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Fate of Composted and Non-composted Sewage Sludge in Sandy Soil in terms of Nitrogen Mineralization and Recovery of Organic Matter

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***Abstract* - An incubation study was conducted over a period of eight weeks under controlled conditions (30^{o}C). The study was conducted to assess the dynamics of N mineralization, organic matter decomposition, and pH change in a sandy soil amended with sewage sludge (SS), and co-composted sewage sludge-CSS (SS + green waste-GW). The CSS and SS were obtained from Sharjah municipality and Dubai municipality respectively. Sandy soil was amended with different quantities of CSS and SS (0, 5, 10, and 20 tons/ha). Over the incubation period various observations were recorded to assess the accumulation of mineral N, change in soil organic matter content and pH. At the completion of the study the recovery of organic matter was 56-74% in CSS and 64-72% in SS. Gross nitrogen mineralization rate (N mass released expressed as a percentage of initially added N) ranges between 20-36% and 3-10% from SS and CSS respectively. However, the change in the pH of CSS and SS amended soil as compared to control during incubation period was in significant.**

***Key words* - Incubation period, Organic matter, N mineralization, pH, Co-composted Sludge, Sewage Sludge**

I. INTRODUCTION

Sandy soils in arid and semi-arid regions are infertile due mainly to lack of organic matter and clay content. Under such conditions, the high temperature in general, scanty and infrequent rainfall makes agriculture a difficult task. The sandy soils are highly porous and structureless resulting in the loss of nutrients and water through leaching to soil layers inaccessible to plant roots. In order to improve such soils in terms of structure development and functions as a plant-supporting medium, addition of organic matter would appear essential. Organic matter can be obtained either by growing plants in-situ or bringing in organic matter from external sources. In-situ generation of biomass to serve as a source of organic matter is hardly possible as the soils do not support plant growth and biomass generation effectively.

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An alternate source of organic matter could be city waste including sewage sludge and biomass resulting from green landscapes and other sources.

Sewage sludge (SS) could indeed be a useful soil conditioner and soil health enhancer as it is readily available in sufficient quantities in all municipalities in the United Arab Emirates, in case if these wastes are not used sustainably, this ends up in landfills that may cause environmental issues as well as occupying prime lands for agriculture. This is particularly true for countries that have reasonable standards of producing and handling of SS with particular reference to the quantities of contaminants and pathogens. Composting of SS is generally used as a means to avoid excessive numbers of pathogenic organisms while other contaminants are controlled through regulations and legislation.

In many countries a greater proportion of SS ends up in landfills. However, being rich in organic matter and nutrients, composting of SS and its use in urban landscaping and agriculture (crops included) production is becoming increasingly popular not only as a means of environment friendly disposal but also to intensify agriculture through improving soil health. Such a friendly disposal is important because of the envisage increase in production of SS as the population increases [1].

The SS is valuable due to high organic matter and nutrients and can be used as soil conditioner to improve physical, chemical, and biological properties of soil [2,3,4,5,6,7]. In addition, nutrient availability in highly alkaline soils (high pH) is a major constraint to crop production. The SS not only improves soil fertility but also alters the nutrient availability through change in soil pH [8,9,10,11].

Being relatively low in easily decomposable organic carbon, co-composting of SS (CSS) with green waste would appear as an appropriate approach to obtain good quality compost relatively quickly. Co-composting is an aerobic decomposition process whereby two or more materials are

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composted together, that decomposes organic matter to CO_2, releases inorganic nutrients and forms humic-like substances and reduces the bulk volume of sludge by 40–50%. Co-composting of green waste (GW) and SS can be advantageous because it enhances the stability of SS in a shorter time [12]. Proper ratios of GW and SS in the starting material ensures optimum C:N ratio to enhance the biodegradation process [13]. Without co-composting most of the nutrients are not released [14], thus reducing the fertility potential of the material. The amendment of soil with compost is an environmentally-friendly option for organic farming, contributing to enhanced soil fertility and further crop development, thus producing both economic and environmental benefits [15].

The use of CSS and SS leads to improved soil fertility [16], mitigate the disposal issues [17], improve soil health and crop yields [6,7,18,19,20,21,22]. Composted materials when applied to soil results in net mineralization of nutrients like N and P and thus their availability to plants. A study [23] reported rapid N mineralization in coarse textured soil (well aerated) following addition of composted materials.

