UDK 631.4

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NICKEL IN SOILS AND RESILIENT PLANTS ON ROADSIDES OF KERALA, SOUTH INDIA

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Nickel (Ni) is a common metal found in high quantities on roadsides. Systematic, two year investigations of 110 km roadsides of two traffic-dense roads of Kerala, South India, were carried out to assess the degree of accumulation of the metal in plants growing on these roadsides in relation to the amount of Ni in soils. Ni contamination of about 12 to 30 mg kg^{-1} observed on these roadside soils is quite moderate, but the metal accumulation in most of the plant shoots were found quite higher than that in natural vegetations. It was quite interesting to note that, of the 19 plants examined, all except *Chloris brbata Sw.,* accumulated Ni in their shoots much higher than that in the soils around them. In *Eclipta prostrata (L.) L.,* a very fast growing tropical species with significantly high aboveground biomass, Ni content of shoot was 48.2 mg kg^{-1}, about three times the amount of Ni in the soils. Overall assessment was that the contaminated roadsides of biodiversity rich tropics are significant places to find out species of high resilience to physico-chemical disturbance including heavy metals. Such investigations are significant to the preliminary identification of the metal accumulating potentials of many species.

Key words: nickel, soil, plants, roadsides.

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НИКЕЛЬ В ПОЧВЕ И УСТОЙЧИВЫЕ РАСТЕНИЯ НА ПРИДОРОЖНЫХ ПОЛОСАХ ШТАТА КЕРАЛА, ЮЖНАЯ ИНДИЯ

Никель (Ni) – распространенный металл, найденный в больших количествах на придорожных полосах. Были проведены систематические двухгодичные исследования 110 км обочин двух дорог с интенсивным движением в штате Керала (Южная Индия) для оценки уровня накопления металла в растениях, произрастающих на придорожных полосах, в отношении к содержанию Ni в почве. В придорожных почвах наблюдается умеренное загрязнение никелем – около 12–30 мг $кг^{-1}$, но выявленное содержание металла в большинстве стеблей растений значительно превышает его содержание в естественной растительности. Из 19 образцов растений, все, за исключением *Chloris brbata Sw.*, содержат в стебельной части большее количество Ni, чем почва, в которой они произрастают. В *Eclipta prostrata (L.) L.*, быстрорастущем тропическом виде с хорошо развитой надземной биомассой, содержание Ni в стебле – 48,2 мг $кг^{-1}$. Это количество примерно в три раза превышает количество Ni в почве. Общая оценка исследования: загрязнение придорожных полос с богатым тропическим разнообразием указывает на необходимость нахождения видов с высокой устойчивостью к физико-химическим нарушениям, включая тяжелые металлы. Такие исследования важны для предварительного распознания потенциала накопления металла во многих видах.

Ключевые слова: никель, почва, растения, придорожные полосы.

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НІКЕЛЬ В ҐРУНТІ ТА СТІЙКІ РОСЛИНИ НА ПРИДОРОЖНІХ СМУГАХ ШТАТУ КЕРАЛА, ПІВДЕННА ІНДІЯ

Нікель (Ni) – розповсюджений метал, знайдений у великих кількостях на придорожніх смугах. Були проведені систематичні дворічні дослідженнями 110 км узбіч двох доріг з інтенсивним рухом в штаті Керала (Південна Індія) для оцінки рівня накопичення металу в рослинах, які зростають на придорожніх смугах, відносно вмісту Ni в ґрунті. В придорожніх ґрунтах спостерігається помірне забруднення нікелем – приблизно 12–30 мг $кг^{-1}$, але виявлений вміст металу в більшості стебел рослин значно перевищує його вміст в природній рослинності. З 19 зразків рослин, усі, окрім *Chloris brbata Sw.*, містять в стебловій частині більшу кількість Ni, ніж ґрунт, в якому вони ростуть. В *Eclipta prostrata (L.) L.*, тропічному виді, що швидко росте, з добре розвинутою надземною біомасою, вміст Ni в стеблі – 48,2 мг $кг^{-1}$. Ця кількість майже в три рази перевищує кількість Ni в ґрунті. Загальна оцінка дослідження: забруднення придорожніх смуг з багатим тропічним різноманіттям вказує на необхідність знаходження видів з високою стійкістю до фізико-хімічних порушень, включаючи важкі метали. Такі дослідження важливі для попереднього визначення потенціалу накопичення металів в багатьох видах.

Ключові слова: нікель, ґрунт, рослини, придорожні смуги.

