant differences were found in the extractable metals between different compost application rates.

Table (7). Available heavy metals content (mg kg^{-1}) in sandy soil conditioned with biosolids compost after 60 days incubation under controlled conditions.

Treatments	Zn^{2+}	Cu^{2+}	Ni^{2+}	Pb^{2+}	Cd^{2+}	Cr^{2+}
	DTPA	**DTPA**	**DTPA**	**DTPA**	**DTPA**	**DTPA**
W1 BS_0	13.6 *a*	11.9 *a*	15.2 *a*	0.3 *a*	0.23 *a*	0.11 *a*
Mul. W1 BS_1	23.6 *b*	22.6 *b*	19.9 *b*	1.5 *b*	0.9 *b*	0.43 *b*
Mul. W1 BS_2	26.3 *b*	26.8 *b*	21.2 *b*	1.8 *b*	0.9 *b*	0.53 *b*
Mul. W1 BS_3	29.9 *b*	28.6 *b*	22.4 *b*	1.8 *b*	1.1 *b*	0.58 *b*
Inc. W1 BS_1	26.6 *b*	25.9 *b*	18.1 *ab*	1.3 *b*	0.8 *b*	0.42 *b*
Inc. W1 BS_2	31.1 *b*	31.9 *b*	21.3 *b*	2.2 *b*	1.2 *b*	0.60 *b*
Inc. W1 BS_3	29.8 *b*	30.2 *b*	20.9 *b*	2.2 *b*	1.1 *b*	0.59 *b*

**Means of three samples within a column followed by the same letter are not significantly different (P≤0.05) as measured by the LSD method.*

Because most trace elements in biosolids are strongly associated with mineral phases **(Algarahy et al., 2024)** the hypothesis is that most trace elements are expected not to leach easily through a coarse-textured sandy soil. Under the conditions of this study, the hypothesis that most trace elements are not leached readily through such soil profile must not be rejected. Results of this experiment revealed that soluble organic shapes of the trace elements could move from the zone of incorporation or from the mulching layer of compost, especially in the case of continued compost application at high application rates. In Egypt, because of the alkalinity and the calcareous nature of sandy soils and the very low precipitations, increases of heavy metals in subsoil or in the groundwater are not presumed as compost applied **(Abd El-Azeim et al., 2021).** It is evident that the primary characteristics of soil impacting soil-metal interactions are pH, the amount and quality of organic matter, Fe and Mn oxides, and the percentage of clay content **(Ross, 1994).** The pH does affect the availability of heavy metals to the ground water and the topsoil. The addition of biosolids compost had a liming effect and raised the pH into the range, which affected the availability of heavy metals.

Dowdy et al. (1991) argued that metal mobility might be enhanced if biosolids add soluble organic matter or reduce the soil pH. The results of many studies have indicated that metals in biosolids tend to accumulate in topsoil **(Schirado et al 1986; Dowdy et al., 1991)**. The law limits of metals under investigation in groundwater are 0.50, 0.10, 2.00, 0.20, 0.02 and 2.00 for Zn, Cu, Ni, Pb, Cd and Cr, respectively **(Pinamonti et al., 1996).** According to **Sawyer et al. (1994),** heavy metals in public water sources are often defined arbitrarily as those for which drinking water standards are typically in the range of 1 mg/L or less. While several heavy metals were found in extremely low concentrations, all of the heavy metals in the leachate fractions from compost-amended pots were well below this value, and Cd was below the technique detection limits.

The amount of heavy metals in the biosolids, their adsorptive qualities, the production of insoluble precipitates, and the biosolids themselves all affect the solubility and mobility of heavy metals in soil treated with biosolids **(Corey et al., 1987; Sommers et al., 1987)**. It is anticipated that adding composted biosolids to soil would change its SOC concentration and composition. This might have an impact on the mobility, speciation, and ultimate destiny of heavy metals in the supplemented soil **(Barbarick et al., 1998).** The experiment's findings showed that, in sandy soil, low biosolids application rates raised the DTPA-extractable levels of Zn, Cu, Ni, Pb, Cd, and Cr. But when the pH rose, the high application rates produced identical outcomes for these metals (not much of a difference). In fact, in sandy soil treated with compost, rises in pH neutralize the impact of compost additions on soluble heavy metals. These findings concur with those of **(Barbarick, et al., 1998).**

There is broad confidence on the heavy metal concentrations in leaching water in terms of environmental protection, according to data from leachate studies (Table 6). This demonstrates the favourable effect of biosolids with increasing pH of the sandy soil. However, the solubility of heavy metal increased by the increases in soluble organic N. This appeared in the case of mulching where the amount of SON increased. In general, according to this research, relatively few metals deposited in biosolids compost leak into the groundwater and very few move to any depth in the soil. The levels of heavy metals in the leachate and soil were within allowable limits. However, it should be monitored regularly in case of repeated applications.

