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Determination of Transfer Factor of Different Elements from Soil to Fenugreek

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Abstract

The soil to plant transfer factor of elements is an important parameter which governs the concentration of elements in plant to that in soil. Transfer factor depends on both different parameters such as soil characteristics, plant type and climatic conditions. Present study determines the transfer factor of different elements from soil to fenugreek. Both soil and plant samples are collected near Mankhurd railway station, Mumbai. Soil and plant samples are processed and concentration of different essential and trace elements is determined in both type of samples. To ensure the quality of data, concentration of these elements were also determined in reference standard materials being processed along with the samples. Results indicate that the transfer factor value is very less for Cr, Mn, Fe, Co and Ni ~10^{-3}-10^{-4} while it is appreciably high for elements such as Na and K. Difference in transfer factor value for different elements were tried out to correlate with the physicochemical properties of soil and the bioavailable form to the plant.

Keywords: *Transfer Factor; Trace elements; Essential elements*

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Aims

Trace elements are released into the environment from the natural weathering of rocks and minerals and from various sources related to human activity [1,2]. Although the concentration of these elements occurring in nature is generally low, they may directly or indirectly affect the chemical composition of foodstuff and animal feed, potable water supplies and airborne particulates and dust. Bioavailability of trace elements depends on the physical, chemical, and biological properties of the soil and processes such as sorption, speciation, redistribution and mobility [3]. Although TEs are mainly inherited from the parent rocks, their distribution within the soil profile and between the solid and liquid phases reflects the properties of soil types. Quantitatively, TEs are negligible chemical constituents of soils, but are important since some of these elements are essential for plant growth, while at high concentrations, these elements are toxic to plants, animals, and humans [3].

Plants are a rich source of various essential elements. They contribute protein, vitamins, iron, calcium [4] and various essential elements such as K, Na, Mg, Mn, Zn, Cu which are required for body functioning. The concentration of elements in any plant depends both on soil properties and external environment. Plants can take up elements from soil either by root uptake or by adsorption through external environment [5,6]. In both of these processes, root uptake is considered to be more important [5,6]. However the uptake of different elements will be different which will depend both on the properties of soil as well as on the plant. One of the properties that are very important in deciding the uptake of any element is their distribution coefficient (K_d) which differs widely for different elements and for different soils. Determination of K_d value is very important in effective management of the trace elements in the soil.

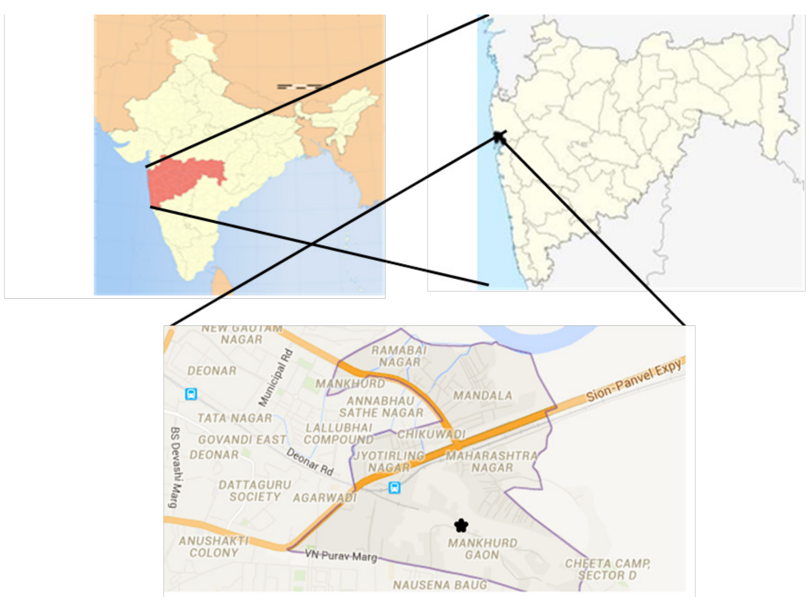
The soil–plant transfer of trace elements is a very complex process governed by several factors such as soil properties, plant properties and climatic conditions [7-9]. Several factors control the processes of mobility and availability of elements; in general, they are of geochemical, climatic and biological origin. Thus, the prediction of trace element uptake by plants from a given growth media should be based on several biotic and abiotic parameters that control their behavior in soil. The risk to both the environment and human health of a given trace element is a function of its mobility and phytoavailability and the amount of trace element in plant will decide its behavior whether it will be toxic or essential. Therefore it is very important to understand the transfer factor values of elements in different soil to plant system.

