EFFECT OF ^{137}Cs ON THE TRANSFER OF NUTRIENT ELEMENTS AND ON GROWTH OF LETTUCE (*Lactuca sativa*)

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ABSTRACT

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A pot experiment was conducted during the month of March, 2006 to May, 2006 in the net house of the department of Soil, Water and Environment of University of Dhaka to examine the effects of ^{137}Cs on the growth of different parts (root and shoot) of lettuce *(Lactuca sativa)* and nutrient uptake by lettuce grown in three representative soils of Bangladesh (Pabna, Gazipur and Munshigang) having different soil characteristics (pH, organic matter content, clay content and CEC). The soils belonging to three different series were used to see the effects of ^{137}Cs on the dry weight production of roots and shoots of the lettuce plant and two treatments of ^{137}Cs were used in this purpose. From the study it has been observed that the imposed radiation in the soils reduced the uptake of nitrogen by 15.19%, potassium by 15.67% and calcium by 42.58%. The average dry weight production of shoot of lettuce in the three soils was also decreased by 46.83% though no significant growth reduction of root was noticed due to the imposed radiation in soil. Imposed radiation in soil reduced the average dry weight production of lettuce (root and shoot) by 24.22% and showed the negative impact on the growth of lettuce plant.

Key words: cesium-137 effect, nutrient uptake, lettuce, growth

INTRODUCTION

Radionuclides are unstable isotopes, which undergo radioactive decay; some occur naturally in air, rocks, soils and plants of concentrations that give measurable amounts of radiation and some are produced artificially as in nuclear weapon testing. Among all the radiations released from different kinds of nuclear and non-nuclear power installations, the most penetrating are neutrons and gamma-rays and they constitute the major external exposure hazards to occupational workers, the population at large and the immediate environment. Exposures to radiations are generally regarded undesirable at all levels although no harmful effects are known to occur in case of very low level of exposures (Anonymous, 1987).

Radioactivity in Bangladesh is due to natural deposition in Sylhet and Coastal areas of the Bay of Bengal and was detected in tertiary sandstones of Cox's Bazar, Teknaf and in exposed rocks of Sylhet. In these areas cereals (rice), vegetables (tomato, lettuce), tea and fruits (water melon, banana) are being grown continuously for many years and are taken up by the people specially the local inhabitants in their daily diet. The grasses grown in the field are also fed to grazed cows and goats. These radioactive materials are carcinogenic and might have entered into the food chain and hence into the human body through cereals, vegetables, fruits, milk, milk products, meat etc. These radiations, if beyond permissible limit, may cause diseases to man as well as to animals. These are not only somatic effects, these are genetic effects and the effects are long lasting effects.

Radionuclides released into the environment reach the human body through several transfer processes (Anonymous 1978). The soil- to-plant transfer factor is one of the important parameters are widely used to estimate the internal radiation dose from radionuclides through food ingestion. These are also used as parameters for transfer models for predicting the concentration of radionuclides in foodstuffs and for estimating dose impacts to man (Ng *et al.,* 1979). The levels of radionuclides in the environment and food have been extensively compiled by United Nations Scientific Committee on the Effects of Atomic Radiation (Anonymous 1982).

Bangladesh is a densely populated country and all living beings here are in harmony with the nature. So, a minimum of pollution like radiation hazard, industrial pollution or waste disposal has a tremendous impact on us as well as on the environment. The distribution of radionuclides in nature and xenophobic exposure of radiation due to misuse or mishandling of radioactive materials or installation, their concentration and movements can seriously affect human and animal lives by entering into the body through different metabolic path ways (Anonymous 1990). The objective of this experiment is to study the influence of ^{137}Cs on the transfer of some nutrient elements from soil to a vegetable plant Lettuce (*Lactuca sativa*) and growth of it's of roots and shoots.

METHODS AND MATERIALS

A pot experiment was conducted during the month of March, 2006 to May, 2006 to study the effects of soil properties on the transfer of ^{137}Cs into plants and its transfer factor. Lettuce (*Lactuca sativa*) was used as test crop. The soil samples were collected from different areas and were processed for subsequent pot experiment and necessary analyses. After harvesting the crop, soils were kept for subsequent analyses. The bulk soil samples differing in textural classes and other properties were collected at a depth of 0-15 cm from three different locations namely Gazipur Sadar Thana, district- Gazipur; Shirajdikhan Thana, district- Munshiganj and Chatmohar Thana, district- Pabna. Some of the general characters of the three investigated soils with their correlation with different soil classification systems have been presented in the next page (Table 1).

Table 1. General characteristics of three soil series

Soil series	Location	AEZ	Land type	FAO soil units	USDA soil units
Bhatpara	Mirjapur Gazipur Sadar Thana Gazipur	Madhupur Tract	High land	Eutric Regosol	Aeric Haplaquent Entisols
Pagla	Kieyne Shirajdikhan Munshiganj	Old Brahmaputra floodplain	Medium low land	Eutric Fluvisol	Aeric Fluvaquentic Haplaquept Inceptisol
Gopalpur	Bothor Chatmohar Pabna	Ganges floodplain	High land	Not classified	Aquic Eutrochrepts

Description of the soil series

The soils used in this experiment correspond to three representative soil series of Bangladesh namely Bhatpara, Pagla and Gopalpur series. The series thus selected from different locations had wide variations in their physical, chemical, minerialogical and physico-chemical properties.