Roadsides are physically and chemically highly disturbed environments (Bakirdere and Yaman, 2008). Vegetations of challenged environments usually have a unique combination of species with specific adaptations. Learning the environment potentials of resilient species in all kinds of disturbed environments is highly significant to the skillful sustainable management of natural systems. Major direct applications of resilient species include reclamations of degraded lands and phytoremediations of contaminated soils (EPA, 2000), and there are also very many indirect uses with them. Specific genes that enable them resistant to disturbance (Pollard et al, 2002; Bert et al, 2003; Heaton et al, 2003) have uses in genetic engineering of better phytoremediation plant tools. Similarly, knowledge of specific enzymes or physiological mechanisms, which serve as biochemical reasons of hyper-tolerance (Peer et al, 2006) is useful in the complete elucidation of mineral accumulation processes of plants in general. Moreover, knowledge of specific micro-biota that is associated with such specialized plants that enable them to be resilient (Abou-Shanab et al, 2006) and behave as excluders/accumulators/hyper-accumulators has applications in various scientific programmes of soil and crop improvements. Instead of ignoring the resilient plants of disturbed environments as weeds or wastes, identification of the ecological potentials of all of them is the preliminary task of ecologists in general.

Heavy metals continuously accumulate in roadside soils and vegetations (Mashi et al, 2005), and an increase in concentrations of the same in urban top soils is an index to the extent of pollution (Massas et al, 2009). Heavy metals have been the subject of particular attention, because of their long-standing toxicity to plants, animals and humans when exceeding specific thresholds (Coskun et al, 2006). Heavy metals in soils transfer to aquifers and cause serious ecological threats to humans (Riga-Karandinos, 2006). Among the heavy metals with toxic impacts released from automobiles (Nriagu, 1979), Nickel (Ni) is one of the very toxic metal found in high quantities on roadsides. Moreover, knowledge of the increasing Ni pollution in soils as well as the functional role and toxic effects of Ni in plant growth are also significant (Chen et al, 2009).

The largest anthropogenic source of Ni is the burning of fuel and residual oils, and Ni concentrations in diesel exhaust are 500-10000 mg l^{-1} (Frey and Corn, 1967). Other sources of Ni on roadsides include wearing and tearing of Ni alloys and plating used in vehicles (WHO, 1991). Examination of nickel levels in vegetation is significant to learn its flow into grazing animals and their predators (Groppel et al, 1980), especially on Indian roadsides where animal grazing is common. Vegetations on roadsides of the State of Kerala are significant, because the State is situated in the Southern Western Ghats, which is one of the biodiversity rich regions in the world and a 'hotspot'. Therefore, investigations into tolerant plants on roadsides have high relevance in the region. Moreover, ecological function of metals within different metal accumulating *taxa* is needed to clarify the selective value of this ecologically and physiologically unique trait (Davis and Boyd, 2000).

In highly, physico-chemically disturbed natural communities such as roadsides, hyper-tolerant species are plants that survive in comparatively higher numbers than others, and the degree of hyper-tolerance of individual species may be measured in terms of their relative abundance. Nickel in tissues of hyper-tolerant roadside plants in relation to Ni in soils provides information whether some of them accumulate the metal more than that in the soil. Accumulation of metals in plant tissues excess of that in soils is a tendency of hyper-accumulators. Phytosociological parameters, especially the Relative Abundance (RA) of roadside vegetation is thus useful to the inventory of hyper-resilient plants which may have hyper-accumulation potentials.

Though many hundreds of Ni hyper accumulators are well known (Reeves et al.1996; Chaney et al, 1997; Prasad, 2005; Ghaderian et al, 2007) and phytomining is currently being practiced for nickel (Chaney et al, 2000), knowledge of more of such species is still in demand to meet the challenges of contaminations in diverse environments, especially in the tropics. Therefore, certain hyper-resilient plants were identified initially by means of phytosociological methods. Ni content in the shoots and roots of the 19 plants of high resilience were further examined in relation to the amount of the metal in the contaminated roadside soils around them during monsoons and summer seasons, for two years (2005-07). Since very rapid and selective uptake of metals, rapid transport to shoots, and very effective storage of metals in leaf cell vacuoles appear to provide the mechanisms for hyper accumulation (Chaney et al, 2007), analysis of the amount of Ni in shoots and roots of roadside annual herbs in relation to its amount in the soils were useful to account the species specific Ni accumulation potential of some of the common hyper-resilient plants on roadsides a biodiversity-rich zone, Kerala, South India.

