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### Title
Effect of Cd-Enriched Sewage Sludge on Plant Growth, Nutrients and Heavy Metals Concentrations in the Soil–Plant System

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## Introduction

Land application of sewage sludge (SS) is practiced throughout the world and is of increasing concern as a safe and less costly method of disposal. SS is a source of organic matter and rich in essential nutrients to plant, therefore, is considered a fertilizer and soil conditioner for improving soil fertility and crop productivity (Athamneh, 2003). On the other hand, SS contains heavy metals, such as Cd, that can accumulate in the soil and subsequently be absorbed by the plants with possible negative impact on soil fertility and quality of the crops. Cadmium, which is the most concerned heavy element, can adversely affect soil productivity and plant development and accumulate in edible parts of the plants, becoming a pathway into the food chain (Michalska and Asp, 2001). Therefore, improper application of SS may lead to excessive accumulation of Cd in agricultural products and pose health hazards to human and animals (Skjelhaugen, 1999). Proper management of SS application on the other hand can alleviate such health hazards and pollution problems (McBride, 2002). The objectives of this study were to determine changes in soil fertility and nutrient and heavy metal contents of radish in response to original and Cd-enriched SS application to calcareous soil

## Materials and Methods

A calcareous soil with low organic matter content was collected, air-dried and sieved through a 5-mm screen. Sewage sludge (SS) was collected, air dried and grounded to about 5 mm-granules, and applied as such to each soil according to the treatments. The soil and SS were analyzed for general characteristics, nutrients and heavy metals according to the standard procedures. The major soil and SS characteristics are showed in Table 1.

Greenhouse pot experiments with the following treatments were conducted in a randomized complete block design with four replications: 1) zero SS application (control); 2) 20 ton SS $ha^{-1}$; 3) 40 ton SS $ha^{-1}$; 4) 80 ton SS $ha^{-1}$; 5) 160 ton SS $ha^{-1}$; 6) 80 ton Cd-enriched SS $ha^{-1}$; 7) 160 ton Cd-enriched SS $ha^{-1}$; and 8) 80 kg DAP (diammonium phosphate) $ha^{-1}$ that represented the recommended fertilizer rate. The SS was enriched with Cd by addition of $CdCl_2$ to a Cd concentration of 50 mg $kg^{-1}$. Each pot was filled with 7 kg air dry soil, air dry soil-SS mixture or air dry soil fertilized with DAP per treatments. Three radish seedlings per pot were planted in seven-liter pots. Plants were watered on alternate days to maintain water content at approximately field capacity. At the end of the growing period (12 weeks), the whole plants (shoot and tuber) were harvested from each pot. The fresh weights of both shoots and tubers were recorded.

Plant parts were oven-dried at $70^0$C for 48 hours, then dry weights recorded. Plant parts were ground to a fine powder using a laboratory mill with 0.5 mm sieve. The milled plant samples were analyzed for nutrients and heavy metals by standard procedures. The soil at the end of the experiment was analyzed for the same parameters mentioned above.

## Results and Discussion

### Plant growth

The fresh weight of radish tubers increased with increasing SS rates with the rate of 40 ton $ha^{-1}$ sufficient to achieve the greatest fresh weights (Fig 1). With higher rates of original (non-enriched with Cd) SS, the fresh weights of tubers were not significantly different. This highest fresh weight was also achieved with an addition of 80 ton of Cd-enriched SS. However, doubling the rate of the Cd-enriched SS resulted in a significant decrease in tuber fresh weight. Addition of DAP fertilizer (fertilized control) resulted in radish tuber fresh weight equivalent to that obtained with an application of 20 ton SS $ha^{-1}$ but lower than those obtained with higher SS rates. The relationship between the rate of original SS (from zero to 160 ton $ha^{-1}$) and tuber fresh weight followed a second degree quadratic equation (Fig 1: $y = -0.0045x^2 + 0.8694x + 128.84$ with $R^2 = 0.869$).