(A) Bhatpara series

Bhatpara series includes imperfectly drained, olive-coloured, heavy clays occupying gently undulating to gently rolling topography in closely dissected areas of the Madhupur tract. The topsoil consists of a few inches of grey, mottled yellow and brown, silty clay loam to silty clay, which is sticky and plastic when wet and very hard and cracked when dry. Below this occurs olive, or olive-grey, heavy clay, which is somewhat, mottled yellow and reddish yellow. Large lime concretions are sometimes found in these soils, usually below a depth of 1-2 feet. Because of the mottling, Bhatpara series have an overall pale olive-brown appearance, when dry, which readily differentiates them from the redder soils of Gerua series. They differ from Demra soils in occupying dissected relief and in being relatively better drained. Bhatpara soils occur in the southwest of the Madhupur tract, mainly patchily amongst Gerua soils. These soils are highly erodible and have very poor soil-moisture relationships. The heavy topsoils make tillage difficult and they are poorly suited for irrigation. Bhatpara soils are very poorly suited for agriculture. They do not support forest and are best left under grassland. Pasturage could be considerably improved by better management, including rotational grazing and use of fertilizers. Only by costly leveling they could be made suitable for sustained agricultural use, with irrigation they could then produce two transplanted rice crops per year (Reconnaissance soil survey, Dacca district, 1965).

(B) Pagla series

Pagla series includes grey soils developed on low floodplain ridges on the old meander floodplain. The topsoil consists of about 6 inches of grey (dry) to very dark grey (wet) silty clay, iron-stained along root channels and cracks. Below this occurs grey to olive-grey, finely mottled brown or reddish brown, silty clay or clay which cracks into blocks on drying; these blocks have grey to dark grey coatings. This layer may continue for several feet, or it may be underlain at 2-3 feet by lighter textured material. Pagla soils differ from Savar Bazar soils in being slightly acid rather than alkaline in the subsoil; they are also rather darker, less compact in the upper subsoil and have smaller subsoil blocks. Pagla soils are almost level to gently sloping, slowly permeable and poorly retentive of moisture in the dry season. They are flooded up to 8-10 feet deep for about six months. Irrigation would be easy but monsoon season drainage difficult and costly. They would respond moderately well to good management, including use of fertilizers. Tillage would be improved by the use of moderately heavy equipment.

Pagla soils are well suited for paddy cultivation throughout the year. With irrigation, good yields of dry land crops or of boro paddy could be obtained in the dry season. In addition, with costly flood protection, two very good paddy crops could be grown in the monsoon season and a very good dry land crop in the dry season (Reconnaissance soil survey, Dacca district, 1981).

(C) *Gopalpur series*

Gopalpur series includes poorly drained, seasonally flooded soils developed in moderately fine textured Gangetic alluvium. They occupy nearly level to very gently undulating upper and middle slopes of young abandoned levees on the Ganges meander floodplain. Gopalpur soils consist of olive-brown, friable, calcareous clay loams and silty clay loams usually overlying a moderately fine textured substratum. They show a weak coarse blocky structure in the subsoil with patchy coating on ped faces. They are calcareous and moderately alkaline in reaction throughout the profile. Gopalpur soils differ from associated soils as follows: from Sara in their finer texture and in occupying lower topographical positions where they occur together; from Rupper and Bangaon which are coarser in texture, looser in consistence and have less developed profiles; and from Ishurdi and Pakuria which are finer in texture, heavier in consistence and have stronger structure. They differ from Silmondi and Sonatala soils on the neighbouring Karatoya meander floodplain in their browner colour and in being calcareous. Seven phases have been recognized: highland phase, highland irregular relief phase, medium highland phase, medium highland irregular relief phase, medium lowland phase, lowland flood hazard phase, lowland erosion hazard phase.

Table 2. Physical properties of three soil series

Name of the soil series	Moisture %	Particle size distribution			Textural Class
		Sand (%)	Silt (%)	Clay (%)	
Bhatpara	3.36	6.8	54.3	39	Silty clay
Pagla	6.42	1.3	40	59	Clay
Gopalpur	3.85	6.3	65	29	Silty clay loam

Table 3. Chemical and physico-chemical properties of three soil series

Name of the soil series	pH (1:2.5)	EC µS	Organic matter (%)	Total N (%)	C/N Ratio	CEC (Meq/100g)
Bhatpara	5.40	43	2.34	0.368	4	9
Pagla	5.85	189	1.98	0.178	6	30
Gopalpur	7.14	363	1.56	0.332	3	14

Gopalpur soils are mainly double and triple cropped land. Medium highland phase: Aus/jute- rabi crops and Aus/jute- transplanted Aman-rabi crops. Medium lowland phase: Aus/jute- rabi crops and mixed Aus and broadcast Aman-rabi crops. Lowland phase: broadcast Aman either alone or mixed with Aus and followed by rabi crops. Locally: Sugarcane, year-round rotations of vegetables and some fruit trees (Reconnaissance soil survey, Pabna district, 1981). Results of the physical and chemical analysis of the original soil samples are presented in the tables 2, 3, 4 and 5.

Table 4. Contents of available nutrients in the studied soils

Name of the soil series	Available (mg/kg)			Available (Meq/100g)				Available (mg/kg)			
	N	P	S	K	Na	Ca	Mg	Fe	Mn	Zn	Cu
Bhatpara	48	0.98	1.19	0.048	0.172	0.89	3.221	23	36	5.7	0.19
Pagla	54	1.49	3.56	0.107	0.448	5.63	3.245	33	22	17.5	0.72
Gopalpur	37	2.84	2.91	0.119	0.55	11.3	3.772	53	16	13.4	0.39

Table 5. Contents of total nutrients in the studied soils

Name of the soil series	Total (%)			Total (Meq/100g)				Total (mg/kg)			
	N	P	S	K	Na	Ca	Mg	Fe	Mn	Zn	Cu
Bhatpara	0.368	0.052	0.027	1.62	5.96	3.05	7.18	116	415	34	13
Pagla	0.178	0.115	0.055	7.12	29.12	4.17	45.85	188	179	108	47
Gopalpur	0.332	0.158	0.045	7.23	26.87	7.29	53.28	253	116	75	26

A pot experiment was carried out in the net house of the Department of Soil, Water and Environment, University of Dhaka. Total 9 pots were used for the experiment. Each pot was filled with 10 kg soils. The soils were previously pulverized and mixed well with doses of fertilizers as per recommendation of the Fertilizer

Recommendation Guide (Anonymous, 1989). The experiments were arranged in a completely randomized design.

