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Soil-Plant-Ni-As: Four-Fold Interactions – Modest Blessing from Total Disguise

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ABSTRACT

As an essential plant nutrient, deficiency of nickel (Ni) can cause metabolic and enzymatic disorder in plants; however an excess amount of this element can also be proven deadly for a plant. To examine the critical level of Ni tolerance two plant species, Kalmi (*Ipomoea aquatica*) and Red Amaranthus (*Amaranthus cruentus*) were selected where Red Amaranthus (*Amaranthus cruentus*) was verified as a hyper accumulator of Ni. In this diverse experimental set up, arsenic (As) was applied with irrigation water and increased doses of Ni was observed to put antagonistic effect on availability as well as plant uptake of As. The results from such a complex and diverse four-fold interaction can be concluded as a little blessing of remediation of As toxicity from a disguise of Ni toxicity.

Key words: Soil, Plant, Nickel, Arsenic, four-fold interaction, phytoremediation

INTRODUCTION

With the ever increasing world populations, two main challenges emerging in this century are feeding people and industrial development. Both the issues are related with the existence and development of human being. For ensuring food for the rapidly growing world populations, intensive cultivation with accentuated cropping pattern and excessive use of chemical fertilizers is being practiced all over the world ultimately resulting heavy metal loads in the soil as well as in the environment (Adriano, 2001) . Side by side, industrial revolution also adding more load of heavy metals in the soil, water and other environmental components. Nickel (Ni) is one of such heavy metals that has drawn significant attention in recent years owing to its swiftly increasing concentrations in the environmental components such as soil, air, and water round the globe (Ahmad and Ashraf, 2011).

In the earth's crust, Nickel is by far the 24th most abundant metal and 5th most profuse element by weight constituting about 3% of the earth composition (Iyaka, 2011). Nickel was first extracted from 'niccolite' mineral by a Swedish scientist Axel Crostedt in 1751 (Iyaka, 2011) and was named from the German term 'Kupfenickel' meaning 'Old Nick's Copper' as it emitted of toxic fumes after heating (Kotov and Nikitina, 1996). It comes to the environment from both anthropogenic and natural resources (Cempel and Nikel, 2006; WHO 1991). Anthropogenic activities for Ni pollution of environment include alloy manufacturing, impurities in oils and gasoline, combustion of coal, incineration of waste and sludge, electroplating and mining, manufacturing of batteries and electric heaters, manufacturing of cement, ink, dyes and paint factories, jewellery making, varnishing and use of different fertilizers (Ni content in rock phosphates, TSP and ammonium nitrates can be 16.8 to 50.4 ppm, 15.6 to 25.2 ppm and <0.20 ppm respectively) (Raven and Loeppert, 1997), limes, pesticides and amendments in agriculture and so on (Iyaka, 2011; Chauhan et al., 2008; Von Burg, 1997; Mcllveen and Negusanti, 1994; Kabata- Pendias and Pendias, 1992). On the other hand, natural sources of Ni include volcanic emissions, forest fires and vegetation, wind - blown dust etc. Some geochemical processes (Lazaro et al. 2006) are also major contributors of Ni accumulation in the environment naturally which includes igneous rocks, weathering of parent materials, leaching, run-off and accession of soil eroded from elsewhere (Chauhan et al., 2008). However, commercial and industrial activities are reported to emit almost 100 times more Ni into the environment than the natural sources (Iyaka, 2011; Nriagu, 1990).

Nickel is an essential micronutrient, although in low concentrations, and is a component of different enzymes (eg. Urease) and proteins (eg. Permease) which are necessary metabolic components of different plants, bacteria and fungi (Ahmad and Ashraf, 2011). The principal mechanisms involve in Ni uptake by plants comprise active transport and passive diffusion systems (Ahmad and Ashraf, 2011). Different factors act in active and passive ways to make the adsorbed Ni available or mobile in the soils like pH and organic matter content. With decreasing soil pH, Ni becomes more soluble or mobile. The amount and type of clays, iron- manganese mineral and soil organic matter play secondary role for Ni sorption or availability (Iyaka, 2011; Tye et al., 2004; Suavé et al., 2000). Therefore, deficiency of Ni causes range of adverse effects like reduced growth, metabolic disorder, enzyme inactivation, induction of senescence, leaf and meristem chlorosis, foliar necrosis, inhibits photosynthesis and transpiration as well as reduced uptake of other essential micronutrients like iron (Ahmad and Ashraf, 2011).