MATERIALS AND METHODS

Sampling Area and Collection Procedure

The roadsides investigated are about 55 km each of two roads - the ‘Main Central Road’ (MC road) and the ‘Kottayam-Kumily Road’ (KK road) of average traffic densities of 15300 vehicles per day - in Kottayam District (total area 2208 km^2; total population 1952901; population density of 884 per km^2; latitude $9^0 15^l$ to $10^0 21^l$ and longitude $76^0 22^l$ to $77^0 25^l$) of Kerala State, South India (Government of India, 2007; Kerala Government Report, 2008). The region has a tropical wet climate with total annual average rainfall of about 3130.33 mm received mainly in two monsoons – southwest monsoon (May to August) and northeast monsoon (September to December), separated by a break of summer (January to April). During the summer also, there are random summer showers in the zone.

Specific urban and rural sampling sites of 1 m distance from tar-edge and 1 km length of both the sides were identified on both the roads. Urban sites were those with high degree of traffic densities and other anthropogenic disturbances (trampling by people and crushing by vehicles) whereas rural sites were those with comparatively lower degree of disturbances of both the types. Samples representing monsoons (south-west and northeast monsoons; May to December) and summer (January to April) seasons were collected from these sites using quadrat methods (Trivedy and Goel, 1986). Quadrats of 40 cm X 40 cm size, of approximately 0.1 m^2 (Uzbeck, 1981) were used; at each site, 100 to 110 quadrats from both sides of the roads at random (of both the seasons) were observed. Altogether there are eight urban sites (4 from KK road and 4 from MC road) and five different rural (3 from KK road and 2 from MC road) sites (Fig. 1). Total 1350 quadrats were taken from all the sites in two seasons.

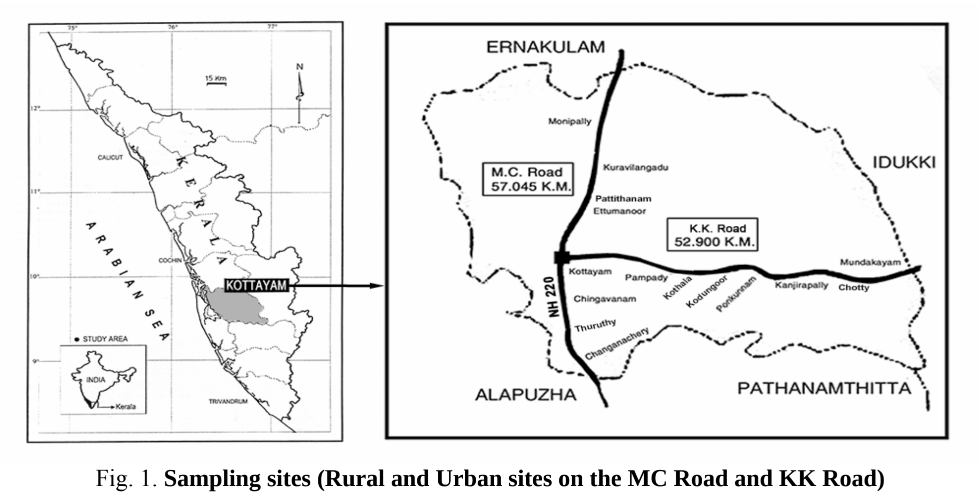


Fig. 1. **Sampling sites (Rural and Urban sites on the MC Road and KK Road)**

Plants and soil samples of were collected separately (at random) in pre-washed polythene bags. Phytosociological measures were done in the field and recorded in the field book. Plant species were dug out carefully using a polythene shovel. From all the different sites specimens of each plant species available was collected from different quadrats at random during different months of the monsoon and the summer seasons. Different specimens of each species from a site were kept in a common bag; different species were kept in separate bags. During each sampling time, surface soil samples (about 500 g of top soil 0-5cm) of each site were taken from quadrats at random and the soil samples from different quadrat of a site were put in separate labeled bags.

Measurement of Ni in Soil Samples

Altogether there were 30-40 packets of monthly soil samples representing both the seasons from a specific roadside site, kept undisturbed for air drying in dust-free racks in the laboratory. Prior to chemical analysis soil samples representing a season (15-20) of each site was divided into three equal groups and each group was mixed thoroughly. The three different composite soil samples from each site were treated as three distinct samples of each season. 500 g of each air dried composite sample was ground separately to pass through a 2 mm sieve. About 5g of the homogenized sample from each group was ground into fine powder using agate mortar and pestle and further dried in hot air oven at 70°C for 72 hrs to constant weights (ISO 1995). Exactly 1 g from each of these finely ground soil samples were weighed out using an electronic balance into properly cleaned 250 ml glass beakers.