Treatment combination

In order to study the effect of ^{137}Cs on the uptake of different soil nutrients and growth of roots and shoots of Lettuce, Liquid solution of 73260 Bq ^{137}CsCl was mixed uniformly with 10 kg soil in each pot. Treatments for the experiment were as follows:

To = Control (3 pots of each soil series where no ^{137}Cs was applied)
T_1 = 73260 Bq ^{137}Cs/ pot

The seeds were sown by spreading them over the surface of the soil in the pot. Then the seeds were covered by a thin layer of soil. The pots were left in a dark place for germination. Weeds grown in the pots were controlled by uprooting. After 15 days of germination, the seedlings were thinned keeping few seedlings (4-6) in each pot. Besides, a knife was used to loosen the soils at a regular interval of seven days. Lettuce was harvested after 45 days of sowing. The plants were uprooted and the roots and the basal part of the shoot were washed with tap water. The plants were separated for roots and shoots and fresh weight of each part were recorded and then prepared for radioactivity measurement. Some of the plant samples were initially dried in the sun and finally oven-dried at 70^{o} C for four days. The oven-dry weight of samples was recorded. The samples were ground and stored for analysis.

In laboratory, basically there were three main parts of the experiments-

a) Soil analysis
b) Plant analysis
c) Radioactivity measurement.

Most convenient methods having greater precision were used in this experiment. The radioactivities in soil and plant samples were measured by gamma ray spectrometry system. The measurement was carried out at the Health Physics Laboratory of Atomic Energy Centre, Bangladesh Atomic Energy Commission at Ramna, Dhaka. A brief description of the equipments used is given in the following sections. The gamma ray spectrometry system consists of an HPGe detector, a detector shielding, a preamplifier, a linear amplifier, high voltage power supply, a multichannel analyzer system and a printer. The high voltage bias was supplied to the detector through the preamplifier from a high voltage supplier (HV Supply Model ORTEC 459). A high voltage bias of 3200 volts was applied for the present measurements in order to operate the HPGe detector.

Determination of ^{137}Cs in soil and plant samples

270 g of soil from each soil samples and various amounts of plant were taken in cylindrical plastic pots of equal diameter, which are used as sample container in order to maximize the counting efficiency and precision and to minimize the self-absorption for that specific geometry. The basic performance studies on various parameters, e.g. operating voltage, lower and upper level discriminators, energy calibration; relative and absolute efficiencies of the detector system for various sample volumes were carried out. The efficiency was calculated by dividing the obtained count rate by the rate of disintegration of standard sample mixed with ^{137}Cs radionuclide. Having established the efficiency curve, the measurements of radioactivity in plant and soil samples were carried out. At first, the empty container was counted for 1000 sec to obtain background count. Then each sample was counted for 1000 sec. The background count was subtracted from the gross spectrum obtained with the sample. The net spectrum was used for subsequent analysis.

Having determined the integral counts under the interested gamma-energy peaks, the gamma activity was calculated based on the measured efficiency of the detector from the following equation:

$$A = \frac{C}{\varepsilon(E)p}$$

Where,

A = Activity in Bq.
C = Peak area counts in cps.
ε (E) = Efficiency on the diameter at energy E (MeV) and
P = Photon emission probability at energy E (MeV).

Soil properties and fertility status

The values of soil properties like pH, organic matter, particle size distribution, clay mineral content, CEC, total and available contents of mineral nutrient were presented in the tables 2, 3, 4 and 5. The pH in water (1:2.5) of the soils of Bhatpara, Pagla and Gopalpur series was 5.40, 5.85 and 7.14 respectively, (Table 3). Several chemical and physical analyses were done according to the methods described by Huq and Alam (2005). According to the classification by Anonymous (1989), Bhatpara series belongs to strongly acid, Pagla to moderately acid and Gopalpur to neutral. pH of the soils has been influenced mainly by parent material and vegetation, which are responsible for such variations. The organic matter contents of the soils were 2.34% for Bhatpara, 1.98% for Pagla and 1.56% for Gopalpur series (Table 3). Bhatpara and Pagla series fell in the medium and Gopalpur series fell in the low range (Anonymous, 1989). These variations in organic matter content might be due to the differences in natural vegetation, landscape, fertility status and intensity of cultivation in those areas. The classification of BARC systems has been presented in appendix table 1. The Department of Soil Survey (Now SRDI) has analysed about 11,000 samples from 2500 representative soil profiles covering agriculturally important areas of Bangladesh and found that the organic matter content of soils were generally low; it ranges from 0.3 to 1.5% in upland soils. 1.5 to 2% in the medium low land areas and 2.0 to 3.5% in the low land areas. In Bil areas, this fraction is about 4% (Hossain, 1998). Haque *et. al.,* (1992) also reported that most agricultural soils of Bangladesh have low organic matter content. This was in well agreement with Gopalpur series. The C/N ratio values in the studied soils ranged from 3 to 6. The highest value of C/N ratio (6) was obtained in Pagla series, followed by Bhatpara (4), and Gopalpur (3) soil series (Table 3). The variations of C/N ratio values in the different soils may be due to the difference in the degree of decomposition of organic matter. The cation exchange capacity (CEC) of the soils was 9, 30 and 14 meq/100g for Bhatpara, Pagla and Gopalpur soil series, respectively (Table 3). Bhatpara and Gopalpur series fell in the medium range, while Pagla series fell in the very high range (Anonymous, 1989). The variation in CEC is associated with the type of clays and amount of organic matter content in soils.

