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Effects of Sewage Sludge at different pH Levels on *Ipomoea Aquatica*

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Abstract

An experiment was conducted to study the effects of sewage sludge on the response of *Ipomoea aquatica* to plant nutrients and heavy metals in soil at different soil pH. An incubation study was done for the selection of four individual pH levels, *viz.*, 4.7, 5.7, 6.6 and 7.8 to be used for the plant culture experiment. Yield of *Ipomoea aquatica* and concentration and uptake of N, P, K, Ca, Mg, Cd, Cu, Fe, Mn and Zn in the plant were evaluated. Application of sewage sludge in soil increased the concentration and uptake of the elements in *Ipomoea*. Slightly acidic to slightly alkaline pH was found to be better for amendment of soil with sewage sludge.

Key words : Sewage sludge, pH, *Ipomoea aquatica,* Accumulation, Uptake.

Introduction

Bangladesh is an agrarian country and agriculture is the backbone of our national economy. The soils of Bangladesh are generally poor in quality so far the fertility status is concerned. To increase soil fertility, commercial fertilizers have been used in agriculture for a long period. Sewage sludges are also used in agriculture because they act as a fertilizer. Agricultural use of sewage sludge has been increasingly favored as a means of disposal and beneficial use (Sikder *et al.* 2007). Land application of sewage sludge can both have beneficial and harmful effects. Growing crops may use its nutrients such as N, P, K, Ca, Mg etc., micronutrients and organic matter. It also improves the physical, chemical and biological conditions of soil with no danger, in short or medium term, to the environment as well as to the crops (White *et al.* 1997; Aggelides and Londra 2000; Benitez *et al.* 2001; Selivanovskaya *et al.* 2001; Sikder *et al.* 2007). However, the presence of heavy metals and organic pollutants in sewage sludge can result in phytotoxic effects, soil and water contamination and accumulation of heavy metals in food supplies (Keller *et al.* 2002; Yingming and Corey 1993).

To minimize the threat of food-chain contamination, accurate estimation of movement and potential for plant accumulation and food-chain cycling of sludge-borne heavy metals is important (Yingming and Corey 1993). Either the metal contents in the sludge or the application should be reduced below quantities accepted by given prescriptions.

Liming is a common practice in agriculture to raise soil pH of acid soil and also to reduce the solubility of heavy metals. The application of lime should generally be considered for strongly and moderately acid soils to improve the physical, chemical and biological properties of the soils, although many factors, such as kind of crops, soil type and climate influence plant response to lime. Application of lime in low pH soils neutralizes soil acidity, reduces toxicity levels of Al, Fe and Mn and improves soil properties. There are reports on the effects of lime addition to reduce heavy metal solubility (Basta and Sloan 1999; Fang and Wong 1999; Krebs *et al.* 1998; Little *et al.* 1991). Peles *et al.* (1998) found that Zn, Cu, Cd and Pb concentrations in various plant species were significantly lower in plants collected from limed compared to unlimed sludge treated soils though these effects were different for the individual metals.

Ipomoea aquatica, a leafy vegetable commonly known as Kalmi shak, is widely cultivated in Bangladesh and meets the nourishment here, especially in the rural area. Kalmi is a good source of vitamin A and C as well as iron and calcium, although it is a hyper accumulator of toxic heavy metals. The variability of pH has significant effect on agricultural production. The availability of micronutrients is related to soil pH. It is well known that as pH decreases, the ability of soils to adsorb and hold metals decreases (Brady and Weil 2002).

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The present study aims to assess the role of sewage sludge as a source of plant nutrients at different pH levels on the growth and nutritional status of *Ipomoea aquatica* and its response to heavy metals.

Materials and Methods

Soil sample collection and sample preparation

The soil used in the present study was acidic in nature and it belonged to the Ramnagar soil series. The soil samples were collected from Malackochha of Sherpur district, Bangladesh. The collected soil samples were dried in air for 3 days (at ~35^oC) by spreading in a thin layer on a clean piece of paper after it was transported to the laboratory. Visible roots and debris were removed from the soil and discarded. For hastening the drying process, the soil samples were exposed to sunlight. After air-drying, a portion of larger and massive aggregates were broken down by gently crushing them using a wooden hammer. Ground samples were screened to pass through a 2 mm stainless still sieve. The sieved samples were then mixed thoroughly for making the composite sample. Soil samples were preserved in plastic bags and labelled properly marking the soil name, sample number, date of collection, etc. These soil samples were used for various physical, chemical and physico-chemical analyses. The bulk of the soil samples collected for the pot experiment was crushed to make the bigger clods smaller and then was screened through a 5 mm sieve.