4. CONCLUSION

Major concerns of applying biosolids compost to recently recovered sandy soils include the groundwater pollution by nitrate and the concern of heavy metals build-up. Application of high rates of biosolids compost with high N and heavy metals content may result in excessive leaching of nitrate, ammonia and heavy metals into groundwater. The efficiency of nitrogen use by crop plants depends, in part, on the leaching losses below the rooting depth in soils. On the other hand, in Egypt sandy soils have high pH and are generally calcareous favouring the adsorption and precipitation of most nutrients and heavy metals. In addition, the water table is generally deep, and the possibilities of leached nutrients or heavy metals are low. Therefore, the hypothesis inferred is that the effect of high rates and different methods of biosolids compost application would not increase the concentrations of nitrate, ammonia and some selected heavy metals in groundwater as the soil moisture increased above saturation. Generally, results of this study indicated the feasibility of using biosolids compost at high rates with low heavy metal contents to ameliorate sandy soil without environmental consequences.

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الملخص العربي

قابلية ترشيح صور النيتروجين والعناصر الثقيلة في الأراضي الرملية بعد التسميد بكمبوست مخلفات المجاري الصلبة.

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يمثل الغسيل مشكلة خطيرة في التربة الرملية في المناطق القاحلة نظرا لخصوبتها المنخفضة، وقوامها الخشن، ومحتواها الضعيف من المادة العضوية وعدم القدرة على الاحتفاظ بالمياه. الهدف من هذا البحث هو تقليل الأضرار البيئية لاستخدام كمبوست مخلفات المجاري الصلبة كسماد عضوي بمعدلات عالية في الأراضي الرملية في ظل الظروف القاحلة من حيث تلوث التربة بالنيتروجين المعدني والعناصر الثقيلة. أجريت تجربة أصص تم تحضينها عند درجة حرارة ثابتة (٢٥ درجة مئوية) واشتملت على أربع معدلات اضافة (٠.٠ و ٢٠ و ٤٠ و ٦٠ طن / هكتار) من الكمبوست، وطريقتين للتطبيق (علي سطح التربة والخلط مع التربة) وفترتين للري (٣ و ٦ أيام). دلت نتائج هذه التجربة أن تركيز النترات في الراشح من التربة تجاوز ٥٠ ملغم / لتر، وهي قيمة تعتبر شديدة السمية إذا كانت موجودة في مياه الشرب. وتجاوزت تركيزات الأمونيا ٢٠ ملغم / لتر في الراشح بعد الرية الثانية ولكنها انخفضت إلى أقل من حدود الكشف في الراشح لجميع المعاملات السمادية بعد الريات المتتالية مع العلم أن الحد الأقصى المقترح لمستوى تلوث المياه الجوفية هو ١.٥ ملغ / لتر من NH_4-N الأمونيا. وكانت تركيزات NO_3-N في جميع أجزاء الراشح من التربة بعد كل رية أعلى بكثير من المستوى الموصي به في مياه الشرب للبشر (١٠ ملغم / لتر) ولكن أقل بكثير من المستوى الموصي به في مياه الشرب للماشية (١٠٠ ملغم / لتر). وفيما يتعلق بتركيزات المعادن الثقيلة في الراشح من التربة، أعطت النتائج تأكيدا واسعا بأن البيئة محمية بنجاح من التلوث بالعناصر الثقيلة تحت ظروف التجربة. من خلال هذه الدراسة، يمكن الاستنتاج أن معدلات الاستخدام العالية من كمبوست مخلفات المجاري الصلبة العالي الجودة في التربة الرملية يؤدي الي فوائد محصولية عالية مع مخاطر بيئية محدودة إذا تمت إدارة التسميد والري بشكل صحيح.

الكلمات المفتاحية: كمبوست مخلفات المجاري الصلبة، النترات، الأمونيا، العناصر الثقيلة.