Biotransfer of Cadmium, Lead and Zinc from Sewage Sludge and Fly Ash Amended Soil in Mustard – Aphid – Beetle Food Chain

ABSTRACT

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In the present work, experiments were conducted to study the biotransfer of three potentially toxic heavy metals (cadmium, lead and zinc) of sewage sludge and fly ash along mustard – aphid – beetle food chain. The application of sewage sludge and fly ash for agricultural use is encouraged indiscriminately as part of their disposal management due to the presence of majority of elements essential for plant growth. But, presence of some toxic heavy metals in both the solid wastes and their biotransfer along the food chains pose a serious threat to the entire agroecosystem. The cadmium (Cd), lead (Pb) and zinc (Zn) are among the most dangerous heavy metals present in both the solid wastes.

Zinc has essential physiological and biochemical functions in plants and animals, but excessive levels can be damaging. In contrast, Cd and Pb have no essential role in organisms. The Cd and Zn are among the most labile heavy metals in the soil-plant system. The Pb, a relatively immobile metal is considered as a noxious contaminant. After their absorption by plant roots, these heavy metals are translocated into different plant parts and transferred to the organisms of higher trophic levels in the food chain.

In this work, the biotransfer of cadmium, lead and zinc along mustard-aphid-beetle food chain has been studied. The sewage sludge used in the present study was collected from old waste water treatment plant of Aligarh Muslim University and the fly ash used was brought from the ash pan of Kasimpur Thermal Power Plant located about 12 kms away from Aligarh city. Five experiments were conducted to study the effects of the applications of variable amounts of sewage sludge and fly ash separately and their combinations on the growth of plants as well as uptake of three selected heavy metals (Cd, Pb and Zn) along the food chain. The major objectives of the present study were:

1. To screen out the amount of sewage sludge required for optimum growth of the selected mustard plant.
2. To examine the extent of accumulation and biotransfer of Cd, Pb and Zn from sewage sludge amended soil in mustard – aphid – beetle food chain.
3. To screen out the amount of fly ash required for optimum growth of the selected mustard plant.
4. To examine the extent of accumulation and biotransfer of Cd, Pb and Zn from fly ash amended soil in mustard – aphid – beetle food chain.
5. To determine the extent of accumulation and biotransfer of Cd, Pb and Zn in mustard-aphid-beetle food chain from soil-sludge-fly ash complex.

In order to achieve these objectives, five experiments were conducted. In first and second experiments, the quantity of sewage sludge and fly ash to which the selected mustard plant (Brassica juncea L. cv. Alankar) was resistant and performed better growth and yield, was determined. In third and fourth experiments, the selected plant was grown in soil mixtures with 5%, 10%, 20% and 40% (w/w) of sewage sludge and fly ash, respectively (the range of plant resistance as determined in Experiment 1 and 2). The aphids (Lipaphis erysimi) were fed for three weeks on the shoots of these mustard plants under controlled conditions and the biotransfer and accumulation of three selected heavy metals (Cd, Pb and Zn) were examined. These aphids were then fed to fourth instar larvae of predatory beetles (Coccinella septempunctata) at third trophic level. The extent of heavy metal elimination at second and third trophic levels via honeydew and pupal exuviae, respectively, were also examined. In fifth experiment, the varying concentrations of fly ash were added to stabilize soil-sludge mixtures and resultant variations in uptake of selected heavy metals along the mustard – aphid – beetle food chain were studied.

In Experiment 1 and 2, the pH of the fly ash, garden soil and sewage sludge were in the decreasing order of potential as fly ash > garden soil > sewage sludge. Separate applications of 10-40% sewage sludge and fly ash in garden soil enhanced the vegetative and reproductive growth of the selected cultivar of mustard. The higher amounts of these solid wastes (≥ 70%) increased uptake of selected heavy metals in shoots, but reduced the plant growth. The accumulation of cadmium, lead and zinc also increased significantly in mustard shoots on application of 40% of the solid wastes in the soil without adversely affecting the plant growth.

In Experiment 3, the pH of amended soil decreased in proportion to the amount of sewage sludge added in it. The concentrations of cadmium, lead and zinc increased significantly on addition of (10-40%) sewage sludge in the soil. So was the
trend of the accumulation of cadmium, lead and zinc in the roots, shoots, aphids and adult beetles (ladybirds). The correlation coefficients were strong and positive between metal (Cd, Pb and Zn) uptake in the mustard roots and their extractable concentrations in the soil. Very strong and positive correlations were determined between concentrations of these metals in shoots and in roots. Strong and positive correlations existed between metal concentrations in aphids and concentrations in their diets (shoots). The concentrations of cadmium, lead and zinc in predatory beetle had a strong degree of dependence \( (R^2) \) on concentration in their prey (aphids). To examine the biomagnification of these heavy metals along the food chain, the transfer coefficients were determined at varying trophic levels. With some exceptions, both the non-essential metals (Cd and Pb) did not biomagnify along the food chain. Whereas, the zinc- an essential element, biomagnified in aphids at second trophic level when fed on shoots of mustard grown in sewage sludge amended soil. But the level of biomagnification of Zn in aphids decreased with the increase in the sewage sludge application rates. The magnitude of transfer coefficients of Cd and Pb decreased with the increase in the sewage sludge application rates. The aphids excreted Cd, Pb and Zn with honeydew in proportions to their concentrations in aphid bodies. Elimination of Cd and Pb with honeydew was relatively more efficient than Zn.

In Experiment 4, the additions of fly ash in soil increased the pH proportionately in resultant mixtures. The soil nitrogen contents reduced consistently with the increase in amounts of fly ash added in the soil. The concentrations of Cd, Pb and Zn also increased with the amounts of fly ash applied in the soil. The amounts of extractable Cd, Pb and Zn were relatively lesser in the soil samples amended with fly ash than of sewage sludge (Experiment 3). Unlike in third experiment with sewage sludge, the application of fly ash in this experiment led to biomagnification of Cd at second trophic level and Zn at second and third trophic levels. The magnitude of biomagnification of Zn at third trophic level in predatory beetles was relatively lesser than at second trophic level (in terms of transfer coefficients) in experiment 4 with varying concentration of fly ash.

In Experiment 5, the applications of fly ash in soil-sludge mixtures stabilized the pH of the resultant mixture to some degree. The overall concentrations of Cd and Zn decreased on fly ash additions in soil-sludge mixtures. The uptake of both these metals (Cd, Zn) also decreased in aphids and predatory beetles on applications of 10%
and 20% fly ash in soil-sludge mixtures. But, the stabilization of soil-sludge mixture with the addition of varying levels of fly ash was relatively less efficient in minimising the lead uptake along the food chain.

It may be inferred from these findings that addition of alkaline fly ash in acidic sewage sludge may stabilize the pH of resultant mixture and can also minimise the uptake of heavy metals along the food chain studied. More detailed experiments are warranted to find out the fate of uptake and accumulation of heavy metals in several other food chains on varying crops and cultivars.