Growth and yield characteristics of plants

Growth may be defined as an increase in mass, which is accompanied by change in form. It is usually desirable to give some quantitative expression to the amount of growth, which is accomplished by a plant during a given period of time. Various methods have been adapted to measure plant growth. The principal measures, which have been employed for this purpose, are increase in length of the stem and root and other organ of the plant, increase in the area of leaves and increase in dry and fresh weight of plant. The yield of a crop may be considered in biological as well as agricultural terms. “Biological yield” has been defined as the total production of plant material by a crop, whereas “the economic and commercial yield” takes into account only those plant organs, which for particular crops are cultivated, and harvested.

Of the various growth and yield parameters fresh weight of roots/pot and shoots/pot of lettuce plants were considered for the present investigation. The analysis of variance (ANOVA) of the data was computed to determine the F-value. The test of significance of treatments was calculated by Duncan’s New Multiple Range Test (DMRT).

DRY MATTER PRODUCTION OF LETTUCE

Yield of root

Values of the dry weight of root (g/pot) of lettuce grown in three different soil series as affected by the soil properties and application of ^{137}Cs (T_1) have been evaluated and presented in the table 6 and fig 1. The results are significant at 1% level. The test of significance of root yield obtained in different soils was computed by Duncan’s New Multiple Range Test (DMRT) at 5% level of significance. The average dry weight of lettuce root treated with ^{137}Cs (T_1) was 1.19, 1.12 and 1.84 g/pot in Bhatpara, Pagla and Gopalpur soil series, respectively (table 6). The lettuce roots obtained from soil of Gopalpur series differed significantly from those of both Bhatpara and Pagla soil series. But there was no difference between Bhatpara and Pagla series. The results in the table also showed that the average dry root production of lettuce, when no ^{137}Cs was artificially applied (T_0), was significant at 1% level. The test of significance was computed by Duncan’s New Multiple Range Test (DMRT) at 5%. The average dry weight of lettuce was 1.78, 1.47 and 2.26 g/pot (T_0) in Bhatpara, Pagla and Gopalpur soil series, respectively. The soil of Gopalpur series differed significantly with those of Bhatpara and Pagla series. But there was no significant difference between Bhatpara and Pagla series. The highest root production was in Gopalpur series (2.26 g/pot; T_0) and the lowest was in Pagla series (1.12 g/pot; T_1).

Yield of shoot

The values of dry matter production of lettuce shoot were presented in the table 6 and 1. The table showed that the results in both cases (T_1 and T_0) were significant at 5% level. The test of significance of shoot yield obtained in different soils was computed by Duncan’s New Multiple Range Test (DMRT) at 5% level of significance. The average dry weight of lettuce shoot was 11.09, 9.81 and 8.56 g/pot (for T_1) in Bhatpara, Pagla and Gopalpur soil series, respectively (table 6). The lettuce roots obtained from soil of Bhatpara series differed significantly from those of both Gopalpur and Pagla soil series. But there was no difference between Gopalpur and Pagla series. The average dry weight of lettuce was 6.95, 15.82 and 16.10 g/pot (T_0) in Bhatpara, Pagla and Gopalpur soil series, respectively. The soils of Pagla and Gopalpur series differed significantly with that of Bhatpara soil series. But there was no significant yield difference between Pagla and Gopalpur series. This was due to similar properties of soil in both series. The highest shoot production was in Gopalpur series (16.10 g/pot; T_0) and the lowest was in Bhatpara series (6.95g /pot; T_0). This was due to the favourable soil properties in Gopalpur series for vegetable production (Table 6).

Table 6. Differences in dry matter yield (g/pot) of root and shoot of lettuce grown on three investigated soils

Plant parts	Treatments	Name of the soil series: Bhatpara	Pagla	Gopalpur
		Dry weight (g/pot)		
Root	T_0	1.78b	1.47b	2.26a
	T_1	1.19b	1.12b	1.84a
Shoot	T_0	6.95b	15.82a	16.10a
	T_1	11.09a	9.81b	8.56b

Same letters in a row are not significantly different

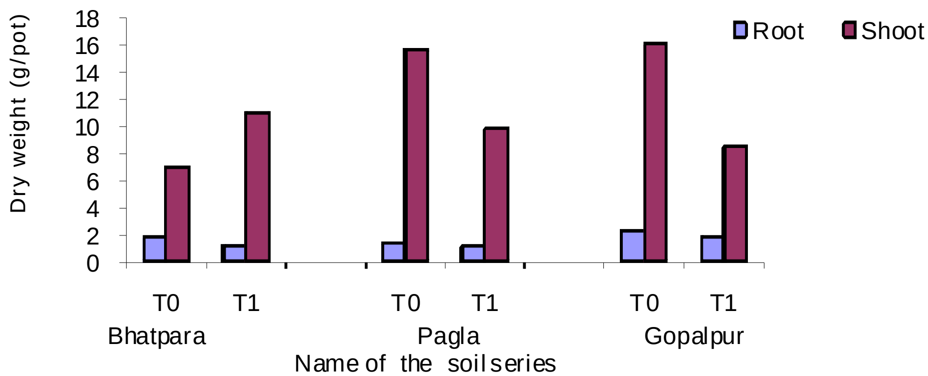

Figure 1. Differences in dry matter yield (g/pot) of roots and shoots of lettuce grown on three investigated soils

Table 7 showed the comparison (between plant parts and between treatments) of average dry matter production (g/pot) of lettuce and it was observed that the yield of shoot was higher than the yield of root. From the table 7, it was also observed that the yield was high at controlled condition than the ^{137}Cs treatment.

Table 7. Comparison (among the plant parts and between treatments) of average dry matter (g/pot) production of lettuce

Plant parts	Name of the soil series: Bhatpara	Pagla	Gopalpur	Mean
	Dry weight (g/pot)			
Root	1.48b	1.29b	2.05b	1.61b
Shoot	9.02a	12.81a	12.33a	11.39a
	Dry weight (g/pot)			
Treatments	Bhatpara	Pagla	Gopalpur	Mean
T_0	4.36b	8.64a	9.18a	7.39a
T_1	6.14a	5.46b	5.2b	5.60b

Same letters in a column are not significantly different.