## Concentrations of N, P and K

Addition of original and Cd-enriched SS increased shoot N content compared to both control and DAP fertilizer treatments (Table 2). All rates from 40 to 160 ton SS $ha^{-1}$ of both original and Cd-enriched SS gave the highest shoot and tuber N contents with no significant differences among each treatment. The tuber N content was the lowest for the DAP fertilizer treatment and was even lower than that of the non fertilized control treatment; possibly this decline could be attributed to the dilution effect caused by the higher growth with DAP fertilizer application.

Shoot P content increased with increasing rates of SS and was the lowest for the control, and then the DAP fertilizer treatments (Table 2). Tuber P content was higher with SS application being the highest with higher rates of SS. The lowest tuber P content was obtained with the control treatment and the DAP fertilizer treatment gave a value higher than that obtained by the control and the SS rate of 20 ton $ha^{-1}$. Both shoot and tuber K contents were not affected by SS application except by the highest rate of the Cd-enriched SS which might attributed to the increased concentration caused by the stunted growth.

Increased plant concentrations of N, P and K with SS application is mainly attributed to the increased levels of the available forms of these nutrients in th soil following SS application (Jarausch-Wehrheim, 2000). Moreover, Oudeh et al. (2002) reported that sludge contains large amounts of N and P, and found an increase in their levels in SS-treated soil when compared to a control or even to the chemical fertilizer treatments. It should be mentioned however, that excessive application of N and P by high rates of sludge application can be detrimental to crop production and the environment (Fine and Mingelgrin, 1996).

On the other hand, other researchers (Linden et al., 1995) reported that little differences were found between tissue concentrations of N, P, and K in corn grown on SS amended soil versus the control. However, it has been reported by Rubin et al. (1991) that applying SS at a rate sufficient to meet the plant's N requirement would provide an excess of P but insufficient K. Therefore, they stated that balancing the amount of nitrogen applied in the SS with the plant’s requirement is an important management factor to avoid nutrient imbalance.

## Concentrations of micronutrients and heavy metals

Shoot Fe concentration increased with application of SS at rates equal to or higher than 40 ton $ha^{-1}$ (Table 3). The highest two application rates resulted in lower shoot Fe when the SS was enriched with Cd. Similar trends, but with lower values, was obtained for tuber Fe concentration. Concentrations of Mn in the shoot increased with SS addition, with the highest values obtained by the highest two rates. The treatments effect on tuber Mn concentration was not significant. Application of SS at rates equal to or higher than 40 ton $ha^{-1}$, similarly or equivalently increased both shoot and tuber Zn concentrations over other treatments. Addition of 80 and 160 ton $ha^{-1}$ of SS, with or without Cd enrichment, resulted in the highest Cu concentrations in both the shoot and the tuber of radish.

The highest shoot Cd concentration was obtained with the application of the highest rate of the Cd-enriched SS (160 ton Cd-enriched $ha^{-1}$) followed by the next highest rate (80 ton Cd-enriched $ha^{-1}$). Application of original SS increased shoot Cd only at the highest rate of 160 ton SS $ha^{-1}$. A similar trend was observed with tuber Cd concentration. SS may facilitate higher mobility for heavy metals through the effect of dissolved organic compounds from the applied SS that form soluble complexes with Cd and Zn and to a lesser extent with Cu and Pb (Schaecke et al., 2002). It is well documented that most of the heavy metal accumulation occurs in the roots of vegetable crops (Michalska and Asp, 2001). Differences between root and leaf content was larger for Cd than for Pb, indicating that the translocation of Pb from roots to leaves is more limited than for Cd (Michalska and Asp, 2001). Frost and Ketchum

(2000) found higher Cd in leaves with SS application. On the other hand, Oudeh et al. (2002) found that Zn and Cu but not Cd concentrations were higher in roots than in shoots. In this study, such a differentiation in Pb and Cd distribution were not observed.