On the other hand, Arsenic (As) is ubiquitous in nature and a proven potent killing agent, if exceeds limit. This element has been dubbed as the most vicious and potent source of human disaster when climbed up the food chain (Sanchary and Imamul Huq, 2015). Among the anthropogenic causes of As pollution in soil and water, different industrial, commercial and agricultural activities play vital role whereas most natural causes are geogenic like As-contained parent material weathering, ground water contamination with As and so on (Sanchary and Imamul Huq, 2017; Ali and Ahmed, 2003). Arsenic is not a plant essential element but still be uptaken by plant roots because of its availability in soils from different fertilizer impurities and by irrigation water. If taken up in higher concentrations, As is evidenced to cause phytotoxicity and reduction of uptake of some other macro and micronutrients like potassium, calcium, manganese, iron, magnesium, zinc and copper (Shaibur et al., 2012).

Several measures are taken into considerations for reducing the concentration of such hazardous elements in soil and water. Phytoremediation is one of the most popular, eco-friendly, sustainable and cost-effective approaches among them. Different leafy vegetable, in fact algae, are in experiments to remediate the toxicities of such heavy metals from soils. This experiment is designed four-fold to conclude the remedial effects of Ni on As with a potential phytoremedial leafy plant from soils.

MATERIALS AND METHODS

A bulk of composite soil sample was collected from the upper 15cm of the profile of an agricultural field near Dhaka city and transported to the laboratory. The visible roots, leave and non-soil materials were thrust aside manually. The sample was divided into two portions, one was sieved through a 5mm sieve and used for pot culture experiment and the other part was sieved through a 0.5mm wire sieve and used for background analysis of some physical, chemical and physic-chemical parameter determination of the soil.

Firstly, the pH and the textural class (Imamul Huq and Alam, 2005) of the soils were determined. Then the content of organic carbon, organic matter, total N, available P, available K, (Sanchary et al., 2019) available Ni (Sabudak et al., 2008) and total and available As (Sanchary and Imamul Huq, 2017) of the 0.5mm sieved soil samples were determined using the procedures stated in the corresponding reference.

In total, 30 plastic pots of 5kg size were selected and 2kgs of 5mm sieved soils were taken in each pot. Five recommended dose of Ni were (Ni-0 , Ni-20, Ni-40, Ni-80 and Ni-80 indicating control-no Ni and 20, ppm Ni,) mixed with the soils along with the recommended doses of N, P and K fertilizers and mixed thoroughly for ensuring uniformity before 15 days of sowing seeds. Two types leafy vegetable seeds were sown Kalmi (*Ipomoea aquatica*) and Red Amaranth (*Amaranthus cruentus*) in different pots and 5-6 plants were allowed to grow in each pot. Each of plant-pots was treated with each dose of Ni and each of the treatments was replicated three times. Plants were allowed to grow for 60 days. During this time, the pots were irrigated with 100 ml of arsenic contaminated water of 1mg/L strength and irrigation was started after 10 days of seed germination. Arsenic solution for irrigation was prepared by dissolving 80% Na-meta arsenite and 20% Na-arsenate in distilled water (Sanchary and Imamul Huq, 2017).

Plants were uprooted after 2 months. After harvesting the plans samples of each pot were cleaned, dried, weighed separately, oven-dried, ground, sieved with 0.2mm sieve, digested with HNO_3 and H_2O_2 acid mixtures (Sabudak et al., 2008) in sand bath at 150°C temperature, cooled, volume to 100 ml with distilled water and preserved in plastic containers for further test. Liquid samples were passed through the atomic absorption spectrophototmeter (AAS) for As and Ni determination.

After harvest soil samples of each pots were collected and prepared using the same procedure as stated for background soil preparation. Total and available As and Ni content of the soils were also determined by acid digestion and water extraction respectively.

RESULTS AND DISCUSSION

The initial analyses of the collected samples showed following parameters with corresponding values (Table 1).

Table 1: Initial physical, chemical and physic-chemical parameters of the sample

Parameters	**Values**
pH	6.71
Sand (%)	13.8
Silt (%)	73.2
Clay	13
Textural class	Silt loam
Moisture (%)	18.26
Organic carbon (%)	0.903
Organic matter (%)	1.557
Total N (%)	0.096
Available P (ppm)	2.33
Available K (meq/100 g soil)	0.19
Available S (ppm)	8.13
Water extractable As (ppm)	0.007
Total As (ppm)	1.02
Water extractable Ni	Below Detection Limit (BDL)
Total Ni (ppm)	0.0872

The soil reaction was found in the range of agriculturally neutral (6.6-7.3) as described by the Soil Survey Manual (1993). The textural class was calculated Silt loam type. The total and available N, P, K, S were determined to supply fertilizers to the soils according to the needs of two different types of plants. Total and available As and Ni were also detected to compare with the final result.

