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Evaluation of struvite obtained from semiconductor wastewater as a fertilizer in cultivating Chinese cabbage

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ABSTRACT

The present work evaluated the fertilizing value of struvite deposit recovered from semiconductor wastewater in cultivating Chinese cabbage. The fertilizing effect of struvite deposit was compared with that of commercial fertilizers: complex, organic and compost. Laboratory pot test results clearly showed that the growth of Chinese cabbage was better promoted when the struvite deposit was used than with organic and compost fertilizers even though complex fertilizer was the most effective in growing Chinese cabbage. It was revealed that potassium (K) was a key element in the determination of growth rate of Chinese cabbage. Also, the abundant nutrients such as nitrogen (N), phosphorus (P), K, calcium (Ca) and magnesium (Mg) were observed in the vegetable tissue of struvite pot. Specifically, P was the most-founded component in the vegetable tissue of struvite pot. Meanwhile, the utilization of struvite as a fertilizer led to the lowest accumulation of copper (Cu) and no detection of cadmium (Cd), arsenic (As), lead (Pb) and nickel (Ni) in the Chinese cabbage. It was found that the optimum struvite dosage for the cultivation of Chinese cabbage was 1.6 g struvite/kg soil. Based on these findings, it was concluded that the struvite deposits recovered from semiconductor wastewater were effective as a multi-nutrient fertilizer for Chinese cabbage cultivation.

1. Introduction

Semiconductor wastewater generally contains the high levels of ammonium (NH_4) and phosphate (PO_4). It is well known from the previous studies that struvite precipitation is very effective in the removal of ammonium and phosphate of semiconductor wastewater. In field-scale study, Ryu et al. [1] showed that struvite precipitation brought about a high NH_4–N removal efficiency of over 89% on average. Also, it was reported that NH_4–N removal can be enhanced up to 98% by increasing mixing speed in lab-scale study [2]. Moreover, the study of Warmadewanthi and Liu [3] revealed that the removal and recovery of PO_4–P and NH_4–N from semiconductor wastewater as struvite is feasible. Some studies also presented that struvite precipitation by the dissolved CO_2 degasification technique resulted in the effective removal of NH_4–N and PO_4–P [4,5].

However, a considerable amount of struvite produced as a by-product during the removal of ammonium and phosphate has caused another problem of waste disposal. A feasible solution to the problem would be its reuse as a fertilizer because struvite is composed of magnesium (Mg), ammonium and phosphate in equal molar concentrations. The previous study showed that struvite was preferred as a good fertilizer in agriculture for its slow-release rate and much lower impurity [6]. Especially, the presence of Mg in struvite makes it more attractive as an alternative to contemporary fertilizers for a few crops, like sugar beets, that require magnesium [7]. Moreover, since struvite is slightly soluble in water and soil solutions, slow-release struvite has been found to be a highly effective source of phosphorus, nitrogen and magnesium for plants through both foliar and soil application.

Although struvite has been qualified as a fertilizer, as mentioned above, to the best of our knowledge, the plant availability and fertilizer value of struvite precipitate obtained from semiconductor wastewater was never tested before. Such reason for lack of study may be attributable to the fact that semiconductor wastewater commonly contains many refractory chemicals such as organic solvents, acids, bases, salts, heavy metals, fine suspended oxide particles and other organic and inorganic compounds [8,9].

The present study was therefore aimed at investigating the feasibility of the plant availability of nutrients recovered from semiconductor wastewater by struvite precipitation. Specifically,

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Table 1
Characteristics of raw semiconductor wastewater.

Parameter	Concentration range
Total chemical oxygen demand (TCOD) (mg/L)	221–444
Soluble chemical oxygen demand (SCOD) (mg/L)	67–136
Total Kjeldahl nitrogen (TKN) (mg/L)	106–171
Total phosphorus (T-P) (mg/L)	5–402
pH	2.4–4.3
Cations	
NH_4–N (mg/L)	80–250
Mg (mg/L)	1.4–2.0
Ca (mg/L)	6.2–11.6
Na (mg/L)	6.0–40.1
K (mg/L)	9.0–49.0
Anions	
PO_4–P (mg/L)	5–388
F (mg/L)	75–799
SO_4 (mg/L)	3.7–6.4
Cl (mg/L)	6.9–9.9
NO_3–N (mg/L)	1.6–2.8

Table 2
Composition of struvite deposit and commercial fertilizers used in agricultural tests.

Elements	Nutrient source		
	Complex fertilizer	Organic fertilizer	Struvite
N	11	5.0	13.2
O	–	–	36.1
Na	–	–	1.3
Mg	4	9.3	8.2
Si	14	–	0.7
P	6	0.4	12.7
K	6	0.9	4.6
Ca	20	13.3	2.5
B	0.1	–	–
C	–	–	19.1
F	–	–	1.4
Fe	–	–	4.8

Note: all indicated figures are based on weight percent (wt.%).
Note: in this table, compost fertilizer was not included and its composition can be found in the text.

objectives of this study were: (1) to characterize precipitated struvite obtained from a real semiconductor wastewater treatment plant; (2) to evaluate the fertilizing value of struvite precipitate with pot trial tests for cultivation of Chinese cabbage by comparing it with commercial fertilizers; (3) to determine the optimum dosage of struvite precipitate for cultivation; and (4) to analyze the levels of nutrients and heavy metals in vegetables tissue grown with struvite and other fertilizers.