Digestion was performed by adding 12 ml of *aquaregia* (3:1, v/v, Concentrated HCl to Concentrated HNO_3) into the beaker covered with watch glasses on a hotplate for 3 h at 110°C (APHA 1998). After evaporation to near dryness carefully, the sample was diluted with 20 ml of 2% (v/v with water) nitric acid and transferred into a 100 ml volumetric flask after filtering through Whatman no. 42 filter paper and diluted to 100ml with double distilled water (Chen and Ma 2001; Hseu et al. 2002) and used for chemical analyses. Average of the three samples of each season was taken as the average amount of Ni of the site in that specific season. Thus the average Ni content of all the thirteen sites for both the seasons was found out.

Measurement of Ni in Plant Samples

Plant specimens were uprooted along with the entire roots from the field using a polythene shovel. From each site, mature plants (plant in the flowering stage) from different quadrats (where the species were available) of a site were brought to the laboratory; each species in separately labeled packet. In the laboratory, after each collection, all specimens of each species from different quadrats of a site were washed together thoroughly many times with tap water followed by distilled water to remove completely the adhered dust and dirt, and air-dried. After the air-drying all specimens of each species from a site were separated into roots and shoots and kept in separate paper bags labeled as root or shoot a species with a site code; specimens were then dried in hot air oven at 70°C for 72 hrs to constant weights and kept undisturbed for chemical analyses.

For each species, for each rural or urban site, there were many mature plants (plant in the flowering stage) collected at random from different quadrats of both the seasons. However, all species were not available at all sites. The number of available sites for a species varied from 7 to 13. Altogether 30-40 specimens were collected for each available species from a site belonging to the two seasons. At the time of chemical analyses (carried out after field studies) the roots and shoots of all plant specimens of each species from a site were powdered separately using agate mortar and pestle and thoroughly mixed. About 25 g each of the root and shoot sample of a species from a site was then further ground to fine powder. Shoot and root sample preparations for chemical analysis of all species were carried out similarly. Shoot samples of all the species were analyzed, whereas the analysis of root samples were carried out for only four species of grasses, which had significantly high root mass.

The digestion procedure was carried out on a hot plate as per standard methods (APHA 1998; Fakayode and Onianwa 2002; Ho and Tai 1988; Zarcinas 1987). 500 mg each of powdered sample of root and shoot of different species from each site were placed separately into 250 ml beakers (in triplicate) and added 10 ml of concentrated nitric acid, heated for 45 min at 90°C, swirled if frothing occurred and occasionally washed down the sides of the beaker with double distilled water. Increased the temperature to 120°C and continued digestion at this temperature until about 1 ml of acid remained. Continued the heating and added concentrated HNO_3 in necessary volume until digestion became complete as was shown by a light colored, clear solution. The samples were not permitted to drying during digestion. After the digestion, the extract was cooled and diluted to 20 ml with 1% v/v nitric acid. The extract was filtered through Whatman no. 42 filter paper into a 100 ml volumetric flask and made up to 100 ml by adding doubled distilled water, and used for chemical analysis. Reagent blanks for both the plant and soil analysis were also prepared in all cases for calibrations. Average of Ni in a species from all the sites of both the season was taken as the average Ni of the species on these roadsides.

All the chemicals used were analytical grade compounds of Merck Company. Reagent bottles, beakers, and volumetric flasks were cleaned by soaking overnight in 2 N hydrochloric acid, rinsed with water and oven dried at 60°C. Chemical analyses for Ni of both soil and plant samples were carried out in a Flame Atomic Absorption Spectrophotometer (Perkin Elmer model 3110) at the Chemical Oceanography Lab of the Department of Marine Science, Cochin University of Science and Technology, Kochi, Kerala, India. Concentrations of the metal in both the soil and plant samples were computed as mg metal per kg dry sample (mg kg^{-1}). In order to compare Ni content of soils with that of plant samples, average of the metal in sites from where plant specimens of each species were collected was used. Statistical analyses such as ANOVA and correlations were carried out using SPSS package and MATLAB.

RESULTS

Ni is one of the common metals found in high quantities on roadsides. Therefore, knowledge of the increasing Ni pollution in soils as well as the functional role and toxic effects of Ni in plant growth are significant. Average seasonal value of Ni in soils at the five different rural and eight different urban sites belonging to both the roads are given in Table 1 and Table 2 respectively. The amounts of Ni in these roadside soils were found varied from 12.6 mg kg^{-1} to 30.8 mg kg^{-1}. There were no significant seasonal difference in Ni across different urban sites ($0.05<P = 0.7800$) or the different rural sites ($0.05<P = 0.5519$); similarly, there were no significant differences in Ni over the different urban and rural sites, neither during the monsoon ($0.05<P = 0.5718$) nor during the summer ($0.05<P = 0.9770$). Significantly strong positive correlations were found for Ni in soils over the two seasons at the rural zones ($r = 0.897$); but at urban sites, the correlations in Ni over two seasons were not significant.