After harvesting, the fresh and dry weight of the uprooted plant samples were also weighed to know the growth and uptake rate of heavy metals (Table 2).

Table 2: Fresh and dry weight of Red Amaranthus and Kalmi plants after 2 months of growth

Plant wt. / Ni doses (ppm)	Red Amaranthus (g/100 plants)		Kalmi (g/100 plants)	
	Fresh wt.	Dry wt.	Fresh wt.	Dry wt.
Ni-0	110.4	9.58	21.03	1.76
Ni-20	123.9	9.36	28.31	1.99
Ni-40	165.7	11.48	40.03	3.24
Ni-80	189.6	13.04	27.01	1.38
Ni-160	118.6	6.87	20.47	0.99

In accordance with Table 2, maximum growth in terms of fresh and dry weight was detected for Ni-80 dose for red amaranthus whereas the maximum fresh and dry weight for Kalmi plants was detected for Ni-40 dose. The weight record of Kalmi for Ni-80 dose might become toxic resulting in reduced growth but red amaranthus were quiet tolerant of that dose. For Ni-160 doses, the growth was reduced; in fact, lower than the control (Ni) treatment indicating toxic accumulation of Ni both plant types. At the vegetative stages of plants, if Ni concentration becomes higher, the root and shoot growth could be seriously affected. Supporting this statement, Ahmad and Ashraf (2011) and Chauhan et al. (2008) declared reduced root, shoot and branch development of plants leading to decreased biomass production. Necrosis, chlorosis respirational disorder and restrained photosysntesis are also reported as some common effects of excess Ni accumulation (Hayyat et al., 2020). Other reports also revealed that the phytotoxic range of Ni occurs at the plant tissue concentration of 40 to 246 ppm (Kabata- Pendias and Pendias, 2001) or at the leaf concentration range between 10 to 100 ppm (Gregson and Hope, 1994). Accumulation of Ni varies widely depending on plant phenotypes and genotypes. Sabudak et al. (2008) also stated that the accumulation and toxicity of Ni in plants depends on plant species, cultivars and age. A plant can be called hyper accumulator of Ni if it takes Ni against concentration gradient between the soil solution and cell cytoplasm without causing any harm to metabolic activities and growth. As such many plants can be termed as Ni-hyper accumulator and *amaranthus* sp. is one of the marked hyper accumulators of Ni (Selvaraj et al., 2022) which justify the results of this experiment also.

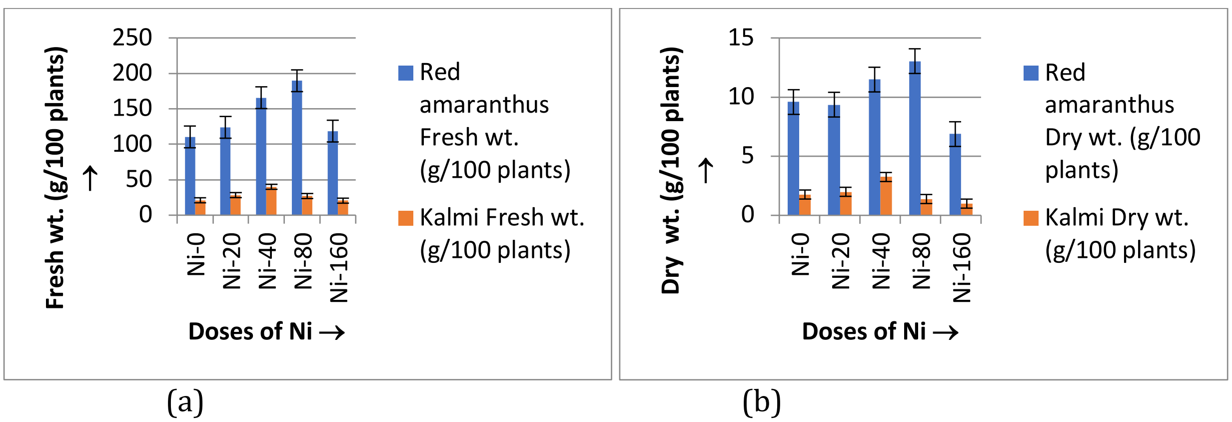

Figure 1 (a, b): Fresh and dry weight of Red amaranth and Kalmi for different doses of Ni

During the growing period, both the plant species were irrigated with a certain concentration of As solutions for each of the applied Ni doses. Plant concentration of As for different doses of Ni treatments are presented in Table 3.