2. Materials and methods

2.1. Collection of struvite

The struvite deposit for experiments were obtained from a semiconductor wastewater treatment facility (SWTF) located in Cheongju, Republic of Korea, where struvite precipitation has been employed to remove ammonia nitrogen (NH_4–N) and orthophosphate (PO_4–P) from wastewater as illustrated in Fig. 1. The SWTF handled a quantity of 500 m^3 of wastewater per day. Table 1 shows the composition of semiconductor wastewater treated in that facility. The wastewater contained significantly high concentrations of NH_4–N and PO_4–P. Raw semiconductor wastewater with an average influent ammonium nitrogen concentration of 154 mg/L was continuously pumped to the equalization basin. In the chemical mixing tank, $MgCl_2 \cdot 6H_2O$ was added to reach the 1:1:1 molar ratio of NH_4–N:Mg:PO_4–P for struvite formation. Additionally, the pH of the wastewater was adjusted to 9 by the continuous addition of 5 N NaOH. Then the liquid stream was moved to the struvite reaction tank to facilitate the formation of struvite. The mixing speed in both the chemical mixing tank and the struvite reaction tank was 250 rpm. The struvite deposit was allowed to settle in the intermediate settler. A part of the settled struvite deposit was collected and used as a multi-nutrient fertilizer for cultivating Chinese cabbage in our experiments. The effluent from the intermediate settler flowed into the fluoride removal tank. Fluoride was finally precipitated into CaF_2 by adding $CaCO_3$ to the final settler. In the facility, the effluent ammonium nitrogen (NH_4–N) concentration was about 17 mg/L and its removal efficiency was 89% on average with the standard deviation of 6% during the experimental period. The collected struvite deposit was dried in the shade at room temperature for 7 days before being used in pot trial tests.

2.2. Pot trial tests: evaluation of collected struvite as a fertilizer

The fertilizing potential of struvite was evaluated by comparing it with that of popular Korean commercial fertilizers: complex, organic, and compost. The compositions of struvite deposit and each commercial fertilizer are given in Table 2. The compost fertilizer was consisted of 5% organic matter, 0.1% nitrogen, 1.0% NaCl and less than 50% of water in weight percent. For the complex fertilizer, N, P, K, and Ca existed in the forms of $(NH_4)_2HPO_4$, K_2SO_4 and $Ca(NO_3)_2$, respectively.

Raw soil samples were taken from a local mountain in Cheongju and dried at room temperature for 15 days. The dried soil was sieved with maximum 1.2 cm prior to filling them in each pot. The soil classification was sandy loam and it was composed of 54.6% of sand,

Table 3
Characteristics of soil used in our experiments.

Items	T-N	T-P	K_2O	CaO	MgO	TCOD	TOC[a]
Concentration (g/kg soil)	0.908	0.572	0.151	0.286	0.048	6.9	4.2

[a] TOC indicates total organic carbon.

Table 4
Concentration of heavy metals in soil, commercial fertilizers and struvite.

Items	Heavy metals (mg/kg)							
	Cd	Cu	As	Hg	Pb	Cr	Zn	Ni
Soil	0.037	0.201	n.d.	n.d.	0.599	0.216	1.750	0.108
Complex fertilizer	0.038	0.452	0.156	n.d.	0.005	3.064	2.711	4.437
Organic fertilizer	0.036	4.028	n.d.	n.d.	0.157	0.398	8.843	0.229
Compost fertilizer	0.008	0.241	n.d.	n.d.	0.022	0.098	0.139	0.044
Struvite	0.046	0.582	n.d.	n.d.	0.004	0.275	0.617	0.217

n.d., not detected.

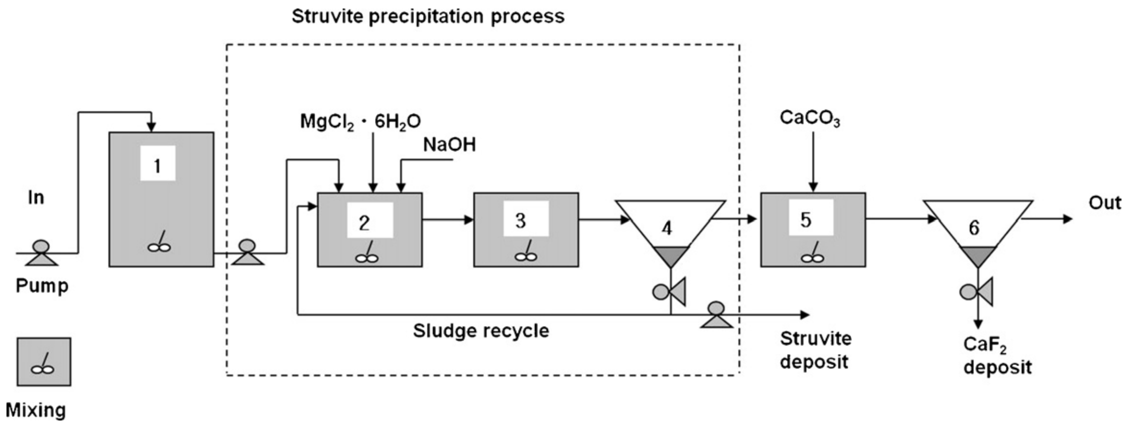

Fig. 1. A schematic of semiconductor wastewater treatment facility: (1) Equalization basin; (2) Chemical mixing tank; (3) Struvite reaction tank; (4) Intermediate settler; (5) Fluoride removal tank; (6) Final settler.