Collection and processing of sewage sludge samples

The treated sewage sludge samples were collected from Pagla Sewage Treatment Plant, Dhaka, Bangladesh. The sewage sludge samples were transported into the laboratory and were dried in the sun for 3 days (at ~35^oC). The samples were then processed and prepared for chemical analyses and application into soil.

The Experiments

In order to study the effects of liming on changing soil pH as well as the effects of sewage sludge on plants at different pH levels, the experiment was divided into two parts *viz*., (i) a laboratory incubation study and (ii) a pot culture experiment with plants.

Laboratory Incubation Study

An incubation study was carried out at room temperature in the laboratory of the Department of Soil, Water and Environment, University of Dhaka. In the incubation study, 20 gm of soil samples into 50 ml size beakers were used. The soil samples were limed with 13 different amounts of $Ca(OH)_2$ (0.0, 0.01, 0.02, 0.04, 0.06, 0.08, 0.10, 0.12, 0.16, 0.20, 0.24, 0.28, 0.30 mg/pot) to raise the soil pH. These amounts corresponds to 0.0, 1.1, 2.2, 4.4, 6.6, 8.8, 11.0, 13.2, 17.6, 22.0, 26.4, 28.0 and 33.0 t $Ca(OH)_2$ ha^{-1} soil, respectively. The soil and $Ca(OH)_2$ were mixed thoroughly and were moistened with distilled water. The beakers were then covered with aluminum foil and allowed to incubate to observe the changes in pH of the soils. Distilled water was added to the soils every week to recover the loss of water from the soil. Thus, the soils were kept moist throughout the incubation period. The study was continued for a total period of 28 days with 4 individual incubation periods, *viz*., 7, 14, 21 and 28 days. Each treatment was replicated thrice for every incubation day.

The pH of the set of soils (with 13 rates of $Ca(OH)_2$) under each incubation period was measured using a glass electrode pH meter (Imamul Huq and Alam 2005). From the pH of all the soils under the incubation study (Table III), four (4) pH levels: 4.7, 5.7, 6.6 and 7.8 were selected for the pot culture experiment.

The pot culture experiment

In order to study the effects of sewage sludge on plants at different soil pH levels, a pot culture experiment with an upland crop, *Ipomoea aquatica*, was done. The experiment was carried out using the collected acidic soil amended with sewage sludge @ 5 t ha^{-1} soil and without amending the soil with sewage sludge. The non-amended soils and the soils amended with sewage sludge are symbolized as S_0 and S_1, respectively, in the text. Four different pH levels *viz.*, 4.7, 5.7, 6.6 and 7.8, as selected from the incubation study, were used for the pot experiment and are designated as pH_0, pH_1, pH_2 and pH_3, respectively, in the text. To make the pH of the soils (1.5 kg) kept in the pots for plant culture at the selected pH levels of 4.7, 5.7, 6.6 and 7.8, $Ca(OH)_2$ amounting 0, 0.75, 1.5 and 3.0 gm were added, respectively. These amounts of $Ca(OH)_2$ correspond to 0, 1.1, 2.2 and 4.4 t ha^{-1}, respectively. The different treatment levels, with their codes, used in this experiment are presented in the Table I. All the experiments were done in triplicates. Accordingly, a total of 24 pots [2 rates (0 and 5 t ha^{-1}) of sewage sludge × 4 pH levels × 1 crop × 3 replications = 24 pots] were used in this pot experiment; 12 pots were used for the non-amended soils and 12 pots for the sewage sludge amended soils.

Table I: Different treatment levels, with their codes, used in the experiment.

Treatment		Code
Sewage sludge	pH levels	
S_0	4.7	S_0pH_0
	5.7	S_0pH_1
	6.6	S_0pH_2
	7.8	S_0pH_3
S_1	4.7	S_1pH_0
	5.7	S_1pH_1
	6.6	S_1pH_2
	7.8	S_1pH_3

Pot preparation

Two kg sized earthen pots with no hole at the bottom were used. Air-dried 5 mm sieved soil samples amounting 1.5 kg were taken in each of the earthen pots. The soils were limed with $Ca(OH)_2$ as per the calculated amounts to raise the pH of the soils to the four selected levels. After addition of the liming material into the soil, the pots were kept for two weeks with occasional mixing and watering of the soil. After two weeks, sewage sludge @ 5 t ha^{-1} was added only to the set of twelve pot-soils and mixed thoroughly and then kept for three days to decompose the sludge.