**Soil fertility parameters**

**pH, salinity, organic matter and P**

Compared to the control and DAP fertilizer treatments, soil pH decreased with application of SS similarly by all rates (Table 4). However, soil salinity increased only with the highest two rates of SS. Soil organic matter increased by application of SS at a rate equal to or more than 40 ton $ha^{-1}$. Soil P increased with increasing SS rates. The increase in soil P caused by the lowest SS rate (20 ton $ha^{-1}$) was equivalent to that obtained by the MAP fertilizer treatment and higher than that for the control treatment.

**Micronutrients and heavy metals**

DTPA-extractable Fe, Mn, Zn and Cu increased with increasing SS application rates. Addition of 160 ton of both SS and Cd-enriched SS $ha^{-1}$ resulted in the highest values for DTPA-extractable micronutrients. On the other hand, DTPA-extractable Pb increased similarly by all rates of SS application rates. Both the control and the DAP fertilizer treatments resulted in the lowest values of the DTPA-extractable Pb. Addition of the Cd-enriched SS resulted in the highest DTPA-extractable Cd being higher at the higher application rate. Comparatively, much lower DTPA-extractable Cd levels were obtained for the application of the original SS. However, the highest two rates of the original SS yielded higher values of DTPA-extractable Cd compared to the lower rates, but the highest levels of Cd were found with the addition of the Cd-enriched SS. The relationships between the DTPA-extractable Cd and the Cd concentration in radish shoot and tuber were significant and followed quadratic equations (Fig 2). The Cd concentration tended to slowly increase with increasing DTPA-extractable Cd within the range from 0.05 to 0.15 mg $kg^{-1}$, after that a steep increase was observed.

It can be summarized that application of SS to calcareous soil improved soil organic matter, available P, and micronutrients as well as the plant growth. However, application of higher rates was unnecessary for plant growth and yet has the potential to cause nutrient imbalance in the soil. Cd-enriched SS resulted in stunted growth at the highest rate and tend to accumulate Cd in the soil and plant parts. Therefore, it can be concluded that SS application to calcareous soils improves plant growth and soil fertility but at high rates of SS and SS rich in Cd should be avoided.

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Table 1. Selected properties of the soil and sewage sludge (SS) used in the experiment.

| Soil analyses : | | SS analyses | |
|---|---|---|---|
| pH | 8.18 | pH | 7.13 |
| EC (dS $m^{-1}$) | 0.61 | EC (dS $m^{-1}$) | 1.09 |
| CEC (cmol $kg^{-1}$) | 34.32 | CEC (cmol $kg^{-1}$) | 51.37 |
| O.M (%) | 0.72 | O.M (%) | 62.30 |
| N (%) | 0.01 | N (%) | 4.50 |
| P (mg $kg^{-1}$) | 7.10 | P (%) | 2.40 |
| K (mg $kg^{-1}$) | 452 | K (%) | 0.27 |
| $CaCO_3$ (%) | 13.38 | Ca (%) | 5.64 |
| - | - | Mg (%) | 0.51 |
| - | - | Na (%) | 0.12 |
| Fe (mg $kg^{-1}$) | 3.56 | Fe (mg $kg^{-1}$) | 731.3 |
| Mn (mg $kg^{-1}$) | 5.58 | Mn (mg $kg^{-1}$) | 685.0 |
| Zn (mg $kg^{-1}$) | 1.88 | Zn (mg $kg^{-1}$) | 621.0 |
| Cu (mg $kg^{-1}$) | 1.22 | Cu (mg $kg^{-1}$) | 132.4 |
| Pb (mg $kg^{-1}$) | 0.68 | Pb (mg $kg^{-1}$) | 62.5 |
| Cd (mg $kg^{-1}$) | 0.06 | Cd (mg $kg^{-1}$) | 1.88 |
| Texture | Silt clay loam | Moisture content (%) | 11.12 |