In the present study we have studied the transfer factor values of different elements from soil to fenugreek. The soil has been characterized for its different physiochemical properties and the concentration of different essential and trace elements was determined. The transfer factor values of different elements were calculated and an attempt was made to correlate the results with the soil properties.

Methods

Study site

Both vegetable and soil samples were collected from field near Mankhurd Railway station. The area selected has a high traffic load and nearby local train line and located in Mumbai (18.9750°N, 72.8258°E) which is known for its high population with an estimated city population of 18.4 million. City has an average annual temperature of 27.2°C (81°F) with an average annual precipitation of 2,167 mm (85 inch). The average total annual rainfall in Mumbai is 2,146.6 mm (85 inch).



Sample collection and processing

Soils samples were collected from the multiple locations in the field at the depth of 15-20 cm. The selection of depth was done according to the root length of plant. Fenugreek (*Trigonella foenum-graecum*) was also collected from multiple locations in the field.

Collected samples were immediately sealed in polythene bags, labeled and stored. For processing of vegetable its non-edible portion was removed and washed with water to remove the soil and air dried. It is then finely chopped, labeled and ashed at a temperature of 450ºC in muffle furnace (make). Dried vegetable sample were weighed and stored. Microwave digestion was used for processing of samples. For vegetable 5 ml of conc. HNO_3 and 2 ml of HF were added to 0.1g of dried sample and for soil digestion 2 ml of conc. HNO_3, 2 ml of HF and 6 mL of HCl were added to 1g of dry soil. Samples were then evaporated to dryness (hot plate open beaker) and a final solution of 25 ml with 0.25% of HNO_3 was prepared for subsequent analysis.

For quality assurance purposes, certified reference materials, NIST SRM 1570a (Spinach leaves) and NIST SRMs 1573a (tomato leaves) (as control sample) were analyzed for vegetable and SRM 2709a (San Joaquin soil) and SRM 2710a (Montana soil) were analyzed for soil. The standards and samples were subjected to similar digestion procedure and measurement condition. Physico-Chemical characterization of soil. To determine physico-chemical characteristics of the soil, it was sieved by 2 mm mesh and standard analytical methods and procedures were used:

pH

By electrometry in a soil–solvent suspension (1:2.5) [10].

Organic matter content (OM)

Pre drying at 150°C followed by pyrolysis at 375°C for 16h [10].

Particle size characterization

The particle size distribution of soil samples was determined using a laser diffraction particle size analyzer (CILAS, France, Model 1190). Particle size distribution analysis was performed with a small-angle light scattering apparatus equipped with a low-power (2m W) Helium-Neon laser with a wavelength of 633 nm as the light source. A 2g aliquot of the sample was introduced into the ultrasonic bath. Finally, the particle size distribution was obtained using the Mie theory.

Measurement of total Carbon, Nitrogen and Hydrogen (C, N & H)

The total carbon, nitrogen and hydrogen in soil, sediment and HA were estimated using C H N S-O elemental analyser (Flash EA 1112 Series, Thermo Finnigan, Italy). About 1.2 mg of dried sample was wrapped tightly in preweighed tin (Sn) container, put into an auto sampler and dropped into the combustion reactor. Tin, in contact with an extremely oxidizing environment, triggered a strong exothermic reaction and allowed to reach the temperature approximately 1800°C. Under extremely oxidizing environment, C, N & H are produced in the form of gaseous mixture of CO_2, N_2, and H_2O respectively. Finally, these gaseous mixtures were allowed to flow into the gas chromatographic column where separation occurs. The eluted gases were conveyed to thermal conductivity detector (TCD) and quantified as percentage of C, N and H in the sample. The elemental analyzer was calibrated and standardized using BBOT Standard {*2, 5-bis (5-tert-butyl-benzoxazol-2-yl)-thiopen,* $C_{26}H_{26}N_2O_2S$, Thermo Finnigan, Italy)}. The minimum detection limit for C, N and H was calculated to be 0.08%.

Determination of elemental concentration

Elemental concentration in both soil and plant was analyzed using atomic absorption spectroscopy, 904 BT, double beam atomic absorption spectrometer (GBC Australia) which uses hollow cathode lamp as radiation source. The concentration of the analyte was determined by calibration curve method. For analysis of Ca, Na, K and Mg the sample was diluted to 100 times and Cs is added for analysis of Na and K while Sr was added for analysis of Mg and Ca. All samples were analyzed in triplicate. Care was taken to avoid cross contamination of samples. All chemicals used for analysis were obtained from Merck or they are of electronic grade. Deionized water (Barnstead T11, Barnstead Nanopure, Thermo Scientific) was used throughout the experiment.