Table 1

Average Ni in soils at different urban sites of two roadsides in two seasons

Sl No	Sites	Average Ni in soils (mg kg^{-1})	
	Road 1: MC Road	Monsoon	Summer
1	Changanacherry	19.40	18.00
2	Chingavanam	22.10	20.90
3	Kottayam	21.30	17.20
4	Ettumanoor	22.80	20.30
	Road 2: KK Road		
5	Mundakayam	17.50	24.60
6	Kanjirapally	12.60	17.00
7	Ponkunnam	28.40	20.20
8	Pampady	15.30	16.70
Mean Value with SD		**19.93± 4.89**	**19.36± 2.68**

Table 2

Average Ni in soils at different rural sites of two roadsides in two seasons

Sl No	Sites	Average Ni in soils (mg kg^{-1})	
	Road 1: MC Road	Monsoon	Summer
1	Thuruthy	20.00	21.10
2	Pattithanam	12.00	13.80
	Road 2: KK Road		
3	Chotty	24.80	15.90
4	Kodungoor	30.80	26.70
5	Kothala	25.20	23.10
Mean Value with SD		**22.56± 7.03**	**20.12± 5.26**

Though, a total of eighty five species were recorded on these roads, only 19 of them with a significantly high relative abundance were included in the chemical studies. Mean Ni in the shoots of all of these 19 plants and that of roots of the four grasses with significant amount of root mass are given in Table 3. The average of Ni in soils from where each species was collected was also calculated. Ni in soil environment calculated in this way for different species were significantly different (P = 0.000) and the mean of Ni in different plant tissues of different species were also significantly different (for shoot P = 0.000; for roots, P = 0.008). Average of Ni in plant shoots varied from 7.95 mg kg^{-1} to 48.2 mg kg^{-1}.

Table 3

Ni in Plant samples in relation to corresponding soil samples

Sl No	Name of Species	Ni in samples mg/kg						Relative Abundance	
		Soil		Plant shoot		Plant root		Mean	SD
		Mean	SD	Mean	SD	Mean	SD		
1	2	3	4	5	6	7	8	9	10
1	*Eleusine indica (L.) Gaertn.*	19.76	± 4.01	35.52	± 9.37	15.50	± 2.09	13.59	±04.63
2	*Cynodon dactylon (L.) Pers.*	20.87	± 3.62	30.13	± 13.43	1.50	± 0.14	08.38	±08.48
3	*Axonopus compressus (Sw.) P.Beauv.*	19.44	± 4.47	34.12	± 12.26	25.93	± 12.91	21.19	±19.93
4	*Cyperus compressus L.*	18.92	± 1.86	32.70	± 7.64	28.4	± 07.98	01.57	±01.53
5	*Chloris brbata Sw.*	20.07	± 3.72	7.95	± 2.16	–	–	02.62	±08.83
6	*Kyllinga nemoralis (J.R & G. Fors.) Dandyex Hutch. & Dalz.*	19.82	± 6.73	29.00	± 10.63	–	–	02.08	±01.84
7	*Hedyotis corymbosa (L) Lam.*	19.77	± 4.12	29.02	± 9.14	–	–	03.41	±02.74
8	*Scoparia dulcis L.*	19.53	± 2.87	32.33	± 10.49	–	–	02.06	±01.08
9	*Cleome rutidosperma DC.*	20.50	± 2.53	29.80	± 9.56	–	–	02.37	±01.63
10	*Vernonia cinerea (L.)*	19.10	± 1.62	34.77	± 20.98	–	–	02.05	±01.29
11	*Phyllanthus amarus Schum. & Thonn*	18.97	± 3.12	20.88	± 10.08	–	–	01.26	±01.16

Continuation of table 3

1	2	3	4	5	6	7	8	9	10
12	*Pilea microphylla (L.) Liebm.*	17.78	± 3.44	36.82	± 8.76	–	–	03.77	±03.43
13	*Portulaca oleracea L.*	20.22	± 4.64	26.28	± 12.57	–	–	03.11	±03.10
14	*Amaranthus viridis L.*	19.75	± 2.22	27.32	± 8.21	–	–	01.99	±02.07
15	*Euphorbia hirta L.*	17.90	± 2.52	29.75	± 7.84	–	–	00.95	±00.85
16	*Eclipta prostrata (L.) L.*	18.76	± 2.25	48.2	± 3.50	–	–	00.64	±00.64
17	*Leucas aspera (Willd.) Spreng.*	19.56	± 1.65	33.93	± 13.28	–	–	00.18	±00.38
18	*Peperomia pellucida (L.) Kunth*	20.60	± 3.81	26.13	± 9.81	–	–	00.07	±00.20
19	*Aerva lanata (L.) Juss. ex Schult.*	19.56	± 1.65	34.53	± 8.10	–	–	00.56	±00.57