Mineral nutrition of lettuce as affected by soil properties

Like Kalmi, soil properties also affected the nutrient availability and uptake into lettuce as an experimental plant. To evaluate the behavior of ^{137}Cs in lettuce plant, the contents of N, P, K, Na, Ca and Mg were determined in root and shoot of lettuce.

Nitrogen concentration in lettuce plant

The average nitrogen content of lettuce root and shoot as influenced by different soil properties and application of ^{137}Cs were presented in the table 8 and fig 2. Analysis of variance (ANOVA) of the results of three different soil series showed that the results of lettuce root was significant at 5% level (when ^{137}Cs was applied) and the results was significant at 1% level of significance (at control condition). But nitrogen contents in shoots differed significantly at 5% level of significance (Table 8) both at control condition (T_0) and ^{137}Cs treatment (T_1). The test of significance of nitrogen contents in different soils was computed by Duncan's New Multiple Range Test (DMRT) at 5% level of significance.

Table 8 showed that lettuce root of Bhatpara and Pagla series accumulated more nitrogen (3.2%) than Gopalpur series (2.90%) at control condition. Concentration of nitrogen in lettuce roots of Bhatpara was not different from that of Pagla series. Bhatpara and Gopalpur series also differed significantly from Pagla series when artificially ^{137}Cs was applied. But there was only a slight difference of nitrogen concentration between Pagla and Gopalpur series. Table 8 and fig. 2 showed that the highest nitrogen content in root was observed in Bhatpara and Pagla series (where no artificially ^{137}Cs was applied) and the lowest in Pagla series (2.46%; T_0). Accumulation of nitrogen in lettuce shoot of Bhatpara and Pagla series differed significantly from Gopalpur series (T_0) but there was no significant difference between Bhatpara and Pagla series. Lettuce shoot of Gopalpur series accumulated the highest amount of nitrogen (T_1; table 8) than Bhatpara and Pagla series. But there was only a slight difference of nitrogen concentration between Pagla and Bhatpara series. The highest amount of nitrogen was observed in lettuce shoot at Pagla series (3.6%; T_0) and the lowest was observed at Bhatpara series (2.17%; T_1).

Table 8. Mean concentration of nitrogen in roots and shoots of lettuce

Plant parts	Treatments	Name of the soil series		
		Bhatpara	Pagla	Gopalpur
		Concentration (%) of nitrogen		
Root	T_0	3.20a	3.20a	2.90b
	T_1	3.17a	2.46b	2.86b
Shoot	T_0	3.50a	3.60a	3.35b
	T_1	2.17b	2.57b	3.53a

** Values in rows having same letter are not significantly different.*

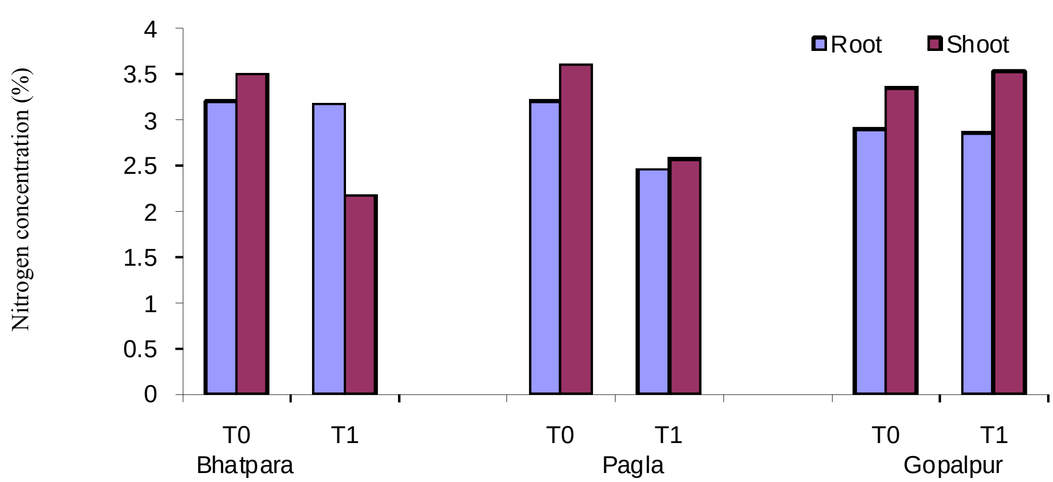

Figure 2. Mean concentration of nitrogen in root and shoot of lettuce

The comparison of nitrogen content in roots and shoots of lettuce were presented in the table 9. The results showed that lettuce shoots generally accumulated more nitrogen than lettuce roots. However, there was a significant difference in nitrogen contents between the treatments (T_0 and T_1). The results showed that the roots did not have any influence on the root to shoot transfer of nitrogen.

Table 9. Effects of plant parts and treatments on nitrogen concentrations of lettuce grown on three investigated soils

Plant parts	Name of the soil series			Mean
	Bhatpara	Pagla	Gopalpur	
	Concentration (%) of nitrogen			
Root	3.18a	2.83b	2.88b	2.96b
Shoot	2.83b	3.08a	3.44a	3.12a
	Concentration (%) of nitrogen			
Treatments	Bhatpara	Pagla	Gopalpur	Mean
T0	3.35a	3.40a	3.12b	3.29a
T1	2.67b	2.51b	3.19a	2.79b

Values in columns having same letters are not significantly different

Phosphorus concentration in lettuce plant

Mean values of the phosphorus concentration in root and shoot of lettuce as affected by the soil properties and application of ^{137}Cs was evaluated and presented in the table 10 and fig 3. Results were statistically significant (F-test) at 1% level. The test of significance of different concentration means was calculated by Duncan's New Multiple Range Test (DMRT) at 5% level of significance.