During the process of organic matter decomposition, soil pH also undergoes changes due to the release of organic acids as well as because of immobilization and remineralization of different N forms particularly NH_4 and NO_3. The process of nitrification is particularly more amenable to changes in pH. It is important therefore to look at not only changes in organic matter content of the soil and N mineralization but also pH dynamics. It is well established that organic matter dynamics and N mineralization processes are affected by the chemistry of the materials and rate of addition [24,25,26,27].

Soil moisture as well as temperature are two key factors influencing the rate of organic matter decomposition leading to the release of nutrients (mineralization) and production of greenhouse gas [28,29]. High moisture in soil creates reduced conditions (low oxygen) and thus affects organic matter decomposition, whereas low soil moisture decreases microbial activity essential for decomposition through reduction of diffusion of soluble substrates [30,31]. Moreover, soil moisture affects carbon mineralization. Studies have clearly demonstrated that when the soil dried out below a critical limit (field capacity), most of the metabolic activities are either stopped or decreased to a significant extent [32,33,34,35,36, 37]. A experiment [38] found positive correlation between soil pH and microbial respiration, soil microbial biomass, C and N nitrification. In addition, nitrification appears to be more sensitive to low pH than ammonification, and the optimal soil pH for nitrification ranges from approximately pH 6.0 to 8.0 [39,40]. Initial soil pH may also influence the direction and magnitude of soil pH changes after the addition of organic residues [41,42] suggested that a relatively low initial soil pH caused decarboxylation of organic anions from added plant residues and ammonification of N residues thereby increasing the soil pH during the incubation period. The availability of nutrients is related to soil pH. It is well observed that if pH of soil decreases the ability of adsorbed metal decreases [43].

In the UAE only, over 120 million tonnes of waste is produced annually including over 22 million tonnes of municipal waste, more than 4 million tonnes of industrial solid waste, and over 0.1 million tonnes of sludge [44]. In The Emirate of Abu Dhabi, annual production of wastes is estimated at >6 million tonnes (16500 tonnes day^{-1}) according to the Centre of Waste Management (CWM)-Abu Dhabi. Most of this material ends up in landfill and other dumping sites [45].

The disposal of these quantities in an environment friendly manner is a serious issue. At the Dubai based International Center for Biosaline Agriculture (ICBA), the scientists are conducting a long term research programme to assess the use of SS and CSS as a soil conditioner and a resource for agricultural intensification. In order to support such experimentation laboratory incubation studies have been conducted.

Incubation studies indeed provide good basic information on soil processes as the experiments are conducted, thus provides reliable information before proceeding for field experiments where no control can be exercised on conditions especially temperature and irrigation.

II.MATERIALS AND METHODS

A Typic torripsamments soil from UAE was used in the incubation study. This type of soil is dominant in the UAE and other GCC countries [46, 47]. The soil is sandy in texture (sand:silt:clay, 98:1:1), slightly alkaline (pH 7.4), non-saline (ECe 1.54 mS/cm), strongly calcareous ($CaCO_3$, 55%), and low in organic matter content (0.28%); and NH_4-N and NO_3+NO_2-N was 3.1 and 8.9 mg/kg, respectively. Sewage sludge collected from Dubai Municipality had pH 6.23, EC (1:5) 4.6 mS/cm, organic matter content 71.8% (41.75% C), total N 5.85%, C/N ratio 7.1, available P (4 mg/kg), and available K (0.45 mg/kg).

Modified Walkley-Black method [47] was used to determine organic matter content of soil and compost. Available P was determined using the method (sodium carbonate, pH 8.2) described by [49], and ammonium acetate (1.0 N) extractable soil potassium was determined using a flame photometer (PFP, Jenway). Total N was determined by Kjeldahl method of [50]. Electrical conductivity of soil was determined from 1:5 soil:water suspension. For the determination of NH_4-N and NO_3+NO_2-N, micro-Kjeldahl method [51] was followed. Potentially mineralizable N was determined by the method of [52]. A 5-g sample was incubated with 10 ml water at 40 °C for 7 days. Ammonium-N accumulated was taken as a measure of potentially mineralizable N.

For co-composting at Sharjah, the feedstock consisted of SS and green waste in the ratio of 70:30. Resulting CSS had pH (1:5) 6.8, EC (1:5) 9.2 mS/cm, organic matter content 42.5% (24.7% C), total N 2.5%, C/N ratio 9.9, available P (1.25 mg/kg), and available K (0.5 mg/kg). The co-compost showed a percentage of organic matter (42.5) slightly higher

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than that required for commercial compost [16]. The above values of N, pH, C/N, available phosphorus, and exchangeable bases are similar to other studies [16,53].