Result and Discussion

Physico-chemical characterization of soil has been carried out which shows that the pH and OM content of soil is 6.8 and 8.6% respectively. Particle size analysis shows that soil has 4.7%, 71.8% and 23.5% of clay, silt and sand respectively. C, H, N, S analysis shows that soil has 2.1% N, 1.9% C, 1.5% H, and 0.88% S. Elemental concentration was determined in both soil and Fenugreek after digestion using AAS. Each sample was analyzed in triplicate. For quality assurance elemental concentrations were also determined in NIST SRM 1570a (Spinach leaves), NIST SRMs–1573a (Tomato leaves), SRM 2709a San Joaquin soil and SRM 2710a Montana soil. The concentrations of analyzed elements were compared with that of certified values. A comparison of determined values with the certified values shows good agreement within ± 10%. Relative standard deviation (RSD) values were < 5% in most cases indicating good precision of the measurements. Therefore, our experimental data are expected to be accurate and precise within ± 10%.

Transfer factor (TF) from soil to plant is defined as

$$TF = \frac{Concentration\ in\ plant\ (\frac{mg}{kg})}{Concentration\ in\ soil\ (\frac{mg}{kg})}$$

Elements	Soil	Fenugreek	TF
Na (%)	0.85 ± .05	0.14 ± .02	0.16
K (%)	0.78 ± .1	0.54 ± .06	0.7
Mg (%)	3.16 ± .04	0.12 ± .02	0.04
Ca (%)	4.94 ± .3	0.06 ± .01	0.012
Fe (%)	6 ± .05	$2.78 \times 10^{-3} \pm 0.08 \times 10^{-3}$	4.6×10^{-4}
Co (mg/kg)	64.86 ± .05	0.02 ± .003	2.8×10^{-4}
Mn (mg/kg)	1466.25 ± 100	5.63 ± .15	0.004
Ni (mg/kg)	175.3 ± .05	0.395 ± .05	0.0022
Zn (mg/kg)	149.42 ± 10	12.8 ± .55	0.086
Cr (mg/kg)	650 ± 20	0.205 ± .03	3.15×10^{-4}
Cu (mg/kg)	35.64 ± 2.05	1.91 ± .05	0.054
Pb (mg/kg)	20.84 ± 1.05	0.966 ± .05	0.046

Table 1: *Concentration of elements in soil and Fenugreek.*

Table 1 shows the concentration of different element in both soil and plant along with their TF values. Result shows that for Cr, Mn, Fe, Co, Ni the concentration of elements in plants is 1000-10,000 times less as compared to that in soil. Transfer factor value for the corresponding elements is very less ~10^{-3}-10^{-4}. These values predict that the concentration in plant can be known if the concentration in soil is known. Since different elements have different concentration in both soil and plant, the transfer factor values for each element can be correlated with the soil properties and the element of interest.

Chromium (Cr)

Amounts of Cr in soil range from 1.4-1100 ppm, depending on the soil type, with an average world-wide level of 54 ppm [11]. Chromium is present in both Cr^{3+} and Cr^{6+} oxidation state. Cr^{3+} is the more stable form and is only slightly mobile while Cr^{6+} is highly toxic and more mobile [11]. The transfer factor value for Cr in the study is found to be 3.15×10^{-4} suggesting very low mobility of Cr in the soil. It suggests that Cr might be present in Cr^{+3} state. It has also been suggested that the presence of organic matter promotes reduction of Cr^{6+} to Cr^{3+}, which may lead to low plant availability [11].

Cobalt (Co)

The overall range for cobalt in soils on a world-wide basis is 0.1-70 ppm [11] and the average amount is 8 ppm [12]. It is present in soil as Co^{2+} and Co^{3+} [11]. The transfer factor value for Co in the study is found to be 2.8×10^{-4} suggesting very low mobility of Co in the soil. It has been suggested that the manganese oxide minerals are the most important factor governing Co distribution and availability in the soil [11,13] and crystalline Mn oxide minerals can retain almost all soil Co even that applied to soil as fertilizer [13]. Iron oxides, clay minerals and organic matter may also adsorb cobalt thereby leading to very less transfer in plants, and the availability is affected by the type of clay minerals and organic matter on which it is adsorbed [11].

Copper-Cu

Average Cu concentration in soil ranges from 1-140 ppm [11]. Cu can also occur in soil in both Cu^{+} and Cu^{2+} state. Transfer factor value for Cu in the studied system is found to be 0.054. Copper in soil can be fixed by adsorption, precipitation, organic chelation and complexation, as well as microbial fixation [11].