Table 2. Concentration of N, P and K in radish shoot and tuber as influenced by application of original and Cd-enriched sewage sludge (SS) to calcareous soil.

| Treatments Ton $ha^{-1}$ | N % | P % | K % |
|---|---|---|---|
| Shoot: | | | |
| 0 | 3.35c | 0.28e | 1.87b |
| 20 | 4.06b | 0.93c | 1.93b |
| 40 | 4.53a | 1.07c | 1.93b |
| 80 | 4.69a | 1.53b | 1.95b |
| 160 | 4.82a | 1.60b | 1.86b |
| 80 + Cd | 4.90a | 2.00a | 2.04b |
| 160 + Cd | 5.05a | 1.92a | 2.82a |
| DAP | 3.25c | 0.61d | 1.87b |
| Tuber: | | | |
| 0 | 1.94b | 0.36d | 3.74b |
| 20 | 1.98b | 0.49cd | 3.64b |
| 40 | 3.37a | 0.52bc | 3.62b |
| 80 | 3.40a | 0.73b | 3.68b |
| 160 | 3.64a | 0.74b | 3.54b |
| 80 + Cd | 3.20a | 0.57bc | 3.43b |
| 160 + Cd | 3.70a | 0.94a | 4.39a |
| DAP | 1.35c | 0.53bc | 3.66b |

* Means with different letter within each column are significantly different at the 0.05 probability level

Table 3. Concentration of micronutrients and heavy metals in radish shoot and tuber as influenced by application of original and Cd-enriched sewage sludge (SS) to calcareous soil

| Treatments Ton $ha^{-1}$ | Fe mg $kg^{-1}$ | Mn mg $kg^{-1}$ | Zn mg $kg^{-1}$ | Cu mg $kg^{-1}$ | Pb mg $kg^{-1}$ | Cd mg $kg^{-1}$ |
|---|---|---|---|---|---|---|
| Shoot: | | | | | | |
| 0 | 295.1ef | 79.5c | 42.1b | 3.90c | 4.25a | 0.20d |
| 20 | 312.6e | 89.3bc | 46.9b | 4.43bc | 4.75a | 0.25d |
| 40 | 389.0d | 127.8b | 60.3a | 5.28b | 6.50a | 0.20d |
| 80 | 609.9a | 170.0ab | 78.1a | 7.05a | 6.25a | 0.33d |
| 160 | 686.5a | 201.3a | 64.9a | 6.48a | 6.75a | 1.23c |
| 80 + Cd | 566.1b | 152.0b | 77.0a | 6.80a | 6.50a | 12.10b |
| 160 + Cd | 432.9c | 187.3a | 66.0a | 6.50a | 6.00a | 25.15a |
| DAP | 263.5f | 64.8c | 42.4b | 3.53c | 6.50a | 0.28d |
| Tuber: | | | | | | |
| 0 | 121.7c | 14.0a | 40.2b | 4.45c | 5.00a | 0.53d |
| 20 | 115.9c | 14.9a | 49.1b | 4.58c | 6.00a | 0.63d |
| 40 | 113.7c | 15.4a | 62.9a | 6.00b | 6.35a | 0.68d |
| 80 | 156.9b | 15.5a | 70.9a | 8.78a | 6.25a | 0.73d |
| 160 | 222.7a | 16.5a | 73.2a | 7.40ab | 5.25a | 1.33c |
| 80 + Cd | 187.4b | 16.0a | 70.8a | 9.88a | 5.25a | 2.95b |
| 160 + Cd | 177.7b | 14.3a | 72.2a | 7.43ab | 7.25a | 4.68a |
| DAP | 75.7d | 10.3a | 48.9b | 3.95c | 5.75a | 0.70d |

* Means with different letter within each column are significantly different at the 0.05 probability level