A. Soil incubation study

For the incubation study, 100 g portions of the typical sandy soil from UAE were mixed with SS and CSS at the rate of 5, 10, 20 tons/ha. This is based on the bulk density (1.6 g cm^{-3}) of sandy soil used in this study where a weight of 2.2 million kg to 15 cm depth was used in determining SS and CSS rates in tons per hectare. A treatment of soil without SS and CSS was also included and considered as control (T1)

Prior to incubation study, the CSS, SS and soil samples were dried at 65 °C. The CSS and SS were ground and passed through 0.5 mm sieve and mixed with 100 grams of sandy soil. The moisture content of the CSS, SS and soil mixture was brought to 11% (field capacity) with deionized water. A total of 147 containers were prepared, incubated and studied at intervals of 0, 5, 10, 20, 30, 45, 60 days of incubation at 30 °C (Fig. 1). At each interval 21 samples were analyzed (triplicate from each of the 7 treatments) for N mineralization, organic matter loss and change in soil pH measured and the samples discarded.

Fig. 1. Set up of incubation study in an incubator

III.STATISTICAL ANALYSES

The two organic sources (CSS & SS) and seven interval of incubation were triplicated in a 2x3×7 factorial design. One-way and multifactor analysis of variance (ANOVA) were performed to test whether there were differences among rate of application, among days of incubation and between the types of organic matter (CSS & SS). The interaction among factors for all the characteristics was also studied. LSD multiple comparison test was used to detect differences among the means. An analysis of variance (ANOVA) was carried out to determine the treatment effects on the measured parameters. Least significant difference values (LSD) was applied to compare the treatments at 0.05 probability. All analyses were performed using Statgraphics Centurion XV (StatPoint, USA) and all graphs were constructed with Excel program

IV.RESULTS AND DISCUSSION

The initial analyses of soil, SS and CSS are given in materials and methods section. This is essential for comparison with the results obtained from the incubation study. In this section the results are presented under different heading separately such as loss of organic matter, change in soil pH and N-mineralization dynamics.

A. Recovery of organic matter during incubation period

Fig. 2 presents the organic matter recovery in CSS and SS after 60 days of incubation. The results show overall significant recovery of organic matter in all treatments, the ranges between 56 to 74% in CSS and 69-72% in SS (Fig. 2). When we compared the OM recovery between CSS and SS, it is apparent that the decomposition during the incubation was slightly higher in SS relative to CSS ($p = 0.01$). The reason being higher organic matter content in the original SS (71.8%) compared to CSS (42.5%), and also the fact that the SS is high in readily decomposable constituents (volatile organic compounds), which has ultimately resulted into greater mass loss from SS compared to CSS). A material with lower C/N ratio as in the case of SS would be much easier to be decomposed by the microorganisms due to more labile material compared to CSS of higher C/N. A study [12] found that Co-composting of green waste (GW) and SS can enhance the stability of SS in a shorter time. In another study [54] found sewage sludge easily decomposes relative to other organic wastes, and it also releases essential nutrients for plant uptake. These findings are supported by [55]. There was significant interaction between types of sludge (SS and CSS), their rates and days of incubation ($p = 0.001$) (Table 1). The multifactorial analysis enabled us to quantify the factors: Type of sludge (A), Rate of sludge (B) and Days of incubation (C) and the combinations of these factors (“A*B”, “A*C”, “B*C”) and A*B*C on recovery of OM evolution in the soil (Table I).

It has been observed during this incubation study, that the rate of decomposition of organic matter is associated with the quantity of organic matter in the substrate used and this has been in agreement with the findings of [56], as well as higher temperature during incubation [57], that ultimately increases the SOC mineralization

TABLE I. Multifactor analysis for recovery of organic matter taking into account the three main effects and their levels: two types of sludge (CSS and SS), rates of sludge (0, 5, 10, 20) and days of incubation (0,5,10, 20, 30 45, 60).