Table 3: Concentration of As in Red amaranthus and Kalmi

Doses of Ni	As conc. in Red amaranthus (ppm)	As conc. in Kalmi (ppm)
Ni-0	1.32	1.25
Ni-20	1.13	1.01
Ni-40	1.01	0.98
Ni-80	0.95	0.76
Ni-160	0.77	0.64

According to Table 3, both the plant species were found to contain reduced concentrations of As with increasing Ni doses. With time, some of the applied Ni got fixed by soil particles which could be a reason for decreasing Ni effect a little. Overall effect of Ni on As can be described by stating that with increasing concentration of Ni, As concentration decreased. Similar finding was evidenced from Sanchary and Imamul Huq (2017) where they concluded to use Zn fertilizers for As remediation from the soils. Complying the same result, Chauhan et al. (2008) wrapped up with the proclamation that Ni performs mostly like Zn in the soil-plant system.

The linear pattern of As reduction with increasing Ni is shown in figure 2.

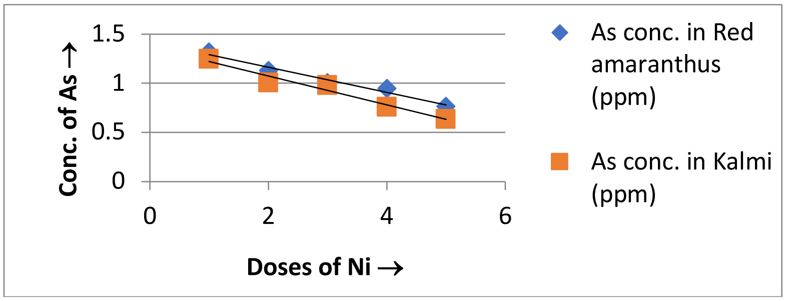

Figure 2: Decrease of As with increasing Ni doses

Not only the plant uptake, increasing Ni doses was also found to impose greater impact on soil total and available As content.

Table 4: Soil content of As (in ppm) from both the plant pots

Doses of Ni	Soil content of As in ppm from Red amaranthus pots		Soil content of As in ppm from Kalmi pots	
	Available	Total	Available	Total
Ni-0	0.003	2.02	0.001	2.01
Ni-20	0.007	2.01	0.009	2.12
Ni-40	0.005	2.39	0.006	2.36
Ni-80	0.005	2.68	0.007	2.88
Ni-160	0.001	2.74	0.002	3.08

Increased concentrations of Ni was evidenced to reduce the availability and mobility of As in soils thereby helping more As to get fixed in soils as immobile total loads. The mobility of Ni in soils depends on many factors like pH, organic matter content, soil mineralogy, clay content, iron- manganese mineral, oxides and carbonates of Ni (organically bound phases) as well as existing microbiological compositions of the soils (Hayyat et al., 2020; Iyaka, 2011, Chauhan et al., 2008; Tye et al., 2004). Mostly, Ni forms ionic complexes to facilitate diffusion but with the decreasing pH level, supplementary mobility effects of Ni impose antagonistic upshot for As. As a result more organo-mineral complexes of As ultimately resulting reduced availability but more fixed and immobile content of As in soils. Moreover, plant uptake and additional microbial activities also play an important role in subsiding As content in soils. The antagonistic effect of Ni on As can thus be compared with the impact of Zn on As (Chauhan et al., 2008).

CONCLUSIONS

Although Ni is an essential plant nutrient element, excess amount of it can cause serious problems in cultivation leading to ultimate crop failure. However, if the soil is contaminated with As too, in that case the antagonistic effect of higher Ni concentration can lower the availability as well as the plant uptake of As. To some extent the effect is like a blessing in a total disguise. A hyper accumulator plant together with Ni-As combination can act as a catalyst of the whole system.

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References

Adriano DC. 2001. Trace elements in terrestrial environments. In: Biogeochemistry. Bioavailability and Risks of metals. Springer Verlag, New York, 2001.

Ahmad MSA and Ashraf M. 2011. Essential roles and hazardous effects of nickel in plants. Rev. Environ. Contam. Toxicol. 214:125-67. doi: 10.1007/978-1-4614-0668-6_6. PMID: 21913127.

Ali MA and Ahmed MF. 2003. Environmental chemistry of arsenic. In*:* Arsenic contamination: Bangladesh perspective. ITN-Bangladesh; Center for Water Supply and Waste Management. Bangladesh University of Engineering and Technology (BUET), Dhaka, Bangladesh. pp. 1-112.