The average relative abundance of the 19 species was also found significantly different (P = 0.006). Paired correlations between Ni in the shoots and the average of that in different soil samples from where each species was collected (Table 4) showed that significant positive correlations were observed only in one species, *Pilea microphylla (L.) Liebm*. Nickel in plant shoots of most of the species was found significantly higher than that in the soil, except in three species; *Phyllanthus amarus Schum. & Thonn., Portulaca oleracea L.,* and *Peperomia pellucida (L.) Kunth.*

Table 4

Paired Correlations between Ni in soils and plant shoot

		N	Correlation	Significance
Pair 1	SO1 and SH1 ...	14	-.187	.522
Pair 2	SO2 and SH2 ...	11	.173	.611
Pair 3	SO3 and SH3 ...	11	-.348	.294
Pair 4	SO4 and SH4 ...	4	.548	.452
Pair 5	SO5 and SH5 ...	4	.179	.821
Pair 6	SO6 and SH6 ...	4	.050	.950
Pair 7	SO7 and SH7 ...	13	.148	.630
Pair 8	SO8 and SH8 ...	12	.381	.221
Pair 9	SO9 and SH9 ...	7	-.085	.857
Pair 10	SO10 and SH10 ...	7	-.054	.908
Pair 11	SO11 and SH11 ...	7	.373	.410
Pair 12	**SO12 and SH12 ...**	**7**	**.807**	**.028**
Pair 13	SO13 and SH13 ...	8	-.045	.915
Pair 14	SO14 and SH14 ...	8	.556	.153
Pair 15	SO15 and SH15 ...	4	-.898	.102
Pair 16	SO16 and SH16 ...	3	-.940	.222
Pair 17	SO17 and SH17 ...	3	-.522	.650
Pair 18	SO18 and SH18 ...	3	-.365	.762
Pair 19	SO19 and SH19 ...	3	.013	.992

SO = Ni in soils; SH = Ni in plant shoot

DISCUSSION

Nickel is naturally present in various ores and to a lesser extent in soil. The range of Ni level observed in roadside soils of South India was 12 to 30 mg kg^{-1}, which may be considered moderate to high but non-toxic; because most natural soils have Ni levels less than 10 mg kg^{-1} and the level critical to human health is 60 mg kg^{-1} or above (Government Report, 2007). In both the urban and rural sites, seasonal (summer and monsoon) differences in the amount of Ni in the soils (Fig. 2 & 3) were not significantly different. Lack of seasonal differences in Ni at all the different sites revealed that the monsoon washing had no serious influence on the concentration of the metal on roadside soils, and the form of metal compounds on roadside soils was quite immobile, which is against the previous observations of WHO (1991) that Ni exhibit a high mobility within the soil profile. However, the Ni mobility depends on soil type as well. The amount of Ni in different rural and urban sites was not significantly different, which point to the fact that slight differences in traffic densities as that existed at the urban and rural sites here have no influence on Ni on roadsides.