Table10 showed that phosphorus concentration in lettuce roots of Pagla and Gopalpur series were the highest (For both T_1 and T_0) and differed significantly from Bhatpara series (For both T_1 and T_0) but there was no significant difference in phosphorus concentration in lettuce root between Pagla and Gopalpur series (For both T_1 and T_0). Lettuce root of Gopalpur series accumulated the highest amount of phosphorus (0.115%; T_1) and lowest amount of phosphorus in Bhatpara series (0.033%; T_1).

Table 10 also showed that lettuce shoot of Bhatpara series also accumulated the lowest amount of phosphorus and differed significantly from others for both cases. The highest amount of phosphorus in lettuce shoot was accumulated in Pagla and Gopalpur series and significantly differed from that of Bhatpara series (For both T_1 and T_0) and the lowest amount of phosphorus in lettuce shoot was accumulated in Bhatpara series (0.042%; T_0) and significantly differed from that of Pagla and Gopalpur series. From the table 4.17 it was also found that there was no significant difference in phosphorus concentration in lettuce shoot between Pagla and Gopalpur series.

Table 10. Mean concentration of phosphorus in roots and shoots of lettuce

Plant parts	Treatments	Name of the soil series		
		Bhatpara	Pagla	Gopalpur
		Concentration (%) of phosphorus		
Root	T_0	0.036b	0.096a	0.071a
	T_1	0.033b	0.101a	0.115a
Shoot	T_0	0.042b	0.174a	0.169a
	T_1	0.072b	0.152a	0.180a

Values in rows having same letter are not significantly different

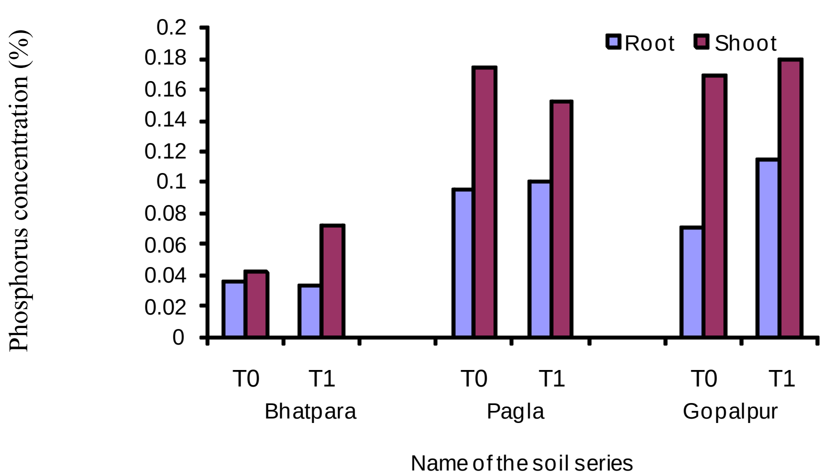

Figure 3. Mean concentration of phosphorus in roots and shoots of lettuce

Table 11 showed that phosphorus contents in lettuce root and shoot were significantly different and there was also a significant difference in phosphorus concentrations in lettuce plants due to application of ^{137}Cs, except Pagla series. It was observed that lettuce shoots accumulated more phosphorus than lettuce roots. It was also found that phosphorus concentration was high in ^{137}Cs treated soil. The differences of phosphorus concentration in root and shoot was mainly due to the variation in phosphorus contents in soils and differences in soil properties, which influenced phosphorus availability, absorption and its transfer into lettuce plants.

Table 11: Effects of plant parts and ^{137}Cs treatments on phosphorus concentrations in lettuce grown on three soils

Plant parts	Name of the soil series			Mean
	Bhatpara	Pagla	Gopalpur	
	Concentration (%) of phosphorus			
Root	0.034b	0.098b	0.193a	0.108b
Shoot	0.057a	0.163a	0.174b	0.131a
	Concentration (%) of phosphorus			
Treatments	Bhatpara	Pagla	Gopalpur	Mean
T_0	0.039b	0.135a	0.120b	0.098b
T_1	0.052a	0.126b	0.147a	0.108a

Values in columns having same letters are not significantly different

Potassium concentration in lettuce plant

The average concentrations of potassium in root and shoot of lettuce as affected by soil properties and application of ^{137}Cs was presented in the table 12 and fig 4. Analysis of variance (ANOVA) of the data obtained in three soil series showed that potassium content in lettuce plant was enhanced significantly at 1% level (T_0) and 5% level (T_1). The test of significance of potassium content in different soil was computed by Duncan's New Multiple Range Test (DMRT) at 5% level of significance.

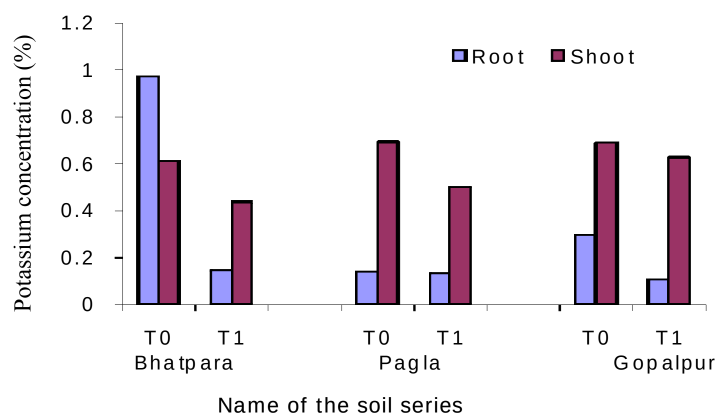

Figure 4. Mean concentration of potassium in root and shoot of lettuce

Table 12 showed that potassium content in root of Gopalpur series differed significantly from Bhatpara and Pagla series both at control condition and ^{137}Cs treatments. But there was no significant difference of potassium contents in roots grown on Bhatpara and Pagla soil series (For both T_1 and T_0). Table 12 also showed that the highest potassium content was recorded in roots of Gopalpur series (1.35%; T_0) and the lowest was recorded in roots of Bhatpara series (0.837%) when artificially ^{137}Cs was applied.