Sowing of seeds

Certified seeds of *Ipomoea aquatica* were collected from Bangladesh Agricultural Research Institute (BARI). Ten seeds of *Ipomoea aquatica* were sown on March 15, 2008 in each of the pots and allowed to germinate. After germination, five seedlings were kept in each pot and allowed to grow. All the pots were arranged in the net-house in a completely randomized design.

Plant culture

Plants received watering everyday. Watering of the pots was made twice daily at the morning and in the afternoon depending on the weather condition. Sometimes watering was done in a gap when the soil was saturated with rainwater. Tap water was used for this purpose. Intercultural operations were carried out whenever necessary. Weeds were removed manually. Positions of the pots were changed every alternate day to allow equal exposure of each of the pots to sunlight. Adequate plant protection measures were taken during the growing period. During the cultivation, different parameters like growth, appearance of any symptoms etc. were noted.

Collection and processing of plant samples

Plants were allowed to grow for 42 days after emergence of the seedlings and then sampling of the plants was done. At harvest, the plants from every pot were collected individually. The plants were harvested manually by uprooting them carefully from the pots. The roots of the harvested plants were washed first with tap water and then again with de-ionized distilled water three times to remove ions from the root free space as well as to dislodge any adhering particles on the root surface. Aerial parts of the plants were also washed. The wet samples were dried using paper towels. The plant samples were separated into two parts - root and edible parts (shoot and leaf). The samples were first air-dried and then oven-dried at $70^{o}\pm5^{o}C$ for 48 hours and the dry weight of the plant samples were taken. The dried plant samples were then ground to pass a 0.2 mm sieve. The ground plant samples were mixed thoroughly to make it composite and stored in a dry place for further chemical analyses.

Laboratory analysis

Various physical, chemical and physico-chemical properties of the soil and sewage sludge samples were analysed in the laboratory, following the procedures described in Imamul Huq and Alam (2005). The background concentrations of total Calcium (Ca), Cadmium (Cd), Copper (Cu), Lead (Pb), Magnesium (Mg), Manganese (Mn), Nitrogen (N), Phosphorus (P), Potassium (K) and Zinc (Zn) in the soils (pre- and post-experiment), plants and sewage sludge were determined.

Results and Discussion

Soil and sewage sludge properties

The selected soil and sewage sludge samples were analyzed to ascertain the levels of nutrients as well as other elements present (Table II).

Incubation study: Changes in soil pH due to liming

The initial pH of the collected soil was 4.7 and the pH levels have been found to increase up to a maximum of 11.62 after the incubation period of 28 days due to the application of different amounts of $Ca(OH)_2$ (Table III). Among these pH values four pH levels of 4.7, 5.7, 6.6 and 7.8 have been selected for the pot culture experiment.

Table II: Physical, chemical and physico-chemical properties of the soil and the sewage sludge.

Soil properties	Soil	Sewage sludge
pH	4.7	3.3
Moisture Content (%)	4.0	62
Textural class	Loam	–
Organic matter (%)	1.10	7.10
Available N (mg kg^{-1})	355.20	390
Available P (mg kg^{-1})	6.10	312
Available K (mg kg^{-1})	33.20	84.33
Total N (%)	0.14	0.62
Total P (%)	0.03	0.43
Total K (%)	0.08	0.28
Total Fe (%)	0.28	0.77
Total Ca (mg kg^{-1})	30	560
Total Mg (mg kg^{-1})	490	900
Total Cd (mg kg^{-1})	1.04	2.59
Total Cu (mg kg^{-1})	8.45	20.72
Total Mn (mg kg^{-1})	88.60	320
Total Pb (mg kg^{-1})	28.85	13.35
Total Zn (mg kg^{-1})	138	720

Effects of pH and sewage sludge on yield, concentration and uptake of different nutrient elements in *Ipomoea aquatica*