33.3% of silt and 12.1% of clay. The soil pH was 5.3. Other important soil characteristics are provided in Table 3. The concentrations of heavy metals in soil, commercial fertilizers and struvite are also presented in Table 4.

Five sets of three pots, for a total of 15 plastic pots, were prepared. Each plastic pot had 9 cm surface diameter and approximately 8 cm of working depth. 320 g of sieved soil was mixed with respective fertilizer sources and added to each pot. One set of three pots was used as control in which no fertilizer source was added. In other four sets, three commercial fertilizers and struvite deposit were added to achieve an equivalent concentration of 110 kg N/ha, respectively. This application rate was chosen based on a scientific recommendation made by the National Academy of Agricultural Science of Korea in growing lettuce. The amount of fertilizer needed to reach 110 kg N/ha was 0.30, 0.66, 33.00, 0.25 g for complex, organic, compost, and struvite deposit, respectively.

The pot trial tests were performed at room temperature. Fluorescent lightening was continuously supplied to the plants in order to maintain the specific intensity of illumination. Illuminances measured during the experimental period were between 5770 and 5850 lux (lx). Three seeds of Chinese cabbage were planted within the top 1.5 cm of soil in each pot. The room temperature of laboratory was 18.3 °C on average with the standard deviation of 1.5 °C during the experimental period. 25 mL of distilled waster was added in each pot every 2 days. Length of leaves was periodically recorded in each pot. After 32 days the plants were harvested from each pot and weighed before and after drying (in an oven set at 105 °C for 24 h) to determine their fresh and dry weight. As conducted by Li and Zhao [10], the Chinese cabbages were sprayed with distilled water to wash the dust off prior to harvesting. The level of heavy metals and nutrients in dry vegetables were also analyzed.

2.3. Pot trial tests: determination of optimum struvite dosage

The optimum struvite dosage for cultivating Chinese cabbage was determined. Six sets of three pots were filled with 250 g of sieved soil and struvite dosages of 0, 0.1, 0.2, 0.3, 0.4 and 0.5 g, which are equivalent to concentrations of 0, 0.4, 0.8, 1.2, 1.6 and 2.0 g struvite/kg soil, respectively. Three seeds of Chinese cabbage were sowed within the top 1.5 cm of soil in each pot. The room temperature was 19.0 °C on average with the standard deviation of 2.0 °C during the experimental period. Fluorescent lightening was also supplied to the plants in order to maintain the intensity of illumination. Illuminances were between 5670 and 5780 lux (lx). 25 mL of distilled waster was added in each pot every 2 days. Length of leaves was periodically recorded for each pot. After 42 days the plants were harvested and weighed to determine their fresh and dry weight.

2.4. Analytical procedures

Total chemical oxygen demand (TCOD) and soluble chemical oxygen demand (SCOD) (standard code: 5220 D), total Kjeldahl nitrogen (TKN) (standard code: 4500-N B), and PO_4–P (standard code: 4500-P E) in all samples were analyzed by the Standard Methods [11]. NH_4–N and total phosphorus (T-P) were analyzed using DR4000 spectrophotometer with relevant Hach regents as provided by the Hach manual (Hach Company, USA). Mg, Ca, Na, K, F, SO_4, and Cl in raw semiconductor wastewater were measured using a DX-100 ion chromatograph (Dionex, USA).

For soil characteristics analysis, 10 g of sieved soil sample was placed in a 100 mL Pyrex tube containing 50 mL of 0.1 N HCl. The mixture was heated at 100 °C for 1 h. After the temperature cooled down naturally, 10 mL of 5% HNO_3 was added into the tube and mixed using a vortex. The mixture was then centrifuged at 1448 × g for 15 min. The supernatant was filtered with 0.45 μm membrane filter. Then T-N, T-P, K_2O, CaO, MgO and organic carbon (as COD) were analyzed. T-N (standard code: 4500-N) was determined according to the procedure described in Standard Methods [11]. The analyses of K_2O, CaO and MgO were performed by inductively

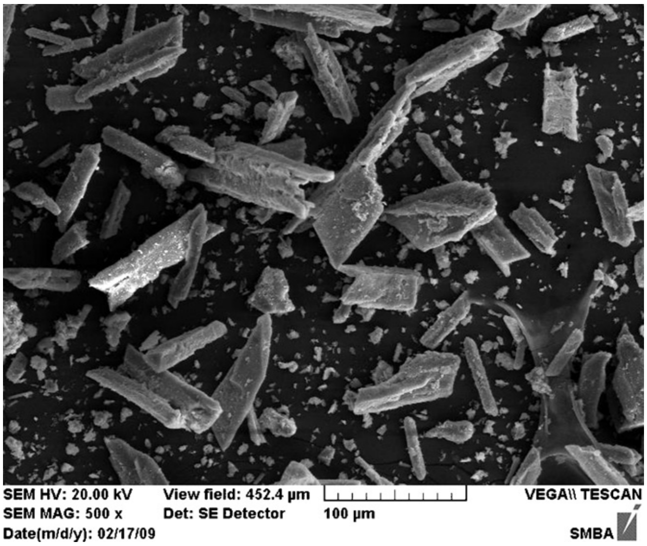

Fig. 2. SEM image (×500) of the precipitated matters obtained from SWTF.