From the table 12, it was found that the potassium content in lettuce shoot of Bhatpara series at treatment, T_0 differed significantly from Pagla and Gopalpur series but there was no significant difference in potassium contents of shoot between Pagla and Gopalpur series. It was also evident from the table 12 that there was no significant difference in potassium content of Pagla and Gopalpur soil series (when ^{137}Cs was applied) and Pagla and Gopalpur series differed significantly from that of Bhatpara series. The highest potassium content was observed in lettuce shoot of Bhatpara series (1.475%; T_0) and the lowest was found in shoot of Bhatpara series (1.062%; T_1).

Table 12. Mean concentration of potassium in roots and shoots of lettuce

Plant parts	Treatments	Name of the soil series		
		Bhatpara	Pagla	Gopalpur
		Concentration (%) of potassium		
Root	T_0	1.025b	1.050b	1.350a
	T_1	0.837b	0.937b	1.137a
Shoot	T_0	1.475a	1.250b	1.170b
	T_1	1.062b	1.362a	1.287a

Values in rows having same letter are not significantly different

Table 13 showed significant differences in potassium concentration among different plant parts and between two treatments (T_0 and T_1) of lettuce plant, which revealed that, application of ^{137}Cs had marked influences on the transfer of potassium into plants. From the table 13 it was observed that lettuce shoots accumulated more potassium than lettuce roots. It was also found that potassium concentration was high at control condition.

Table 13. Effects of plant parts and ^{137}Cs treatments on potassium concentrations of lettuce grown on three soils

Plant parts	Name of the soil series			Mean
	Bhatpara	Pagla	Gopalpur	
	Concentration (%) of potassium			
Root	0.931b	0.993b	1.243b	1.056b
Shoot	1.268a	1.306a	1.493a	1.356a
	Concentration (%) of potassium			
Treatments	Bhatpara	Pagla	Gopalpur	Mean
T_0	1.250a	1.150a	1.525a	1.308a
T_1	0.949b	1.149a	1.212b	1.103b

Values in columns having same letters are not significantly different

Calcium concentration in lettuce plant

The average concentrations of calcium in lettuce root and shoot as affected by soil properties and application of cesium have been presented in the table 14 and fig 5. Analysis of variance (ANOVA) of the data obtained in three soil series showed that calcium content in lettuce root and shoot were enhanced significantly at 0.1% level at control condition and that of root was significant at 5% level when ^{137}Cs was applied (T_1). The test of significance of calcium content in different soil was computed by Duncan's New Multiple Range Test (DMRT) at 5% level of significance.

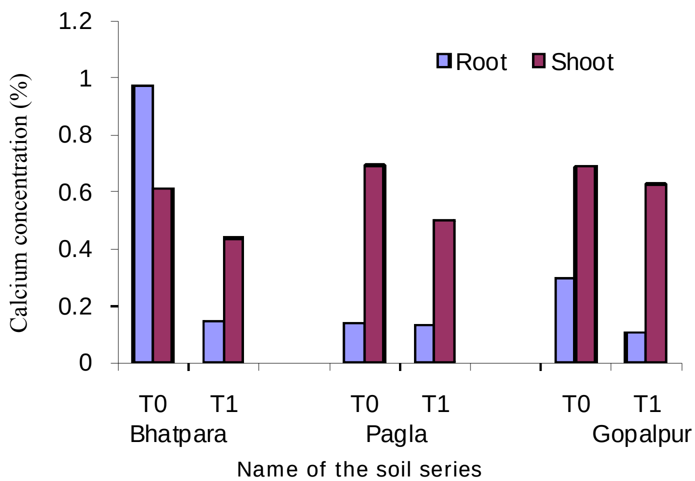

Figure 5. Mean concentration of calcium in roots and shoots of lettuce

Table 14 showed that calcium content in roots of Bhatpara series differed significantly from Pagla and Gopalpur series both at control condition and ^{137}Cs treatment. Gopalpur series also differed significantly from Pagla series at control condition and Pagla series differ significantly from Gopalpur series at ^{137}Cs treatments. Table 14 also showed that the highest calcium content of lettuce plant was recorded in roots of Bhatpara series (0.97%; T_0) and the lowest was recorded in roots of Gopalpur series (0.107%; T_1).

Calcium content in lettuce shoot of Pagla and Gopalpur series differed significantly from Bhatpara series, when no ^{137}Cs was applied and there was no significant difference between Pagla and Gopalpur series. There was no significant difference in calcium content of shoot between Bhatpara and Pagla series at ^{137}Cs treatments. Table 14 also showed that calcium content in shoots of Gopalpur series differed significantly from Bhatpara and Pagla series when ^{137}Cs was applied. The highest calcium content was observed in lettuce shoots of Pagla series (0.692%; at treatment T_0) and the lowest was found in shoots of Bhatpara series (0.438%; at treatment T_1).

Table 14. Mean concentration of calcium in root and shoot of lettuce

Plant parts	Treatments	Name of the soil series		
		Bhatpara	Pagla	Gopalpur
		Concentration (%) of calcium		
Root	T_0	0.970a	0.138c	0.297b
	T_1	0.147a	0.132b	0.107c
Shoot	T_0	0.610b	0.692a	0.687a
	T_1	0.438b	0.501b	0.627a

Values in rows having same letter are not significantly different

Table 15 showed significant difference in calcium concentration between roots and shoots and also between two treatments (T_0 and T_1), which revealed that, application of ^{137}Cs had marked influences on the calcium concentration except in Bhatpara soil series. From the table 4.22 it was observed that lettuce roots accumulated more calcium than lettuce shoots. It was also found that calcium concentration was high at control condition compared to ^{137}Cs treatment.

