Application of biosolids (sewage sludge) in agricultural soils: a case study for corn seed LVN10

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Abstract. Reuse of biosolids aiming to take advantage of its nutrients and micronutrients for arable crops is an economical approach, in which wastes are considered potential resources and bring a variety of benefits. However, heavy metal residuals in sewage sludge have been gaining attention due to accumulation risk and adverse effects on the environment. This study experimented with sludges from Binh Hung municipal wastewater treatment plants treated by anaerobic co-digestion process on corn seed LVN10 to assess corn growth and heavy metals accumulation contents in various components of the corn and the soil. Consequently, within 90 days of using biosolids as treatments 1\% and 3\%, i.e., the corresponding amount of biosolids over the soil weight, there was no inhibition but growth stimulation for corn growth surveyed. Accumulations of Cu, Cd, Pb, Zn, Ni in roots, stalk, leaves, and mature corn and cultivated soil complied with the national regulations. The effectiveness of biosolids application for corn production in this study will benefit the depreciation of sludge production from municipal wastewater treatment plants and other applications for agricultural plants in the future.

1. Introduction
Sewage sludge management obtained from centralized municipal wastewater treatment plants (WWTPs) has faced critical issues due to its growing amount over time, particularly in developing countries. Ho Chi Minh City (HCMC), Vietnam, for example, is a hub for commercial activities with around 8.5 million inhabitants; however, there is only one centralized municipal WWTP, namely Binh Hung, with a treatment capacity 141,000 m\textsuperscript{3}/day in Phase I. According to Decision No.24/QD-TTG dated January 06, 2010, of the Prime Minister approval of adjusting General Planning of Ho Chi Minh City Construction to 2025 \cite{1}, the average total volume of wastewater in the city to 2025 based on the average water supply per capita will reach from 3.15 to 3.2 million m\textsuperscript{3}/day, leading to the amount of sludge from the urban WWTP be up to 125 tons/day.
Sludge treatment is a costly process, accounting for 50-60% of the total wastewater treatment cost [2]. Therefore, treating sludge in HCMC has not been entirely resolved, although several measures are suggested, such as landfill disposal at Da Phuoc, assigning to subcontract for handling [3]. Unfortunately, Binh Hung WWTP’s operation continuously gives rise to foul odors, which annoys the neighbors [4] [5]. It is urgent work to propose appropriate solutions to tackle the problem.

According to Girovich [6], sludge disposal affects the environment and wastes a valuable resource because the composition of the sludge contains a high nutrient content and micronutrients, which can be used as organic fertilizer for agriculture. Application of sludge or biological solids (biosolids) raises the concern among scholars due to its fertilizer source from cheap raw materials and its sources of natural organic matter considered as organic fertilizer with a high content of total organic carbon and humus as well as nutrients such as nitrogen and phosphorus that plants readily absorb. Some benefits of biosolid reuse for soil quality improvement can be greater water-holding capacity, soil erosion reduction, increases in cation exchange capacity, earthworm and microbial activities, and correction of micronutrient deficiencies [7].

Although the sludge from municipal WWTP often contains toxic pollutants such as heavy metals, pathogenic microorganisms with content less than that of other hazardous and industrial wastes (Spinosa et al., 2011), commercial applications require adequate safety assessment, hefty metal accumulation. Several studies showed that the absorption of phytonutrients in the soil, in addition to nutrient absorption, there are potential risks of absorbing heavy metals such as cadmium, copper and zinc and pathogens, nematodes in soils that fertilize for grain products [8]. Additionally, Fu, et al. [9] claimed the existence of a variety of carcinogenic metals such as Cd, As, Cr, Hg, Pb in rice grains, while heavy metal residues were found in vegetables when using biosolids as fertilizer [10, 11]. This study is the subsequent work after assessing the benefits from the sludge treatment with biogas recovery and successfully applied to reduce the number of chemical fertilizers used by nearly 50% of the experiment on wet rice plants [12, 13]. In the current study, we aim to examine the effectiveness of organic fertilizer from biosolids on corn growth and heavy metal accumulation in the soil and some corn plants’ parts. This will be a scientific basis and a new direction in biosolids management applications in agriculture in efforts to reduce the number of chemical fertilizers used toward sustainable agriculture for Vietnam.