Effects on the dry matter yield of *Ipomoea*

The dry matter production of *Ipomoea* was found to decrease significantly ($p \leq 0.05$) with increasing pH of the soils, where as the yield was observed to increase insignificantly due to the application of sewage sludge (SS) in most cases (Table IV). Significant ($p \leq 0.05$) pH×SS interaction effects were observed on the dry matter yield of *Ipomoea*. Treatment with sewage sludge at the lowest pH (S_1pH_0) produced the maximum yield (2.43 gm/pot), while the minimum yield (1.46 gm/pot) was observed at the highest pH (S_1pH_3). Thus, the minimum yields were obtained at the maximum pH level (pH=7.8) for both sludge amended and non-amended soils indicating that higher pH level is not favorable for the growth of *Ipomoea aquatica.*

Effects on the accumulation of N, P, K, Ca and Mg in *Ipomoea*

An increase in the concentration of different plant nutrient elements, viz., N, P, K, Ca and Mg in *Ipomoea aquatica* was observed with increasing the pH of the soils in most cases (Table V). The concentration of the elements in the plants was, in general, higher for the sludge-amended soils compared to that of the non amended soils. pH, sewage sludge and their interaction have been found to have significant ($p \leq 0.05$) effects on the accumulation of N and K in the plants, whereas the effects were found to be insignificant for P and Ca. Sewage sludge showed insignificant effect on Mg accumulation in *Ipomoea*. Higher content of the elements in the plants for the sludge-amended soils was perhaps due to the higher yield of the plants as well as the gain of surplus nutrients from the sewage sludge amended soil.

Table III: Changes in soil pH with time due to addition of $Ca(OH)_2$.

Lime level	Amount of $Ca(OH)_2$ (g/pot)	pH values after different time intervals			
		7 days	14 days	21 days	28 days
L_0	0.00	4.70	4.68	4.71	4.74
L_1	0.01	5.21	5.36	5.50	5.70
L_2	0.02	6.10	6.23	6.39	6.60
L_3	0.04	7.10	7.21	7.40	7.80
L_4	0.06	7.62	7.83	8.00	8.17
L_5	0.08	7.69	7.97	8.11	8.20
L_6	0.10	8.20	8.42	8.23	8.50
L_7	0.12	8.23	8.43	8.29	8.48
L_8	0.16	8.27	8.39	8.42	8.60
L_9	0.20	8.24	8.38	8.21	8.58
L_{10}	0.24	11.12	11.20	11.15	11.35
L_{11}	0.28	11.18	11.31	11.29	11.61
L_{12}	0.30	11.23	11.28	11.37	11.62

Table IV: Dry matter yield of *Ipomoea* with corresponding pH and sewage sludge levels.

Treatment		Dry matter yield (g/pot)
Sewage sludge	pH levels	
	pH_0	2.40
S_0	pH_1	2.11
	pH_2	2.00
	pH_3	1.64
	pH_0	2.43
S_1	pH_1	2.23
	pH_2	2.07
	pH_3	1.46

LSD at 5%: pH = 0.33, SS= ns, pH × SS = 0.33

Effects on the uptake of N, P, K, Ca and Mg in *Ipomoea*

The uptake of the elements by *Ipomoea* was calculated by multiplying the concentration of the elements in the dry matter with the total dry matter produced. The results are expressed as mg per pot. Higher amounts of N, P, K and Mg were taken up by *Ipomoea* from the sewage sludge treated soils than from the non treated soils (Table VI). At the maximum pH level, *viz.* 7.8 (pH_3), uptake of the elements per pot was decreased to a minimum in all the soils; the reason, perhaps, being the lower yield of the crop. The uptake of N and Mg by *Ipomoea* varied significantly ($p<0.01$) due to the change in pH and the sewage sludge, whereas the effects of pH and sewage sludge did not show any significant variation in the uptake of P and Ca. The influence of pH on the uptake of K was found to be highly significant ($p<0.01$), while the application of sewage sludge as well as pH×SS interaction showed insignificant effects on the plant uptake of K.

Effects on the accumulation of Cd, Cu, Fe, Mn and Zn in *Ipomoea*

High concentrations of the metal elements, *viz.*, Cd, Cu, Fe, Mn and Zn in *Ipomoea* were found for both sludge amended and non amended soils at all the pH levels (Table VII). Fe concentration in *Ipomoea* was found to be higher in the non treated soils, while elevated contents of Cd, Cu, Mn and Zn in the plants were observed for the sludge-treated soils, indicating the availability of these elements in soils due to the applied sewage sludge. Lesser amount of Fe in the plants grown in the sludge-treated soils might be due to the antagonistic interaction between Fe and the other elements, viz., N, P, K, Ca, Mg, Cu, Mn and Zn (Pendius 1985). Increased concentration of these metal elements in plants due to application of sewage sludge in soil has also been reported by Barbarick *et al.* (1998), Selivanovskaya *et al.* (2001) and Snyman *et al.* (1998). pH, sewage sludge and their interaction have been found to have highly significant ($p<0.01$) effects on the contents of Zn and Mn in *Ipomoea,* whereas on the concentration of Cd in *Ipomoea* the effects were not significant. Application of sewage sludge showed significant ($p\leq0.05$) effects on the accumulation of Cu and Fe in *Ipomoea.*