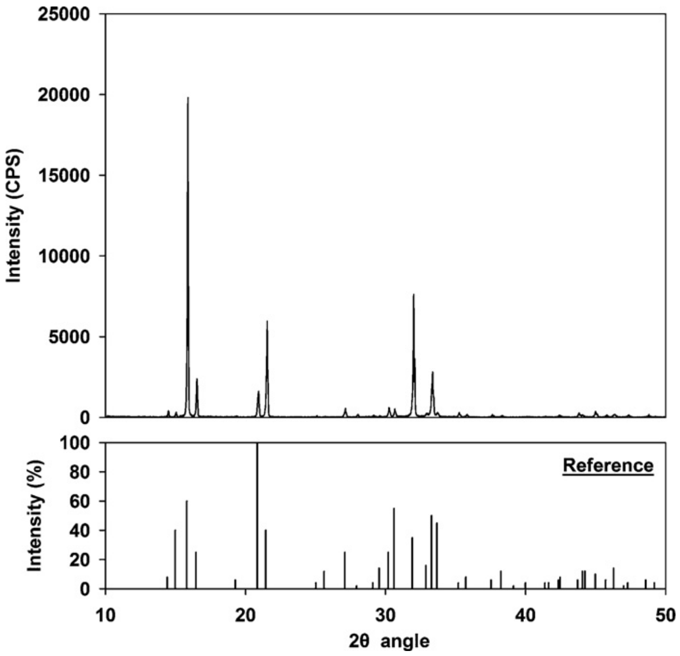

Fig. 3. XRD diffractograms of the precipitated matters.

coupled plasma-atomic emission spectrometry (ICP-AES 3300DV, PerkinElmer, USA).

Heavy metals, which are contained in dry vegetable, were also measured by ICP-AES (PerkinElmer, USA) after acidic digestion. In digestion, the dry vegetable samples were placed in a Pyrex tube containing 4 mL of conc. HNO_3. The mixture was heated at 200 °C until dry. After the temperature cooled down naturally, 20 mL of 5% HNO_3 was added into the tube and heated at 50 °C for 20 min. When the sample temperature was cooled down to room temperature, the solution in each tube was evaluated using ICP-AES. The minimum detection limit of ICP-AES for measuring Cd, Cu, As, Hg, Pb, Cr, Zn and Ni was 0.002, 0.001, 0.0002, 0.0909, 0.004, 0.002, 0.0015 and 0.003 mg/L, respectively.

The compositions of commercial fertilizers and dried struvite deposits were analyzed using energy dispersive analysis (EDS) of X-rays. Additionally, X-ray diffraction (XRD, Model DMS 2000 system, SCINTAG) was used to further characterize the dried struvite deposit obtained from semiconductor wastewater. The crystal morphology of the struvite deposit was also observed using a scanning electron microscopy (SEM, Leica Stereosacan 440)

3. Results and discussion

3.1. Characteristics of struvite deposit

To determine the morphology, the obtained precipitated matters were examined by SEM and the SEM micrograph is illustrated in Fig. 2. The crystal size of struvite deposit was widely distributed in the range 100 μm.

XRD analysis was also used to characterize the purity of struvite deposits collected from SWTF. The X-ray diffractograms exhibited several peaks indicative of the struvite presence as illustrated in Fig. 3. The XRD pattern generated from the precipitated matters matched with the database model for struvite, i.e., position and intensity of the peaks. The high purity of struvite deposits would be due to the high NH_4–N removal of 89%. In the study of Diwani et al. [12], where NH_4–N was recovered from industrial wastewater treatment, XRD diffractogram showed the highest peaks when NH_4–N recovery was highest.

3.2. Fertility evaluation of struvite deposit

The obtained struvite deposits were utilized in cultivation tests and compared with that of commercial fertilizers to asses its