Table 4. Soil analysis at the end of the experiment as influenced by application of original and Cd-enriched sewage sludge (SS)

| Treatments Ton $ha^{-1}$ | pH | EC dS $m^{-1}$ | OM % | P mg $kg^{-1}$ | Fe mg $kg^{-1}$ | Mn mg $kg^{-1}$ | Zn mg $kg^{-1}$ | Cu mg $kg^{-1}$ | Pb mg $kg^{-1}$ | Cd mg $kg^{-1}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 8.15a | 0.54b | 0.69c | 8.13[e] | 2.53e | 6.18d | 1.54d | 1.44d | 0.60c | 0.06d |
| 20 | 7.72b | 0.60b | 1.09bc | 14.47d | 4.68d | 12.19c | 6.33c | 2.65c | 1.52a | 0.08d |
| 40 | 7.61b | 1.71b | 1.46ab | 22.56c | 5.62c | 16.59c | 7.80c | 2.92c | 1.78a | 0.09d |
| 80 | 7.53b | 4.09a | 1.78a | 36.41b | 7.27b | 24.34b | 12.08b | 4.38b | 1.75a | 0.14c |
| 160 | 7.17b | 4.46a | 1.92a | 57.50a | 9.74a | 29.62a | 16.31a | 6.44a | 2.07a | 0.23c |
| 80 + Cd | 7.48b | 3.93a | 1.87a | 41.46b | 6.84b | 21.23b | 13.53b | 4.39b | 1.71a | 1.60b |
| 160 + Cd | 7.47b | 4.55a | 1.88a | 62.34a | 10.83a | 30.55a | 17.21a | 6.49a | 1.76a | 4.47a |
| DAP | 8.27a | 0.42b | 0.71c | 17.78d | 5.44c | 11.68c | 1.44d | 2.10cd | 0.75c | 0.07d |

* Means with different letter within each column are significantly different at the 0.05 probability level