Iron-Fe

Iron is commonly found in soil in amounts ranging from 0.5-5.0% [11] with overall average soil content of 3.8% [12]. The most common minerals containing iron are hematite and goethite [11,14]. In soil, iron occurs predominantly as oxides and hydroxides, it is present in soil solution in 3+ and 2+ oxidation states and as iron chelates, and is absorbed by plants mainly in the form of Fe^{2+} [11]. It has been shown that at pH < 6.5 Fe^{3+} is reduced to Fe^{2+} while at pH > 6.5 Fe^{3+} is major dominating species. Since the soil studied in this system has a pH value of 6.8 which shows that Fe^{3+} should be the major dominating form. As already mentioned that Fe^{3+} is less bioavailable form for plants, our results shows on transfer factor value for Fe also suggests that Fe mainly exist in Fe^{3+} form.

Lead-Pb

Pb occurs as a sulfide in rocks and replaces K, Ba, Sr and Ca in minerals [14]. Pb is least mobile of the heavy metals, [11] and accumulates in the surface horizons of soils and is not usually leached [14]. Its concentration in solution is low, and this limited amount is available for plant uptake [14]. In soil it is mainly associated with organic matter, clay minerals and oxides of Mn, Fe and Al [11]. Transfer factor values for Pb in the present studied system is found to 0.046.

Manganese–Mn

Mn concentration in soil ranges from 7-9200 ppm with average mean concentration of 437 ppm [11]. Mn exists in different oxidation states as Mn^{2+}, Mn^{3+}, and Mn^{4+} [11,15] but only Mn^{2+} is absorbed by plants [12]. Manganese rapidly switches between different oxidation states depending on soil condition that ultimately governs Mn solubility in soil [11] and its transfer factor value. Mn^{2+} is highly soluble and therefore the transfer factor value increases under reducing conditions in which Mn is present as Mn^{2+}, and decreases under oxidizing conditions [11]. Transfer factor value for Mn in the present study is found to be 4×10^{-3}. This low value of transfer value suggests that Mn is not present in its highly soluble form as Mn^{2+}. Since the pH of soil is ~6.8, it also suggests that the other oxidation states of Mn are more dominating at this pH, mainly Mn^{3+} leads to less bioavailability of Mn for plant.

Nickel-Ni

Nickel concentration in soil ranges from 1-450 ppm [11] with an average of 40 ppm [16]. Ni^{2+} is the most stable state of Ni in the soil environment [16]. Ni bioavailability decreases as soil pH increases. The transfer factor value for Ni in the present study is found to be 0.0022.

Zinc-Zn

Zinc content in soil ranges from 10-300 ppm. Weathering of zinc minerals leads to the release of Zn^{2+}, which is the most common and mobile zinc ion in soil [11] and the main form utilized by plants [17]. Zinc solubility in soil is high as compared to other trace elements. At pH < 7 there is less adsorption of Zn^{2+}, which may result in leaching from sandy soils [11]. At high soil pH, the formation of insoluble compounds (Zn (OH) 2 and ZnCO3) may restrict Zn availability [12]. As a result, deficiencies are likely to be found. The high transfer factor value for Zn in the present study can be correlated with more leaching of Zn^{2+} ions from soil leading to more bioavailability of Zn^{2+} ions.

A lot of work has been done to understand the transfer factor values for different elements in different soil plant systems. Earlier Rangnekar., *et al*. [18,19] have studied the transfer factor for Ni, Co and Pb in the similar plants in artificially contaminated soil in Mumbai where they have found that the transfer factor value for Ni and Co is very less and there is relatively less accumulation in leaves. However for Pb the transfer factor value is quite high as compared to both Ni and Co. This result is similar to our study where we have also found that the transfer factor value for Ni and Co is less as compared to Pb. Similarly Chang., *et al*. [20] have also studied the transfer factor values for different elements from soil to different vegetables where they have found that the transfer factor value for different elements are ~10^{-2}-10^{-3}. Jayadev., *et al*. [21] have also studied the transfer factor values in similar plants where they have found an appreciably high transfer factor values due to the contaminated water used for irrigation.

Conclusions

Concentration of different essential and trace elements is determined in both soil and fenugreek. Transfer factor values were determined for all these elements and for Cr, Mn, Fe, Co and Ni the values are found to be very less ~10^{-3}-10^{-4}. These values of transfer factor were tried to correlate with soil property and the bioavailable form of the element. Our result indicates that the concentration of these elements in plant is within the limits and there is no hazard from their consumption.

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