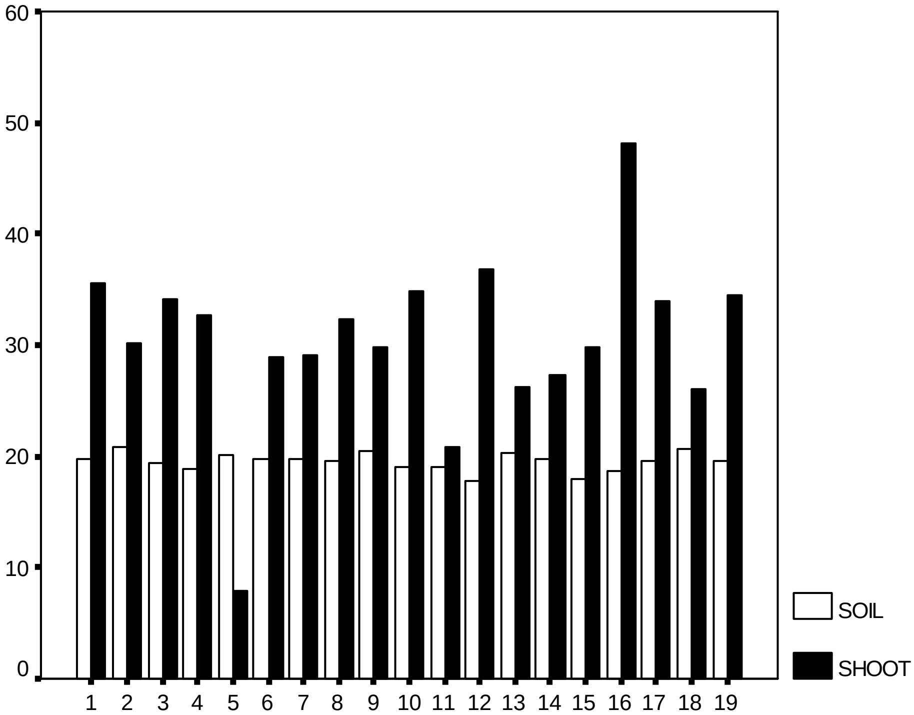
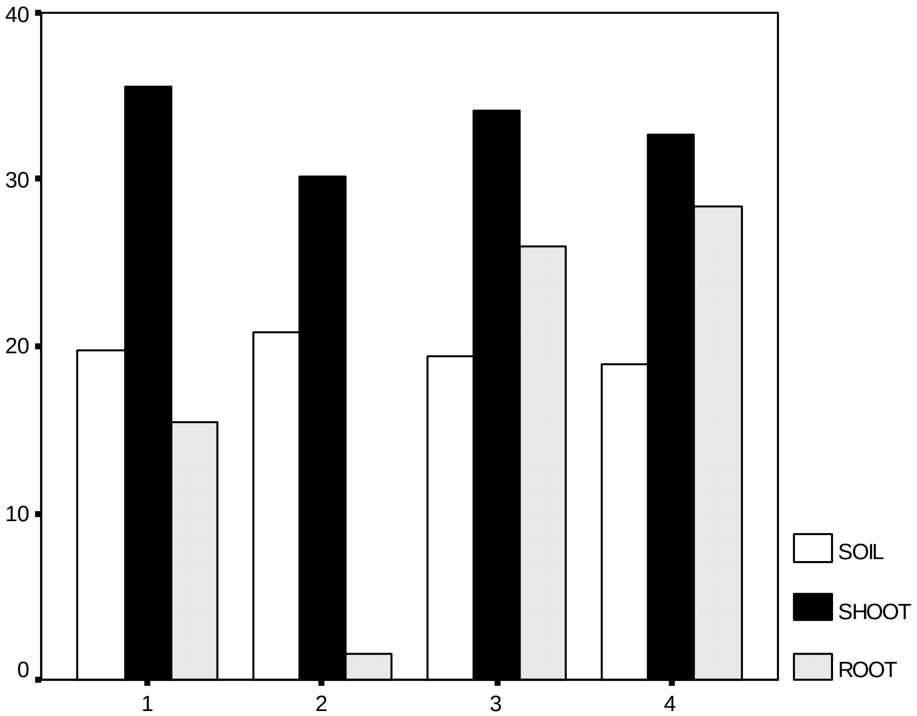


Fig. 2. **Comparison of Ni in Soil and plant shoots (mg kg $^{-1}$)**

Another important dicot species which accumulated Ni more than twice the amount of that in the soil was *Pilea microphylla (L.) Liebm*. Among the dicots it was the plant with the highest of relative abundance. Though, the plant is a fast growing species, the plant possess negligible quantities of biomass. It may also be noted that among the four hyper-resilient grasses with very high relative abundance, *Eleusine indica (L.) Gaertn, Axonopus compressus (Sw.) P.Beauv.,* contained in their shoots almost twice the amount of Ni than that in the soil. Therefore, these species are also subjected to further experimental trials to learn more about their Ni accumulation potentials. A very significant observation was that among the 19 resilient species studied, only one species *Chloris brbata Sw*, alone contained Ni in amounts lesser than that in the soil; only $1/3^{rd}$ of the soil content Ni was observed in the shoots of this plant.