2. Materials and research methods

2.1. Experimental materials

Sewage sludge was obtained from Binh Hung municipal WWTP. Sludge samples were taken from a centrifugal water separator with pH = 7.54, C/N ratio = 16.67, and humidity = 78%. The sludge samples were mixed with smoked rice hull that was finely ground at the ratio of 2:1 [13] so that the C: N ratio can meet the desired conditions for the anaerobic reaction in 20-40 [14]. Once the weight of the substrate has been changed, their proportions will be accordingly changed. The moisture content of the mixture was kept at 65-70% [15] for optimal decomposition. The process of creating fertilizer studied is running under conditions of mesophilic temperatures (30-35°C) [14]. The fertilizer application at the rate of 1% and 3%, i.e., the corresponding amount of biosolids over the soil weight of the estimated 20cm deep surface. The chemical fertilizer used in the study is commercial fertilizer NPK (20:20:15) for soil dressing. The surveyed corn seed is LVN10 with an average yield of 65-75 quintals per ha.

2.2. Study area

The study conducts in a cornfield in Hoi Gia Hamlet, My Phong Commune, My Tho City, Tien Giang Province. The soil category is alluvial with moderate organic content (2.09%) and total protein (0.27%), insignificant $\text{Al}^{3+}$ and $\text{Fe}^{3+}$ contents. Generally, the soil is rich in clay and organic matter and is most favorable for agriculture.
2.3. Experimental design and methodology

The corn cultivation process and research contents are as follows:

| Days after planting | Growth stage          | Cultivation                                                                 | Indicator(s)                                      |
|---------------------|-----------------------|----------------------------------------------------------------------------|--------------------------------------------------|
| 0                   | Field preparation and planting | Soil preparation, making beds, and spraying herbicides to kill germs. Fertilizing the soil by biosolids and then sowing corn seed LVN10. | Heavy metal content in the soil.                  |
| 7                   | Germination            | Recording beds with more than 50% of plants have sprouts breaking the soil surface. Soil dressing by commercial fertilizer NPK for beds. | -                                                |
| 12                  | 3-6 leaves            | Recording beds with more than 50% of plants have 3-6 leaves                | Growth rate                                      |
| 26                  | 8-10 leaves           | Recording beds with more than 50% of plants have 8-10 leaves              | Growth rate                                      |
| 40                  | Silking               | Recording beds with more than 50% of plants have 12 leaves                | Growth rate, kernel count, and kernel weight     |
| 52                  | Blister               | Dimension measurement of stalks. Monitoring diseases. Plant height measurement. Ear height measurement. Harvest and measurements of mature corn ear number per plant, length of mature corn ear, the dimension of mature corn ear, kernel row number per ear, kernel number per row, and weight of 1000 kernels. | Kernel number and kernel weight                  |
| 61                  | Milk                  |                                                                             | Kernel number and kernel weight                  |
| 90                  | Maturity              |                                                                             | Corn yield and heavy metals                      |

The indicators for evaluating the growth rate and development degree rely on QCVN01-56:2011/BNNPTNT - National technical regulation on testing for Value of Cultivation and Use of Maize varieties, including plant height (cm), ear height (cm), mature corn ear number per plant, length of ripe corn (cm), the dimension of mature corn ear(cm), kernel row number per ear, kernel number per row and weight of 1000 kernels (g). The allowable limits of heavy metals in the soils and food area based on QCVN 03-MT:2015/BTNMT - National technical regulation on the permissible limits of heavy metals in the soil, and QCVN 8-22:2011/BYT - National technical regulation on the limits of heavy metals contamination in food, respectively.

Sample treatment and heavy metal analysis referred to the procedures of TCVN 6649:2000 (ISO 11466:1995) Soil quality - Insoluble elements in hydrothermal water, EPA Method 3051A - Microwave Assisted Acid Digestion of Sediments, Sludges, Soils, and Oil (the United States Environmental Protection Agency, 2014), EPA Method 6020B - Inductively Coupled Plasma—Mass Spectrometry, and make some modifications to fit the samples.