Table 15. Effects of plant parts and ^{137}Cs treatments on calcium concentrations of lettuce grown on three investigated soils

Plant parts	Name of the soil series			Mean
	Bhatpara	Pagla	Gopalpur	
	Concentration (%) of calcium			
Root	0.558a	0.135b	0.202b	0.298b
Shoot	0.524b	0.596a	0.657a	0.592a
	Concentration (%) of calcium			
Treatments	Bhatpara	Pagla	Gopalpur	Mean
T_0	0.790a	0.415a	0.492a	0.566a
T_1	0.292b	0.316b	0.367b	0.325b

Values in columns having same letters are not significantly different

Magnesium concentration in lettuce plant

The average concentrations of magnesium in lettuce root and shoot as affected by soil properties and application of cesium have been presented in the table 16 and fig 6. Analysis of variance (ANOVA) of the data obtained in three soil series showed that magnesium content in lettuce roots were enhanced significantly at 5% level (both of T_0 and T_1). From the analysis of variance (ANOVA) of the data of lettuce shoots were significant at 1% level both at control condition and ^{137}Cs treatments. The test of significance of magnesium content in different soil was computed by Duncan's New Multiple Range Test (DMRT) at 5% level of significance.

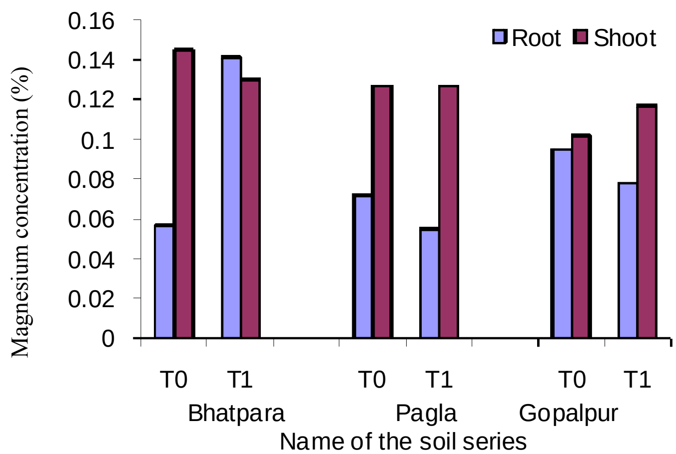

Figure 6. Mean concentration of magnesium in root and shoot of lettuce

Table 16 showed that magnesium content in lettuce roots of Pagla and Gopalpur series differed significantly from Bhatpara series at control treatment but there was no significant difference of magnesium content of root between Pagla and Gopalpur series (T_0). On the other hand, Bhatpara series differed significantly from Pagla and Gopalpur series at ^{137}Cs treatments but there was no significant difference of magnesium content of root between Pagla and Gopalpur series (T_1). Table 4.23 also showed that the highest (0.141%; T_1) magnesium content was observed in roots of Bhatpara series and the lowest (0.055%; T_1) in roots of Pagla series.

Magnesium content in lettuce shoots of Bhatpara series differed significantly from both of Pagla and Gopalpur series at control condition but there was no significant difference of magnesium content of shoots between Pagla and Gopalpur series (T_0). On the other hand, Bhatpara and Pagla series differed significantly from Gopalpur series at ^{137}Cs treatments. From the analysis of variance it was also revealed that there was no significant difference in magnesium content of shoots between Bhatpara and Pagla series when ^{137}Cs was applied. The highest magnesium content was observed in lettuce shoot of Bhatpara series (0.145%; T_0) and the lowest was found in shoot of Gopalpur series (0.102%; T_0).

Table 16. Mean concentration of magnesium in roots and shoots of lettuce

Plant parts	Treatments	Name of the soil series		
		Bhatpara	Pagla	Gopalpur
		Concentration (%) of magnesium		
Root	T_0	0.057b	0.072a	0.095a
	T_1	0.141a	0.055b	0.078b
Shoot	T_0	0.145a	0.127b	0.102b
	T_1	0.130a	0.127a	0.117b

Values in rows having same letter are not significantly different

Table 17showed a significant difference in magnesium concentration between root and shoot of lettuce and also between two treatments (T_0 and T_1). The results showed that lettuce shoots generally accumulated more magnesium than lettuce roots, which indicating that the roots did not restrict the transfer of Mg to shoots. However, there was significant difference in magnesium contents between the treatments (T_0 and T_1) and magnesium concentration was higher at ^{137}Cs treatments, which might be due to replacement of Mg from the exchange complex making it more available to plant. The results also indicate that roots did not restrict the transfer of Mg to the shoots.

Table 17. Effects of plant parts and ^{137}Cs treatments on magnesium concentrations of lettuce grown on three soils

Plant parts	Name of the soil series			Mean
	Bhatpara	Pagla	Gopalpur	
	Concentration (%) of magnesium			
Root	0.099b	0.063b	0.086b	0.083b
Shoot	0.137a	0.127a	0.109a	0.124a
	Concentration (%) of magnesium			
Treatments	Bhatpara	Pagla	Gopalpur	Mean
T_0	0.101b	0.099a	0.011b	0.070b
T_1	0.135a	0.091b	0.097a	0.108a

Values in columns having same letters are not significantly different

CONCLUSION

From the experiment it has been observed that the imposed radiation in soil has effects on the growth and uptake of several nutrients by Lettuce plant. In the experiment it has been observed that the soils slightly varied in responding with the imposed radiation due to the differences in the soil properties. But if the average result is considered then it is observed that the imposed radiation reduced the dry weight production of lettuce plant. From the study it has been observed that the imposed radiation in the soils reduced the uptake of nitrogen by 15.19%, potassium by 15.67% and calcium by 42.58%. The average dry weight production of shoot of lettuce in the three soils was also decreased by 46.83% though no significant growth reduction of root was noticed due to the imposed radiation in soil. Imposed radiation in soil reduced the average dry weight production of lettuce (root and shoot) by 24.22% and showed the negative impact on the growth of lettuce plant. This may be due to the radiation's effect or other nutritional effects.

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