Cempel M and Nikel G. 2006. Nickel: A review of its sources and Environmental Toxicology. Polish J. of Environ. Stud. 15(3), 375- 382.

Chauhan SS, Thakur R and Sharma GD. 2008. Nickel: its availability and reactions in soil. Jr. of Indus. Pollut. Control. 24(1),1-8.

Gregson S and Hope A. 1994. Review of Phytotoxicity, Uptake and Accumulation of Elements and Organic Chemicals in Terrestrial Higher Plants, AERC Report for Department of the Environment, London.

Hayyat MS, Adnan M, Khan MAB, Abd-Ur-Rahman H, Ahmed R, Fazal-ur-Rehman, Toor MD and Bilal HM. 2020. Effect of heavy metal (Ni) on plants and soil: a review. Int. J. Appli. Res. 6(7), 313-318.

Imamul Huq SM and Alam MD. 2005. A handbook on analyses of soil, plant and water. Bangladesh Australia Centre for Environmental Research (BACER), University of Dhaka, Bangladesh. pp.1-246.

Kabata- Pendias A and Pendias H. 2001. Trace elements in Soils and Plants. 3rd Edn. Boca Raton: CRC Press, London.

Kabata- Pendias A and Pendias H. 1992. Trace elements in soils and plants. CRC Press, London.

Kotov V and Nikitina E. 1996. Norilsk Nickel: Russia Wrestles with an old polluter. Environ. 38, 6–11.

Lazaro JD, Kidd PS and Martinez CM. 2006. A Phyto geochemical study of the Tra's-os-Montes region(NE Portugal): possible species for plant based soil remediation technologies. Sci. Tot. Envir. 354:265-277.

Mcllveen WD and Negusanti JJ. 1994. Nickel in terrestrial environment. Sci. Tot. Environ. 148, 109-138.

Nriagu JO. 1990. Global metal pollution poisoning the biosphere? Environ. 32, 7-32.

Raven KP and Loeppert RH. 1977. Trace Element composition of fertilizers and soil amendments. J. Environ. Qual. 26, 551-557.

Sabudak T, Kaykioglu G, Ongen A, Dokmeci H, Celik SO and Dokmeci I. 2008. Determination of nickel and lead contents in soil and plant in Corlu, Turkey. J. Environ. Protec. Ecol. 9(3), 557–565.

Sanchary IJ and Imamul Huq SM. 2015. Interaction of arsenic with zinc uptake by Kalmi (*Ipomoea aquatica*). Bangladesh J. Soil Sci. 37(2), 47-53.

Sanchary IJ and Imamul Huq SM. 2017. Remediation of arsenic toxicity in the Soil-Plant system by using zinc fertilizers. J. Agric. Chem. Environ. 6, 30-37. DOI: 10.4236/jacen.2017.61002.

Sanchary IJ, Kabir KMJ and Imamul Huq SM. 2019. Macro and micro nutrient supply to soil and plants from sugar mill mud. Agric. Sci. 10 (2), 164-172. DOI: 10.4236/as.2019.102014.

Selvaraj K, Ramasubramanian V and Kumar BM. 2022. Phytoremediation of soil contaminated with arsenic, nickel and copper. *Indian J Environ Sci.* 26(2), 51-59.

Shaibur MR, Islam T, Adjadeh TA, Imamul Huq SM and Kawai S. 2012. Arsenic distribution in different parts of baranuniya (*Portulaca oleracea* L.) treated with elevated concentrations of arsenic. *Int. J. Sustain. Crop Prod.* 7(3), 36-46.

Soil Survey Manual. 1993. Soil survey division staff, soil conservation service. U.S. Department of Agriculture Handbook 18.

Suavé S, Hendershot W and Allen HE. 2000. Solid- solution partitioning of metals in contaminated soils: Dependence on pH, total metal burden, and organic matter. Environ. Sci. Technol. 34(7), 1125 – 1131.

Tye AM, Young S, Crout NMJ, Zhang H, Preston S, Zhao FJ and Mcgrath SP. 2004. Speciation and solubility of Cu, Ni and Pb in contaminated soils. Eur. J. Soil Sci. 55, 579- 590.

Von Burg R. 1997. Toxicology update: Nickel and some Nickel compounds. J. Appl. Toxicol. 17, 425- 431.

World Health Organisation (WHO). 1991. Nickel. Environmental health criteria, World Health Organization, Geneva, 1991, 108.