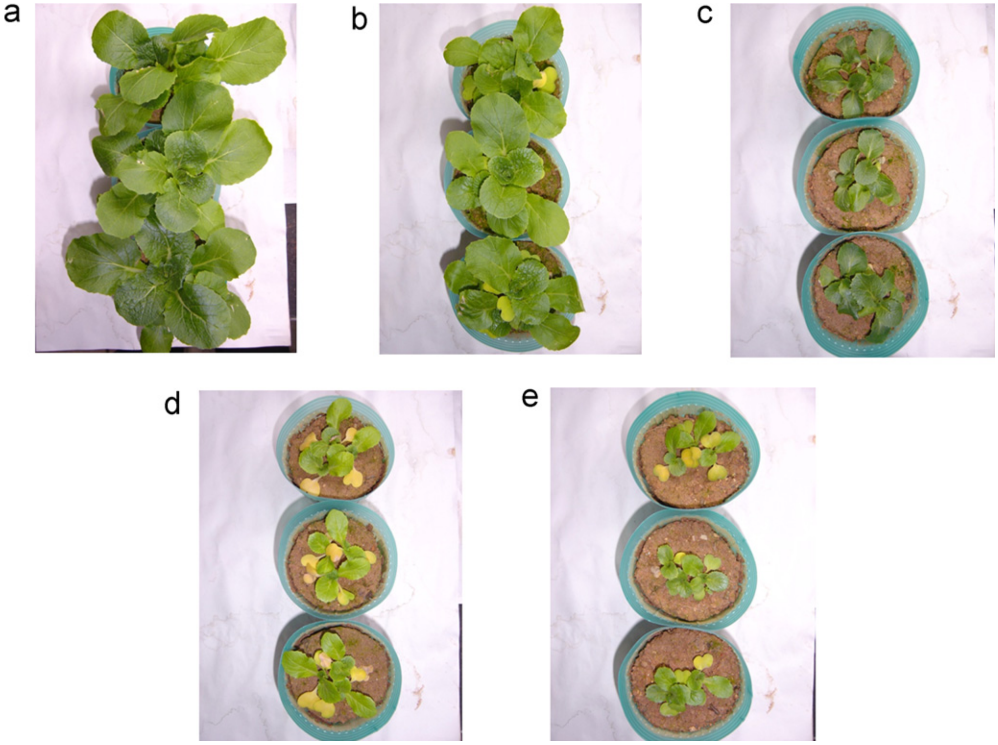

Fig. 4. Growth status of Chinese cabbage on 32nd days depending on fertilizing sources: (a) Complex fertilizer; (b) Struvite; (c) Organic fertilizer; (d) Compost fertilizer; (e) Control.

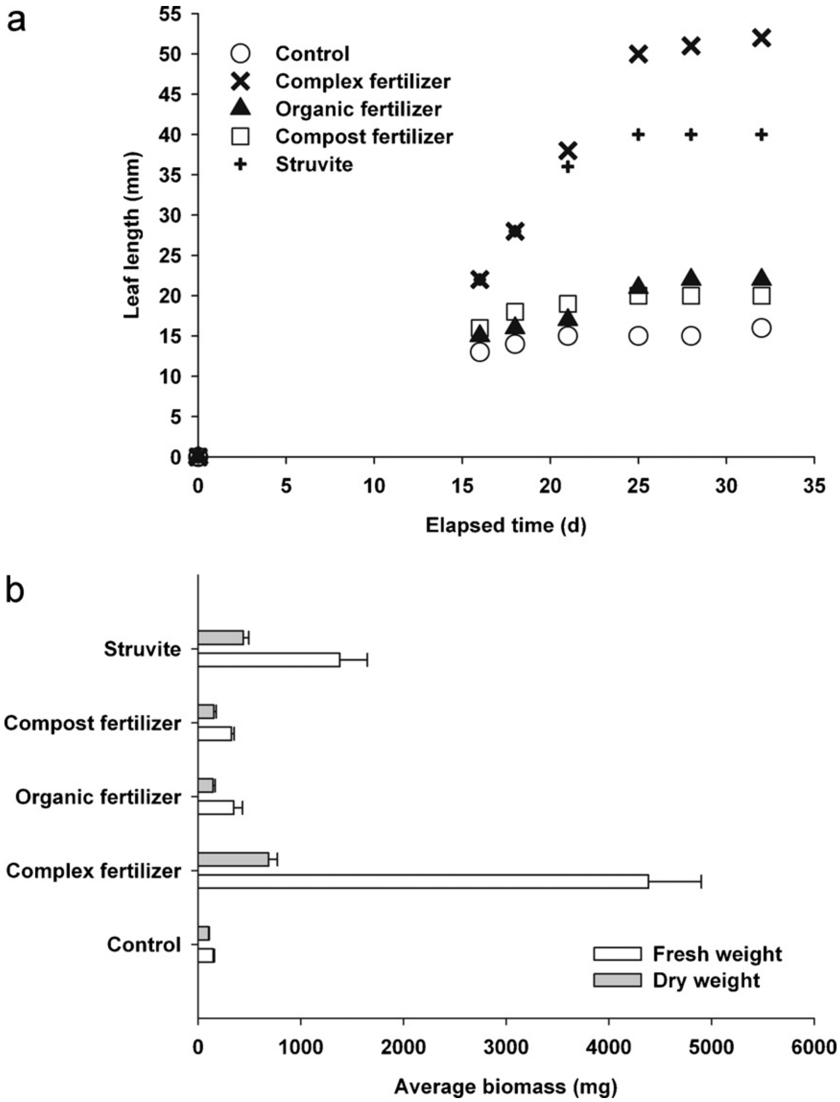

Fig. 5. Temporal variation of leaf length (a) and fresh and dry weight of Chinese cabbage after 32 days growth (b) depending on fertilizing sources: error bars indicate standard deviation.

fertility. During the experimental period of 32 days, the tallest leaf in each pot was selected and measured. The agricultural tests showed that the Chinese cabbage grew at different rates depending on fertilizers as illustrated in Fig. 4. The Chinese cabbages in the struvite pots showed the second highest growth rate (see Fig. 4b). The best growth rate was observed in the complex fertilizer pots (see Fig. 4a). On 32nd days, the average leaf length of Chinese cabbage in control, complex, organic, compost and struvite pots reached 16, 52, 22, 20 and 40 mm, respectively, as presented in Fig. 5a. After 32 days, the plants from each pot were harvested and weighed before and after drying to determine their fresh and dry weights. As evident from Fig. 5b, it was clear that the addition of struvite significantly increased the average fresh and dry weights of Chinese cabbage than control. It is well documented by previous studies that the vegetables grown in struvite pots have had much higher growth rates than control pots (without addition of external nitrogen and phosphorus) [10,12–14]. Also, the average fresh and dry weights of Chinese cabbage in struvite pots ranked second in the experimental group. The fresh and dry weights of Chinese cabbage decreased in order of complex fertilizer > struvite > organic fertilizer > compost fertilizer > control pot. This finding is further supported by data in Fig. 5a, where the longest leaf was also found in the same order. The growth order of Chinese cabbage mentioned above would be related to a difference in the amount of potassium (K). Fig. 6 clearly illustrated that the growth rates of leaves were determined by the amount of K rather than phosphorus (P), magnesium (Mg) and calcium (Ca). The amounts of K in fertilizing sources decreased in order of complex fertilizer > struvite > organic fertilizer > compost fertilizer > control pot and the growth rates of leaves were affected by the applied dosage of K (see Fig. 6a). It is believed that P and Mg are not major contributors to the best growth in complex fertilizer pots because their concentrations were higher in struvite pots than in complex fertilizer pots as shown in Table 5. Ca was also found in the highest concentration in organic fertilizer pots (see Table 5). When considering these facts, it is crystal clear

Table 5
Nutrient concentrations applied to the pots of struvite and commercial fertilizers.