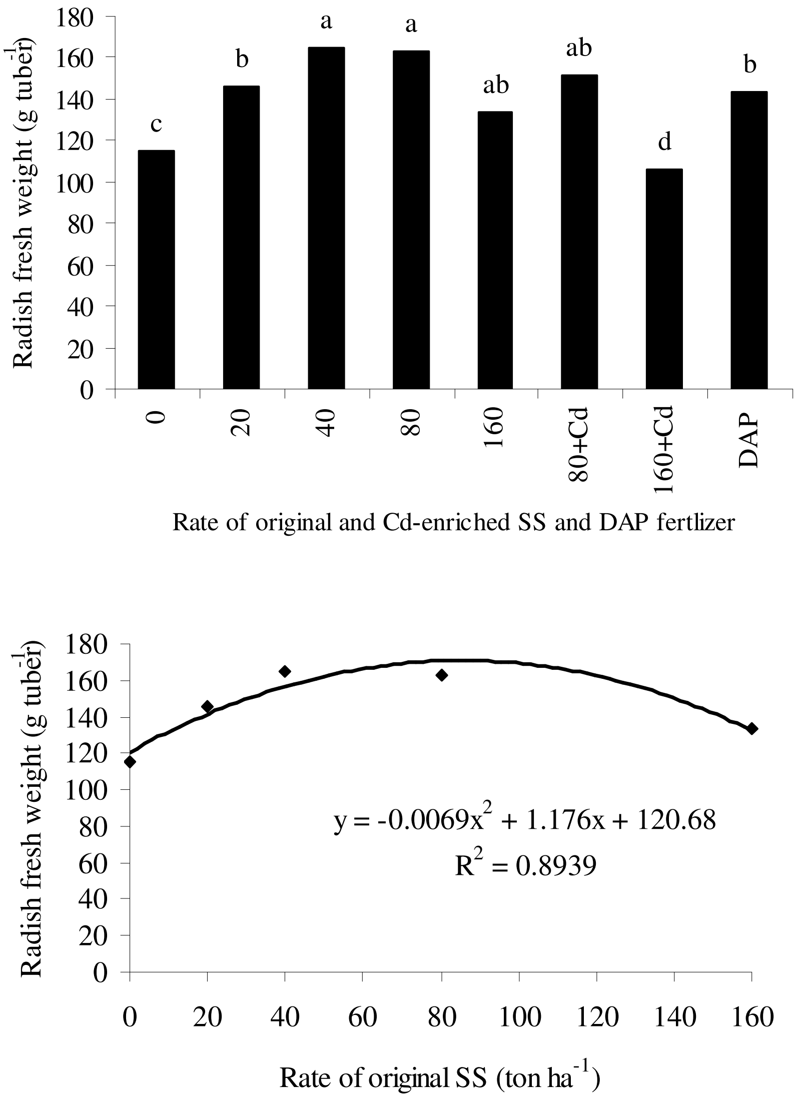


Fig. 1. Radish fresh weight as affected by rates of original and Cd-enriched sewage sludge (SS) and diammonium phosphate (DAP) fertilizer application

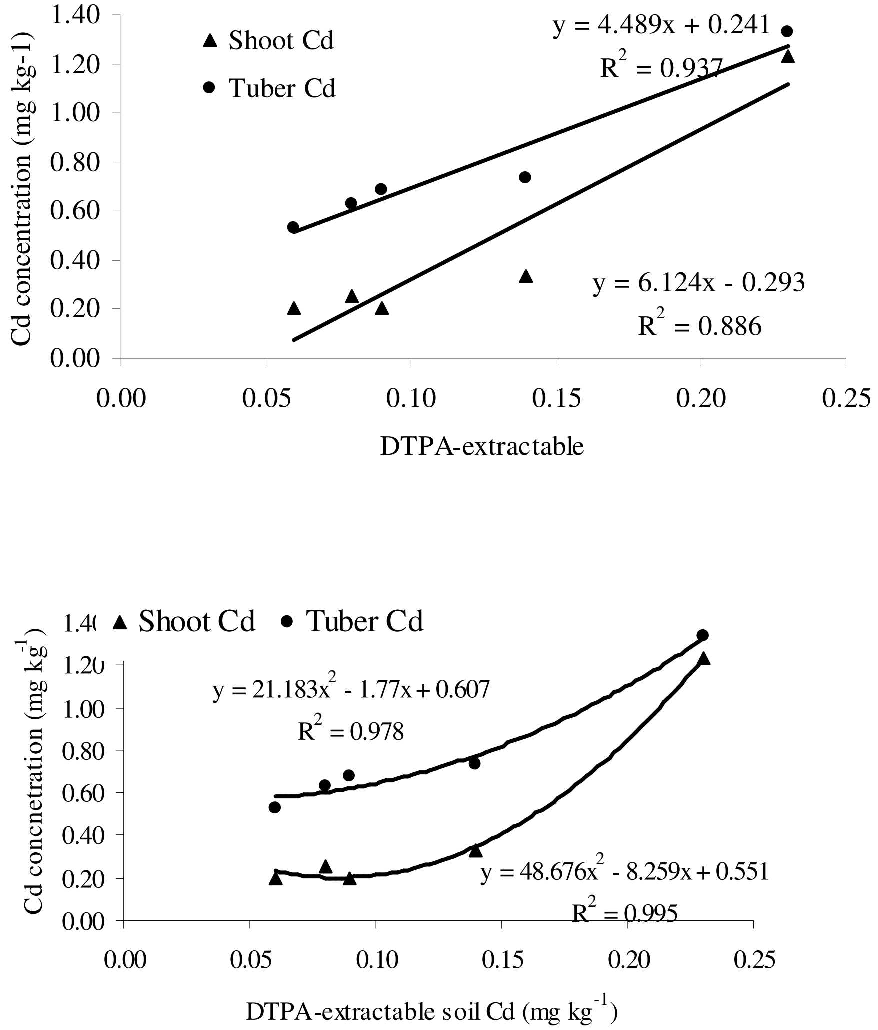


Fig.2. Relationship between DTPA-extractable soil Cd and plant Cd concentration