Ni in plant shoots on roadsides were found to be ranging from 7.95 to 48.2 mg kg^{-1}, which was quite higher than what is expected in natural vegetations; the expected amount of Ni in most natural vegetation range from 0.05 to 5 mg kg^{-1} dry weight (NAS, 1975). It was quite interesting to note that, of the 19 plants examined, all except *Chloris brbata Sw.,* accumulated Ni in their shoots much higher than that in the soils around them (Fig. 4). Ni levels above 50 mg kg^{-1} dry weight are toxic for most plants (NAS, 1975; WHO, 1991); but in one of the roadside species, *Eclipta prostrata (L.) L.,* Ni content of shoot was 48.2 mg kg^{-1}. This plant belongs to one of the already known Ni hyper accumulator families, *Asteraceae*, and is a very fast growing tropical species with significantly high aboveground biomass. Of course, the amount of accumulation was 1/3rd of the highest Ni levels report of 150.9 mg kg^{-1} dry weight (Jenkins, 1980). However, the importance of this plant is that Ni in the shoot of this plant was almost three times that in the soil. The plant was found growing luxuriantly on roadsides without any toxicity symptoms; because Ni toxicity in plants is often characterized by chlorosis and necrosis of the leaves, stunting of the roots, deformation of various plant organs and wilting (Prokipcak and Ormrod, 1986); nothing of that kinds of symptoms were observed in the roadside specimens of this species. Therefore, experiments with this species at significantly higher dozes of Ni in soil are continuing to establish its metal accumulation potentials.



1. *Eleusine indica (L.) Gaertn.*
2. *Cynodon dactylon (L.) Pers.*
3. *Axonopus compressus (Sw.) P.Beauv*
4. *Cyperus compressus L.*

Fig. 3. **Comparison of Ni in Soil, Shoots and Roots of grasses (mg kg^{-1})**

Among the metal hyper accumulators known, 76 % are Ni hyper accumulator plants (Reeves and Baker, 2000). The number of Ni accumulators amounts more than three hundred species (Chaney et al, 1997) with the accumulation capacity of Ni > 10 mg g^{-1}. The most common Ni hyper accumulator plant is *Allyssum*, certain species of that accumulate Ni at concentrations exceeding 1000 mg kg^{-1} (Ghaderian et al, 2007). However, the significance of the present finding was that these roadside plants accumulated the metal in their shoots in much higher quantities than that in the soil where they grew. Moreover, most of these plants are hyper-resilient species existing on physico-chemically, highly disturbed environments and fast growing with high biomass. Correlation studies between relative abundance and metal accumulation revealed that both the values were not at all interrelated; the plant in the highest relative abundance was not the plant with highest metal accumulation potentials.

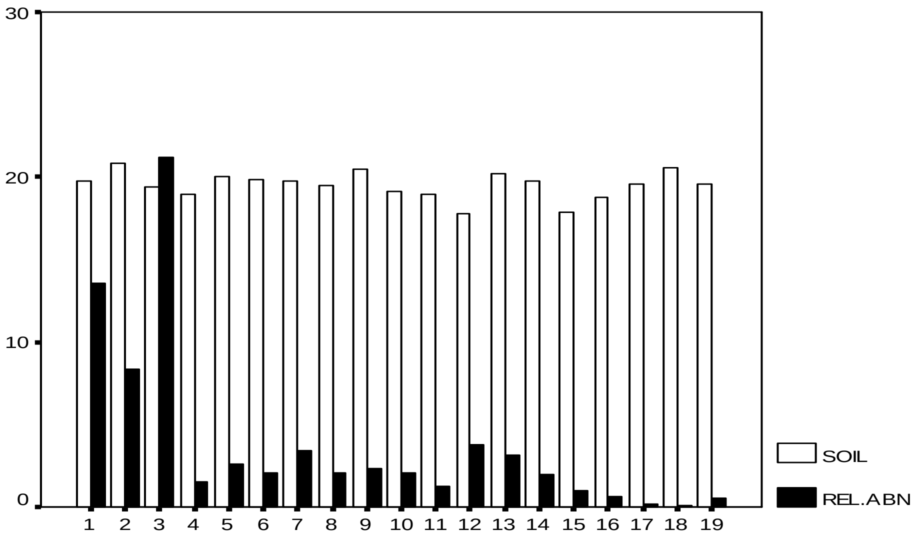


Fig. 4. **Ni in shoots of plants (mg kg $^{-1}$) in relation to their relative abundances (%)**

Overall assessment was that contaminated roadsides of biodiversity rich tropics are significant places of botanical expeditions to find out hyper-resilient species against physico-chemical disturbance, which are of highly ecologically significant in many ways. Such inventories of plants and their environmental relationships are suggested as the task of botanists and ecologists towards the betterment of eco-technologies such as phytoremediation in general (EPA, 2000).

ACKNOWLEDGEMENTS

Support extended to the second author for carrying out this research work under the Faculty Improvement Programme (FIP) of University Grants Commission (UGC) New Delhi is gratefully acknowledged.

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Надійшла до редколегії 03.05.11