Pot	Added nutrients (mg/kg soil)			
	P	K	Mg	Ca
Complex fertilizer	628	182	66	392
Struvite	671	161	93	224
Organic fertilizer	580	144	221	479
Compost fertilizer	572	125	29	204
Control	572	125	29	204

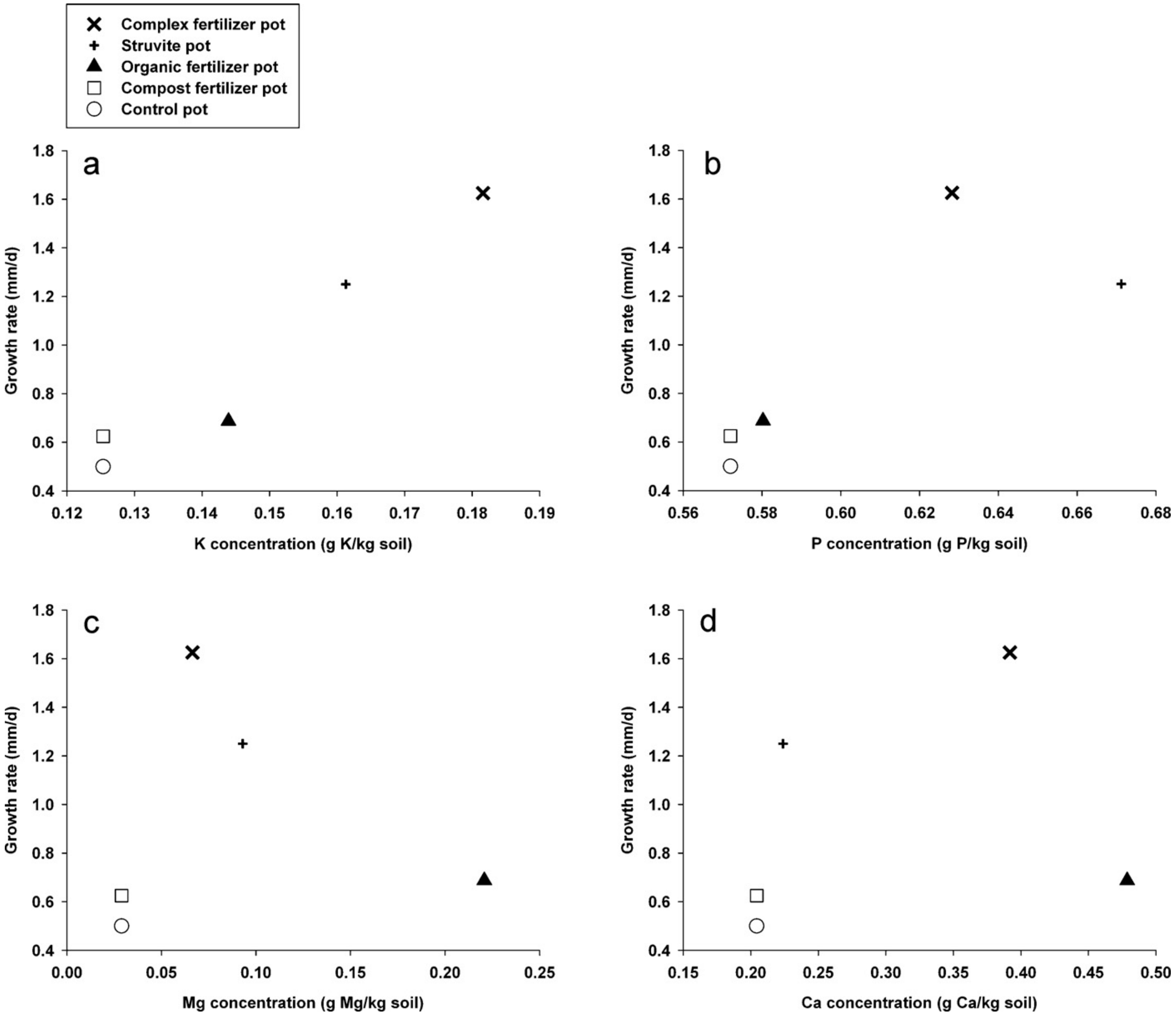

Fig. 6. Leaf growth rate of Chinese cabbage as a function of the concentration of K (a), P (b), Mg (c) and Ca (d).

that the lower growth of Chinese cabbage in struvite pots than in complex fertilizer pots was not due to the lack of P, Mg and Ca, but rather caused by the lack of K. It is inferred that K found in struvite deposits would be present as a potassium magnesium phosphate ($KMgPO_4{\cdot}6H_2O$, struvite-K) which can be formed as a by-product material in the process of struvite precipitation when considering that the raw semiconductor wastewater contains K in the range of 9.0–49.0 mg/L as shown in Table 1. Struvite-K crystal is the natural potassium equivalent to struvite [15]. The previous studies support our experimental finding. From a previous study by Wilsenach et al. [16], it was reported that struvite as well as struvite-K were successfully precipitated from source separated urine through struvite precipitation. Furthermore, Sun et al. [17] also reported that the simultaneous precipitation of struvite and struvite-K was observed in goats during onset of urolithiasis.