We employ Microsoft Excel 2013 software for descriptive statistics and IBM SPSS Statistics 20.0 software for assessing the differences with a significance level of 95%.

3. Result and discussion

3.1. Properties of biosolids after treatment

The concentration of N, P, K analyzed after incubation has the concentration close to TCVN 562: 2002/BNN & PTNT as follows:
Table 2. Nutrient content in biosolids

| Specie | Biosolids after incubation treatment | TCVN 562 |
|--------|-------------------------------------|----------|
| N      | 2.60 %                              | > 2.5 %  |
| P      | 1.32 %                              | > 1.5 %  |
| K      | 1.61 %                              | > 1.5 %  |

After incubation and treatment, the heavy metals contents decreased and were lower than the limit according to QCVN 03-MT:2015/BTNMT and EPA 503, as shown in Table 3.

Table 3. Heavy metals contents in the cultivation

| Specie | Sewage sludge (mg/kg) | After the mixing process (2:0.5 ratio) | After incubation treatment (2:0.5 ratio) | Treatment 1% | Treatment 3% | QCVN 03 | EPA 503 |
|--------|-----------------------|---------------------------------------|------------------------------------------|--------------|--------------|---------|---------|
| Pb     | 14.01                 | 10.51                                 | 7.88                                     | 0.08         | 0.24         | 70      | 300     |
| Cd     | 0.42                  | 0.32                                  | 0.25                                     | <1.00        | <1.00        | 1.5     | 39      |
| Cu     | 18.69                 | 14.02                                 | 13.30                                    | 0.13         | 0.40         | 100     | 1500    |
| Ni     | 6.98                  | 5.24                                  | 6.07                                     | 0.06         | 0.18         | -       | 420     |
| Zn     | 176.17                | 132.13                                | 101.36                                   | 1.01         | 3.04         | 200     | 2,800   |

3.2. Evaluation of the experimental corn quality and corn yield

Regarding the growth rate criteria, with increasing biosolids concentrations, the growth rate of corn plants is happening faster. The results showed that corn uses stored nutrients from seeds in the initial stage of growth (3-leaf corn). However, we can see clearly that the growth rate is significantly different at fertilizer concentrations of 0%, 1%, 3% when applying to the soil. By the stage of nutritional growth (corn plants reach 9-12 leaves), corn will assimilate nutrients from the soil and absorb CO₂ for photosynthesis.

Based on Figure 1, we can see that the growth rates of 1% and 3% concentrations have the metabolism but is still faster than the 0% concentration. This proves that the corn plant is growing well, and there is a difference between the concentrations of 0%, 1%, 3% when entering the real growth phase. At the concentration of 1% and 3% at the 8th week, more than 80% of the plants reached 12 leaves. As for the control sample, about 70% of plants achieved 12 leaves. Hence, the growth rate of 12 leaves in the control sample is slower than in the two samples, concentrations 1%, 3%.

Figure 1. Effect of biosolids concentration on growth time of corn seed LVN10
Table 4. Differences among plant height of samples with additional biosolids concentrations

| Sample              | Plant height (cm) | p-value |
|---------------------|-------------------|---------|
| Control (0%)        | 190.90            | -       |
| Treatment 1%        | 222.30            | 0.000(a) |
| Treatment 3%        | 226.28            | 0.000(b); 0.851(c) |

(a) Difference in plant height between treatment 1% and control;
(b) Difference in plant height between treatment 3% and control;
(c) Difference in plant height between treatment 3% and treatment 1%

Among the plant height of three samples, treatment 3% had the highest value (226.28 cm), followed by treatment 1% (222.30) and control (190.90). This means that the experimental biosolids with concentrations of 1%, 3% are suitable to stimulate the growth of corn plants. In terms of morphological indicators, there was a statistical difference in plant height between treatment 1% and control and treatment 3% and control with \( P = 0.000 < 0.05 \). Similarly, the whole results of corn yield factors in Table 5 revealed the highest values of additional biosolids 3% compared with additional biosolids 1% and control sample. An example of mature corn ear at the different biosolids concentrations is shown in Figure 2.