According to Sauerbeck (1982), Kashem and Singh (1999) and Chowdhury *et al.* (2010), the normal level of Cd and Zn in plants varies from 0.2-2 and 20-100 mg kg^{-1}, respectively, while the toxic level of the metals range from 15-20 and

Table V: Concentration (%) of N, P, K, Ca and Mg in *Ipomoea* with corresponding pH and sewage sludge treatments.

Treatment		N	P	K	Ca	Mg
Sewage sludge	pH level					
	pH_0	1.42	0.73	0.05	0.14	0.31
	pH_1	1.51	0.75	0.07	0.15	0.35
S_0	pH_2	1.55	0.79	0.07	0.14	0.34
	pH_3	1.55	0.94	0.08	0.13	0.36
	pH_0	1.69	0.72	0.07	0.12	0.40
	pH_1	1.71	0.88	0.08	0.13	0.41
S_1	pH_2	1.84	0.83	0.06	0.15	0.37
	pH_3	1.89	0.66	0.07	0.16	0.32
LSD value at	pH	0.12	ns	0.02	ns	0.04
5% level	SS	0.22	ns	0.03	ns	ns
	pH×SS	0.12	ns	0.02	ns	0.04

ns = not significant, SS = sewage sludge

Table VI: Uptake (mg/pot) of N, P, K, Ca and Mg in *Ipomoea* with corresponding pH and sewage sludge treatments.

Treatment						
Sewage sludge	pH level	N	P	K	Ca	Mg
S_0	pH_0	34.1	17.5	1.22	3.36	7.44
	pH_1	31.9	15.6	1.49	3.17	7.39
	pH_2	31.0	15.9	1.36	2.80	6.80
	pH_3	25.4	15.3	1.26	2.13	5.90
S_1	pH_0	41.1	17.5	1.82	2.92	9.72
	pH_1	54.2	19.7	1.69	2.99	9.14
	pH_2	38.1	17.2	1.34	3.11	7.66
	pH_3	27.6	9.70	1.01	2.34	4.68
LSD value at 5% level	pH	2.26	ns	0.08	ns	0.11
	SS	3.92	ns	ns	ns	0.17
	pH×SS	2.26	ns	ns	ns	0.11

ns = not significant, SS = sewage sludge

150-200 mg kg^{-1}, respectively. Zinc is one of the micronutrients essential for normal plant growth, but only a small amount of Zn is required (Adriano 1986). Although the concentration of Cd in the plants grown on the soils, both non-amended and amended with sewage sludge, exceeded the normal range, it has been found to be in the tolerable range, while Zn concentration in *Ipomoea* was observed to exceed even the toxic level for both types of the soil (Table VII).

Although Cu is essential for plant growth, a very small amount of Cu is required by plants (Adriano 1986). The normal level of Cu in plants varies from 3-10 mg kg^{-1}, while the toxic level of the metal ranges from 10-20 mg kg^{-1} (Sauerbeck 1982; Kashem and Singh 1999; Chowdhury *et al.* 2010). In the present study, elevated levels of Cu toxicity were found for the plants under both of the soils (Table VII). Fe and Mn are required by plants in only small quantities, large amounts being toxic (Tisdale *et al.* 1993). The typical contents of Fe and Mn in plants are 100 and 50 mg kg^{-1}, respectively (Imamul Huq and Alam 2005). The concentrations of Fe and Mn in Ipomoea under both the sewage sludge amended and non-amended soils showed higher accumulation of the elements (Table VII).

Effects on the uptake of Cd, Cu, Fe, Mn and Zn in *Ipomoea*

The uptake of the metal elements by *Ipomoea* was calculated by multiplying the concentration of the elements in the

Table VII: Concentration of Cd, Cu, Fe, Mn and Zn in *Ipomoea* with corresponding pH and sewage sludge treatments.