The heavy metal levels were also compared to evaluate the accumulation degree of heavy metals in Chinese cabbage tissue. Table 6 presents that heavy metals including copper (Cu), mercury (Hg), chromium (Cr) and zinc (Zn) were contained in all samples, whereas cadmium (Cd), arsenic (As) and nickel (Ni) were not detected. Similarly, no detection of Cd and As in application of struvite to vegetable cultivation was reported in the previous study in which struvite recovered from landfill leachate was used in growing vegetables [10]. For Cu, its concentration in struvite pots was significantly lower than those in other pots. Additionally, lead (Pb) was not detected in struvite pots although it was found in compost fertilizer and control pots. The reason why Cu in struvite pots was significantly lower than in commercial fertilizer pots is not yet clear. However, one possibility is that Cu could exist as combined materials, such as $CuCO_3(s)$ and $Cu(OH)_2(s)$, in alkaline soil

Table 6
Concentration of heavy metals in dried Chinese cabbage.

Pot	Heavy metals (mg/kg dry vegetable)							
	Cd	Cu	As	Hg	Pb	Cr	Zn	Ni
Control	n.d.	14.0	n.d.	0.09	3.2	1.5	104.7	n.d.
Complex fertilizer	n.d.	22.0	n.d.	0.79	n.d.	1.8	113.0	n.d.
Organic fertilizer	n.d.	10.8	n.d.	0.97	n.d.	1.5	85.5	n.d.
Compost fertilizer	n.d.	11.5	n.d.	0.45	3.4	0.8	58.1	n.d.
Struvite	n.d.	7.2	n.d.	0.70	n.d.	1.1	121.0	n.d.

n.d., not detected.

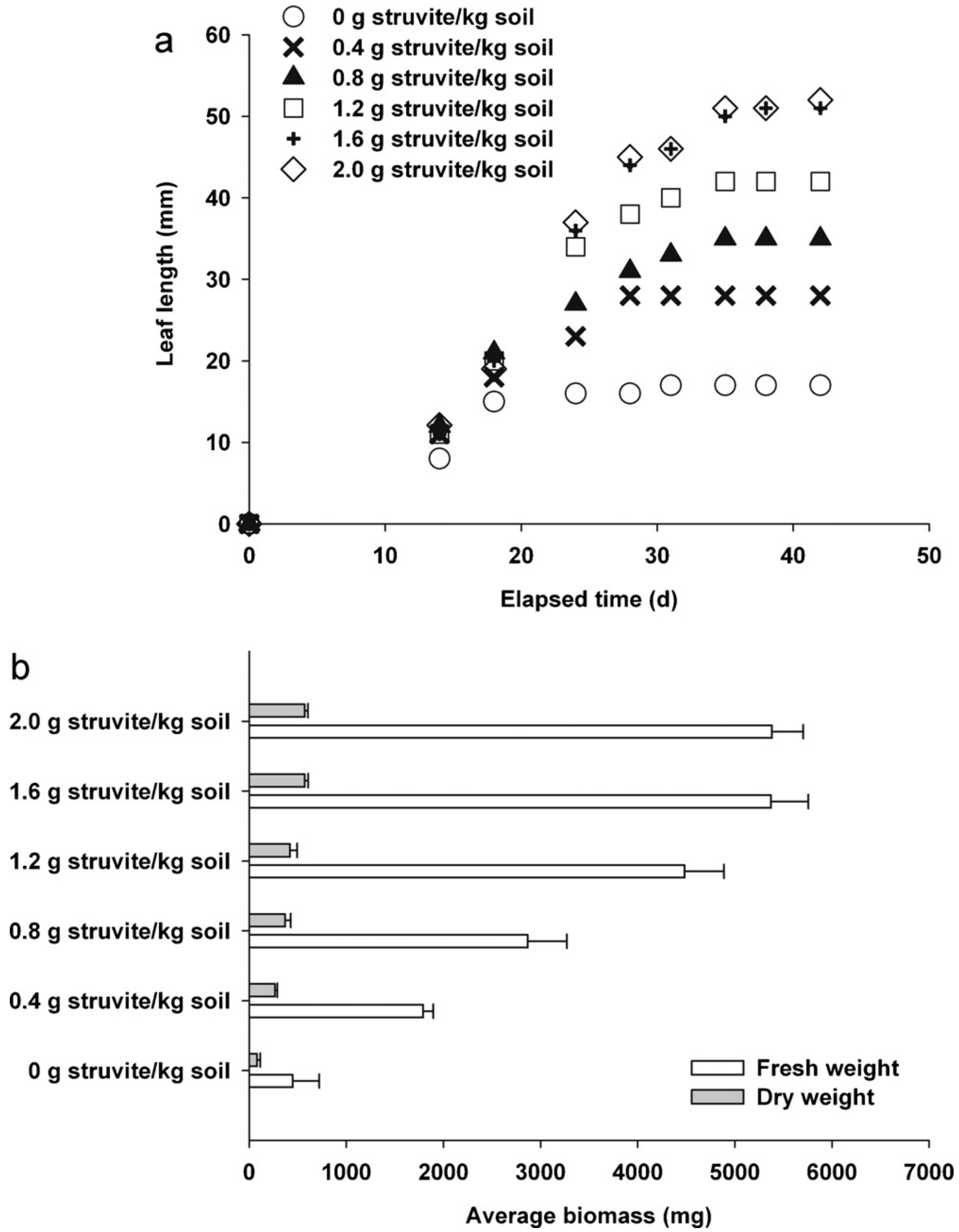

Fig. 7. Temporal variation of leaf length (a) and fresh and dry weight of Chinese cabbage after 42 days growth (b) as a function of applied struvite dosage: error bars indicate standard deviation.