Multifactor analysis for the recovery of organic matter		
Source	**F-Ratio**	**P-Value**
Main effects		
A: Type of sludge	113.7	p‹0.001
B: Rates of sludge	918.1	p‹0.001
C: Days of incubation	263.2	p‹0.001
Interactions		
A*B	40.5	p‹0.001
A*C	76.5	p‹0.001
B*C	11.3	p‹0.001
A*B*C	5.0	p‹0.001

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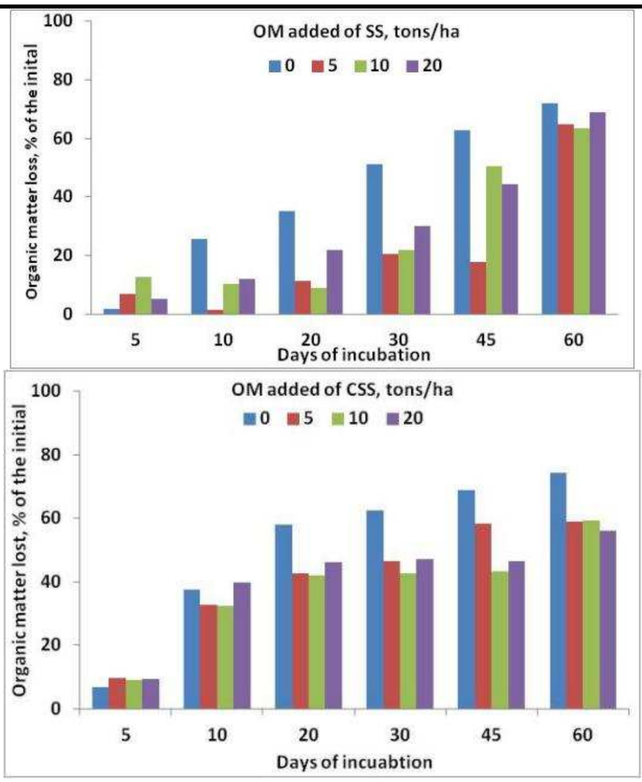

Fig. 2. Recovery of organic matter in CSS and SS over incubation period of 60 days

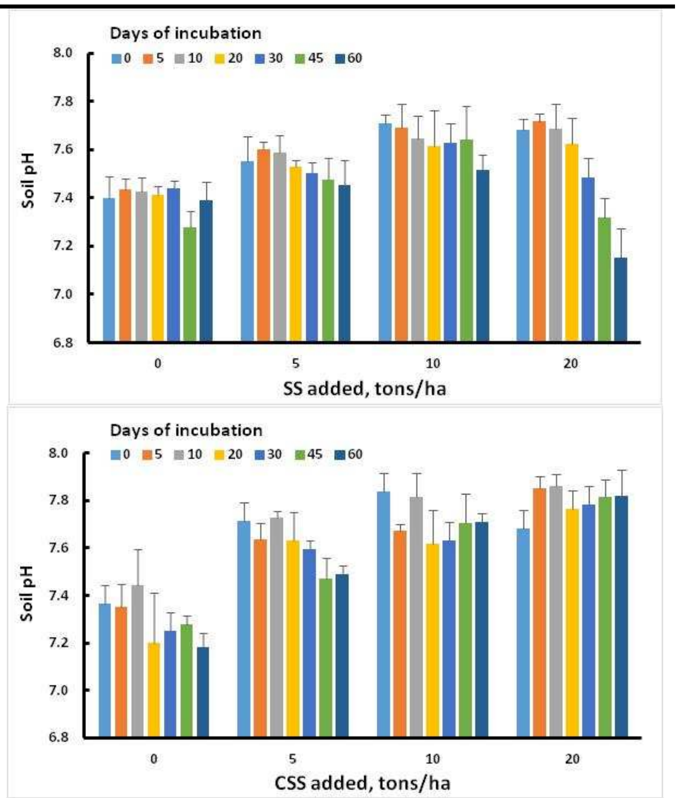

Fig. 3. Change in soil pH during mineralization over incubation period of 60 days

B. Change in soil pH during incubation period

The increasing and decreasing trend of soil pH (1:5) over the incubation period is shown in Fig. 3. The addition of CSS and SS at different rates to soil did not show change in soil pH on day 1, however, later changes in soil pH were recorded. As the incubation time progressed, the soil pH gradually increased and reached to maximum between 10 to 20 days of incubation in both in CSS and SS amended soil. For example, in the case of 20 tons/ha of both SS and CSS, the initial pH was 7.68, these values were increased to 7.69 and 7.86 (after 10 days) for SS and CSS respectively (Fig. 3), this increase is directly related to the application rates of SS and CSS and subsequent ammonification. The soil pH decreased slowly after 20-days of incubation (7.69 to 7.15 for CSS and 7.86 to 7.82 for SS), and this decrease was also related to the application rates of CSS and SS and subsequent nitrification and release of H ions. The comparison of CSS and SS application shows higher decrease in pH where high rates of SS was applied as shown in figure III, this is associated with the increased microbial activity and subsequent higher decomposition rate of OM than CSS.