Treatment		Cd	Cu	Fe	Mn	Zn
Sewage sludge	pH level	(mg kg^{-1})	(mg kg^{-1})	(%)	(mg kg^{-1})	(mg kg^{-1})
S_0	pH_0	11.24	47.87	0.095	86.50	209.58
	pH_1	11.05	45.88	0.084	92.50	244.76
	pH_2	11.26	42.63	0.081	158.75	291.03
	pH_3	10.95	37.00	0.088	86.25	251.70
S_1	pH_0	11.86	57.50	0.077	122.50	292.70
	pH_1	12.18	45.88	0.063	183.75	277.03
	pH_2	11.28	51.38	0.067	192.50	298.64
	pH_3	12.83	46.00	0.065	167.50	157.63
LSD value at 5% level	pH	ns	ns	ns	15.68	21.26
	SS	ns	13.38	0.07	12.83	36.82
	pH×SS	ns	ns	ns	15.68	21.26

ns = not significant, SS = sewage sludge dry matter with the total dry matter produced. The results are expressed as mg per pot. Uptake of Cd by *Ipomoea* varied from 0.018 to 0.029 mg/pot being slightly higher in the sludge-treated soils, whereas the lowest uptake (0.018 mg/pot) was found for the level of pH_3 (7.8) in both type of soils (Table VIII). Copper was taken up by the plants in relatively higher amounts in treated (0.139 mg/pot) compared to untreated (0.115 mg/pot) at the pH level of 4.7 (pH_0). At all the pH levels, higher amount of Fe was taken up by the plants from the non-sludge treated soils. Manganese and Zn uptake was found to be higher for the sludge-treated soils. This may be due to the fact that these metals were in a more labile state in the sludge-treated soils than in the non treated soils. pH has been found to have highly significant ($p<0.01$) effect on the uptake of Cd, Cu, Mn and Zn by *Ipomoea*. Application of sewage sludge in the soils showed highly significant ($p\leq0.05$) effect on the plant uptake of Mn and Zn.

Table VIII: Uptake (mg/pot) of Cd, Cu, Fe, Mn and Zn in *Ipomoea* with corresponding pH and sewage sludge treatments.

Treatment						
Sewage sludge	pH level	Cd	Cu	Fe	Mn	Zn
S_0	pH_0	0.027	0.115	2.27	0.208	0.503
	pH_1	0.023	0.097	1.76	0.195	0.516
	pH_2	0.022	0.085	1.62	0.318	0.582
	pH_3	0.018	0.061	1.44	0.142	0.259
S_1	pH_0	0.029	0.139	1.87	0.298	0.711
	pH_1	0.027	0.102	1.41	0.409	0.617
	pH_2	0.023	0.106	1.39	0.398	0.618
	pH_3	0.018	0.067	0.95	0.245	0.230
LSD value at 5% level	pH	0.05	0.02	NS	0.08	0.21
	SS	ns	ns	ns	0.15	0.03
	pH×SS	ns	ns	ns	ns	0.21

ns = not significant, SS = sewage sludge

Changes in soil pH after harvest of *Ipomoea*

A small change in all the initial pH of both of the soils has been observed after harvest of *Ipomoea* grown in the pots (Table IX). The levels of pH_0 (4.7) and pH_1 (5.7) were found to increase to 5.67 and 6.1, respectively, in the non amended soils and to 5.68 and 6.20, respectively, for the soils treated with sewage sludge. The other two levels of pH_2 (6.6) and pH_3 (7.8) were observed to reduce from their initial values in both types of the soils. However, the changes in the pH of the sludge amended soils and non amended soils were found to be insignificant.

Table IX: Changes in soil pH after harvest of *Ipomoea*.

Initial soil pH	After harvest soil pH	
	Non-amended soil	Sewage sludge amended soil
4.7	5.67	5.68
5.7	6.10	6.20
6.6	6.39	6.48
7.8	7.20	7.10

Conclusion

The results of the present study substantiate that liming can bring a change in the response of plants to nutrients as well as to toxic heavy metals available in soil due to application of sewage sludge. The concentration of the nutrient and metal elements in the plant tissues and the uptake of the elements into the plants indicate the bioavailability of the elements in soil as a result of addition of sewage sludge. The study suggests that acid soils may be used for agricultural purpose through amendment with more levels of sewage sludge. However, further research with more crops is needed to make any recommendation on the commercial use of sewage sludge.

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