Table 5. Effects of additional biosolids concentrations on corn yield factors

| Indicator                        | Control sample | Treatment 1% | Treatment 3% |
|----------------------------------|----------------|--------------|--------------|
| Mature corn ear number (per plant) | 1.4            | 1.9          | 2            |
| Length of mature corn ear (cm)   | 27.86          | 28.11        | 30.18        |
| Dimension of mature corn ear (cm)| 4.09           | 4.11         | 4.31         |
| Kernel row number (per ear)      | 11.07          | 11.42        | 12.14        |
| Kernel number (per row)          | 21.5           | 23.5         | 29           |
| Weight of 1000 kernels (g)       | 329.3          | 330.34       | 334.78       |

Figure 2. Mature corn ears after harvest with fertilized biosolids at: (a) 0%; (b) 1%; (c) 3%

3.3. Assessment of heavy metal residues and accumulation

In order to assess the safety of biosolids reuse, the study measured the content of heavy metal accumulated in soils and mature corn ears after harvest, see Tables 6 and 7.

Table 6. Heavy metal contents in soils before and after harvest (mg/kg)

| Specie | Soil background concentration | Treatment 1% | Treatment 3% | Treatment 1% after harvest | Treatment 3% after harvest | QCVN 03 |
|--------|-------------------------------|--------------|--------------|----------------------------|----------------------------|---------|
| Cu     | 21.95                         | 0.13         | 0.40         | 22.00                      | 22.78                      | 100     |
The results in Table 6 have demonstrated that heavy metal accumulation in soils was not significant, lower than the allowance standard. However, the study should keep tracking the stacks in the next seasons for a better assessment. For heavy metal residues in parts of the corn plant after harvest in Table 7, the results revealed Zn content accumulates most in roots, followed by in ear, in leaves, and the stalk. Zn supports the synthesis of growth substances and yeast systems necessary for plant growth [16]. Thus the highest accumulation of Zn in roots makes sense. The highest value was found in leaves for Cu accumulation, followed by roots, stalk, and ear. The accumulation of a high level of Cu in the leaves helps in chlorophyll formation in the plant. Other accumulations of Cd, Pb, Ni are not significant. Overall, the accumulations of heavy metals in corn plant parts are at the safety threshold.

| Specie | Roots | Stalk | Leaves | Mature corn ear | QCVN 8 |
|--------|-------|-------|--------|----------------|--------|
| Cu     | 1.03  | 2.93  | 2.38   | 2.91           | 1.46   |
| Cd     | 0.01  | 0.01  | 0.02   | 0.02           | 0.03   |
| Pb     | 0.06  | 0.03  | 0.05   | 0.03           | 0.09   |
| Zn     | 8.37  | 10.31 | 1.06   | 2.62           | 5.35   |
| Ni     | 0.55  | 0.28  | 0.53   | 0.61           | 0.44   |

4. Conclusion
At concentrations of 3% and 1% of experimental biosolids used, there was no inhibition but growth stimulation for corn seed LVN10. The yield and quality of surveyed corn after harvest are higher than that of the sample control and the reference yield. Heavy metal contents in soils and biosolids after treatments are lower than the standard QCVN 03-MT:2015/BTNMT, although it appears an accumulation of Cu and Zn in soils with additional biosolids 1% and 3%. In corn plant parts, Zn accumulated most in roots, while the highest value of Cu was found in leaves. The accumulations of heavy metals in corn plants are at the safety threshold, but the study should keep tracking the accumulations in the next seasons for a better assessment. The findings in this study tackle the problem of odor annoyance of WWT system from sewage sludge partly as well as propose a new direction in applications of biosolids management in agriculture to minimize chemical fertilizers use toward sustainable agriculture for Vietnam. Although the research is still undergoing different stages, its benefits of economy and environment are promising.

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