Many studies demonstrated that soil pH was decreased by the addition of organic wastes [8]. Similarly, the addition of SS slightly decreased the soil pH at the highest dose of treatment. The pH was significantly affected by all the treatments and their interactions but no significant differentiation was observed by the rates and days of incubation (Table II).

The initial increase in soil pH during 10-20 days from incubation is mainly due to mineralization of SS and CSS that ultimately shows alkalization effect of ammonification (the process which releases NH_4 ions). The mineralization of organic N in soil consists of two stages: ammonification and nitrification. These processes could be affected by initial soil pH that greatly affects the ammonification and nitrification of the residue N and the rate of residue decomposition [41, 58. 59].

The decrease in soil pH at later stage of incubation is due to nitrification process whereby H^+ ions are released (acidic effect) with final NO_3 formation and release of organic acids during decomposition [41, 59]. The pH was found to be slightly significant ($p<0.01$) during mineralization, while the application of SS and CSS and days of incubation interaction showed insignificant difference during incubation period (Table II). This suggests that temperature, humidity and aeration conditions were adequate for organic matter mineralization and thus, resulting in the production of CO_2, H_2O, organic acids, inorganic compounds accompanied by a release of H^+, resulting in a decrease of soil pH.

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TABLE II. Multifactor analysis pH taking into account the three main effects and their levels: two types of sludge (CSS and SS), rates of sludge (0, 5, 10, 20) and days of incubation (0,5,10, 20, 30 45, 60)

Multifactor analysis for pH		
Source	**F-Ratio**	**P-Value**
Main effects		
A: Type of sludge	23.1	p‹0.001
B: Rates of sludge	80.2	p‹0.001
C: Days of incubation	9.4	p‹0.001
Interactions		
A*B	20.4	p‹0.001
A*C	1.9	p=0.0773
B*C	0.9	NS
A*B*C	2.5	p=0.0019

C.N dynamics of CSS and SS during incubation study

From the comparison of results, it is apparent that total mineralization is higher in CSS compared to SS. This can be related to initial higher quantities of organic matter in SS (71.8%) relative to CSS (42.9%). Changes between initial and final N concentrations were statistically significant for both CSS and SS (Table III). The release of nitrogen from CSS and SS differs significantly (Table III). The N release from SS (20-36 %) was higher relative to N release from CSS (3-10%) after 8 weeks as shown in (Fig. 4). The SS and CSS (p = 0.001) and their interaction with rates and days of incubation (p = 0:001) significantly affected N mineralization (Table III). The results from the present study conform closely to the findings [24, 25, 27] where organic matter dynamics and N mineralization processes have been reported to be affected by the chemistry of the materials and the rate of addition.

The CSS with a high C:N (9.8) presented gross N mineralization rate of 3-10%, such a N mineralization is lower than the organic material with low C:N. The low N mineralization rate of high C:N is due to the presence of stable material developed when composting process is completed. A comparison of CSS and SS showed that, although the SS had the greatest gross N mineralization rate, its N release was not significantly different from that of the CSS. The SS shows the highest N mineralization rate (20-36 %) which is associated with low C:N ratio (7.1).

The trend of NH_4^+-N concentration shows the release being maximum after 7 days of incubation, which can be related to ammonification of CSS and SS (Fig. 5). The NO_3-N remained unreleased during first 7 days of incubation. The trend of soil NH_4^+-N during the incubation of the CSS and SS is shown in figure 4. In comparison to the SS and CSS treatment, the concentration of NH_4^+-N in the untreated control soil was low (due to low initial organic matte); however, it significantly increased in the first week of incubation, but clearly decreased in the soil after 10 days of incubation.