solution, as reported in the previous study [18]. For Hg, its concentration in struvite pots was slightly higher than that in compost fertilizer and control pots, but was lower than that in complex and organic fertilizer pots. For Cr, its level in struvite pots was lower than that in other pots, except for compost fertilizer pots. In case of Zn, struvite pots had the highest concentration in all tested pots. In summary, Cu in struvite pots was lower than in commercial fertilizer pots. In addition, Cd, As, Pb and Ni concentrations were below the detection limit in the Chinese cabbage tissue from the struvite pots. Moreover, it is noticeable that the concentrations of Cu, Hg and Cr in struvite pots were lower than those in complex fertilizer pots even though the growth rate of Chinese cabbage in struvite pots was slower than that in complex fertilizer pots (see Fig. 5). The test data of accumulated heavy metal in Chinese cabbage indicates that the cultivation of Chinese cabbage with struvite deposit recovered from semiconductor wastewater could be safe despite that semiconductor wastewater commonly contains many refractory chemicals such as heavy metals [8,9].

Meanwhile, the availability of nutrients from struvite and commercial fertilizers was estimated by investigating nutrients contained in the tissue of Chinese cabbage. Data in Table 7 shows

Table 7
Concentration of nutrients in dried Chinese cabbage.

Pot	Nutrients (mg/kg dry vegetable)				
	T-N	P_2O_5	K	Ca	Mg
Control	14,200	3572	10,538	3918	102
Complex fertilizer	45,616	8097	47,001	24,816	953
Organic fertilizer	15,300	3964	16,781	12,331	145
Compost fertilizer	16,000	4256	13,438	4261	156
Struvite	17,688	12,422	18,461	5306	831

that the harvested leaves from struvite pots contained relative high concentration of N, P, K, Ca and Mg. The control pots had the lowest concentration of N, P, K, Ca and Mg compared to other pots. It is interesting to observe that P concentration in struvite pots was much higher than that in commercial fertilizer pots. Much more uptake of P in struvite pots would be explained by the fact that P source applied to the struvite pots was the highest level as found in Table 5. Furthermore, it should be noted that the order of amount of K found in the vegetable tissue is identical with that shown in Table 5 where the added amounts of K decreased in order of complex fertilizer > struvite > organic fertilizer > compost fertilizer > control pot. This fact could additionally prove that the growth rates of leaves were determined by the amount of K rather than phosphorus (P), magnesium (Mg) and calcium (Ca).

3.3. *Effect of struvite dosage on Chinese cabbage cultivation*

The optimum struvite dosage for cultivating Chinese cabbage was determined. During the experimental period of 42 days, the leaf length of Chinese cabbage was periodically measured. Fig. 7a illustrates that the leaf length of Chinese cabbage increased as the struvite dosage increased from 0 to 1.6 g struvite/kg soil. However, no additional growth was observed when struvite dosage was increased over 1.6 g struvite/kg soil. Similar trend was also observed in the Chinese cabbage biomass based on fresh and dry weight as shown in Fig. 7b. The heaviest wet and dry weight was found to be 5373 and 573 mg at 1.6 g struvite/kg soil. The test results of wet and dry weight show that increasing struvite dosage up to 1.6 g struvite/kg soil has positive effect on biomass, but ineffective beyond that. These findings were supported by the study of Li and Zhao [10]. They explained that increasing the amount of struvite, which is recovered from landfill leachate, could further stimulate the growth of water convolvulus.

4. Conclusions

Struvite recovered from semiconductor wastewater was applied in cultivation of Chinese cabbage. The fertilizing value of struvite was evaluated by comparing it with commercial fertilizers by pot trial tests. Furthermore, the optimum struvite dosage was determined. Based on the experimental results, the following conclusions were drawn:

(1) The capability of struvite as a fertilizer far surpassed other fertilizers except for complex fertilizer during the experimental period of 32 days. Also, it was revealed that the growth rate of Chinese cabbage was controlled by the amount of potassium.
(2) In the investigation of heavy metal effects on the Chinese cabbage growth, the application of struvite resulted in the lowest accumulation of Cu in vegetable tissue among the tested fertilizing sources. Moreover, Cd, As, Pb and Ni were not even detected in struvite pots.
(3) It was found that the struvite source provided the essential crop nutrients of N, P, K, Ca and Mg for Chinese cabbage as much as other commercial fertilizers. Specifically, much more amount of P was observed in the vegetable tissues of struvite pots.
(4) It was revealed that the Chinese cabbage growth rate increased as struvite dosage increased. The optimum dosage was 1.6 g struvite/kg soil and any additional dosage over the optimum amount did not cause more growth of Chinese cabbage.
(5) Consequently, it was proved that struvite deposits, recovered from semiconductor wastewater were effective as a multi-nutrient fertilizer in cultivating Chinese cabbage.

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