Apparently, the increased application rates of SS and CSS has increased the NH_4^+-N concentration. In a similar study, [60] found that initial ammonification occurred in six contrasting soils in the first 15 days of incubation. This was presumably because the soil had the highest pH (initial pH 7.7), thus leading to NH_4+-N being rapidly transformed to NO_3-N. These results suggest that the NH_4 disappearance might have occurred via nitrification or microbial immobilization. The accumulation of NO_3^--N (Fig. 5) in all the treatments indicated the adequate soil humidity and aeration conditions for the mineralization and nitrification.

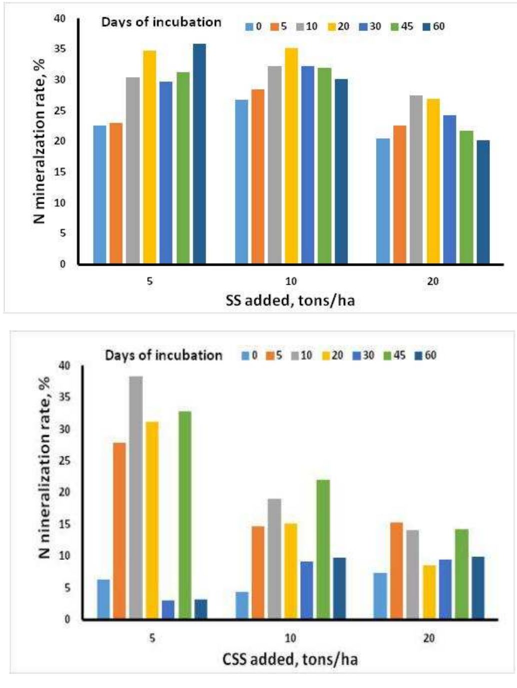

Fig. 4. Total nitrogen mineralization of CSS and SS during the incubation period of 60 days

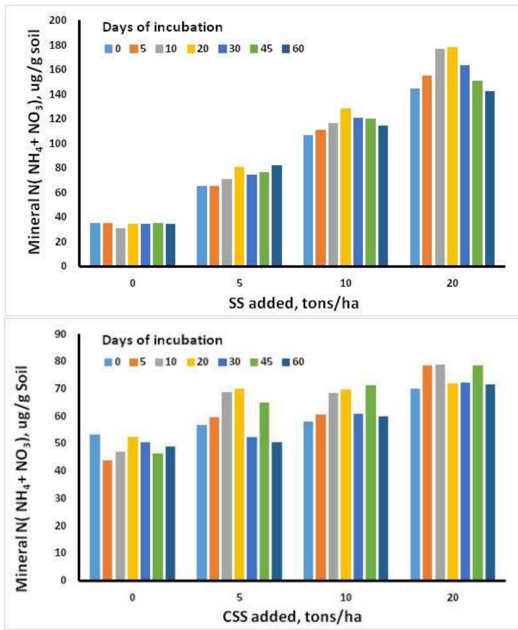

Fig. 5. Ammonium and nitrate mineralization of CSS and SS during the incubation period of 60 days

TABLE III. Multifactor analysis of N-mineralization (NO_3+ NH_4) taking into account the three main effects and their levels: two types of sludge (CSS and SS), rates of sludge (0, 5, 10, 20) and days of incubation (0,5, 10, 20, 30 45, 60).

Multifactor analysis for N-mineralization		
Source	**F-Ratio**	**P-Value**
Main effects		
A: Type of sludge	14866,6	p‹0.001
B: Rates of sludge	8889,9	p‹0.001
C: Days of incubation	372,4	p‹0.001
Interactions		
A*B	4512,9	p‹0.001
A*C	273,5	p‹0.001
B*C	45,3	p‹0.001
A*B*C	36,7	p‹0.001

V.CONCLUSIONS AND RECOMMENDATIONS

From the incubation study of CSS and SS following conclusions have been drawn. The rate of mineralization in CSS and SS mainly depends on the application rates, original organic matter contents and the chemistry of the material. The study shows higher recovery of organic matter in case of CSS and this is due its stable form after composting. In the SS the presence of volatile compounds has increased decomposition of organic matter relative to CSS. The soil pH was initially increased during 10-20 days of incubation and later decreased. Comparatively CSS has shown better results than SS in terms of their nutrient values and stability and can be a better soil conditioner than SS. The present incubation study was conducted under controlled conditions, this is essential as a starting point, however, the mineralization rate of both SS and CSS may be different under field conditions, therefore, it is recommended to further this type of research under field conditions to optimize the rates of application of SS and CSS in sandy soils.

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