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The Uptake and Translocation of Strontium-90 in Soybean Plants

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大豆植物에 의한 스트론튬-90의 吸收 및 移行

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Abstract

The absorption and translocation of strontium-90 by soybean plant, *Glycine max*, was studied by applying strontium-90 solution on the foliage or on the soil surface right after the first flowering time under greenhouse conditions. The results are summarized as follows.

In the foliar application of strontium-90, only a small portion of the radioactivity was translocated to other parts of the plant and most of it remained in the applied leaves, which should cause soil contamination after falling. In the soil surface application of strontium-90, much of the radioactivity was absorbed through the root and translocated to stems and leaves by different patterns depending on the growth stage.

요 약

육상식물인 大豆(*Glycine max*)에 있어서 Sr-90의 吸收 및 移行과정을 온실조건하에서 실험하여 다음과 같은 결과를 얻었다.

葉面처리한 Sr-90은 식물체의 다른 部位로 일부분만이 移行하였고 대부분은 잎에 그대로 殘留하여 낙엽에 의한 토양오염의 원인이 되고 있었다. 土壤처리한 Sr-90은 뿌리를 통하여 吸收된 다음 잎, 줄기, 종자, 뿌리등 각 部位로 널리 分布되는데 식물의 生育단계에 따라 그 패턴이 달리 나타났다.

1. Introduction

Contamination of the natural environment by radioactive fission products has aroused considerable concern in recent years. Some of these radionuclides will eventually be ingested by man through his food supply. Some 25% of the radionuclides released by the explosion of a single nuclear weapon may be fallen down on

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the earth, in which only 1% or less of the fission products are considered to reach the soil in one year. This type of contamination will also occur by the gaseous effluent released during the operation of nuclear power plants. The radionuclides thus formed could be transferred directly to man or animals when the plant leaves are eaten as food or feed.[1]

Among the radioactive fission products, the long-lived nuclide strontium-90 is considered the major hazards to the consumers of agricultural products. Neel *et al.*[2] have shown that plants take up far more strontium-90 than any other fission products from the soil and they concluded that strontium-90 is potentially the most hazardous in agriculture. In addition to uptake via the root system, direct deposition of the nuclide onto leaves may occur and the contamination should be concerned with the direct transfer to animals or man when the foliage portion is eaten. This is one of the most important aspects of food-chain studies on radionuclides. It was reported by many workers that under fallout conditions, 66% of th total strontium-90 uptake in vegetation enters to the plant by foliar uptake.[3] As for the internal hazard of the strontium, the nuclide has its chemical similarity to calcium and follows a metabolic path from soil to vertebrate's bone. Experiments on animals indicated that the pathological effects due to strontium-90 may be anemia, bone necrosis, cancer and leukemia.

The behavior of strontium in the soil and its uptake by plants has been already known in many respects.[4-9] Pablo[4] investigated the behavior of strontium and cesium by certain vegetable crops under Philippines conditions and Schroeder[8] examined this aspect under various German soil and climate conditions by using white clover and ryegrass. Bruce[10] and Vose[11] have compared the absorption of strontium-90 and calcium by six species of clover and six species of grass grown in pots containing three contrasting soil types. These results may be used to reduce the contaminated radiostrontium by choosing particular plant species so that the contaminated land could be reclaimed.

However the extent to which a radionuclide is absorbed from the soil to plants seems to depend on the species of the plant, the properties of cultivated soil especially its calcium content, and the conditions of plant growth. These conditions are quite different in different regions so that any results obtained in one country can not be directly transposed to another country. This paper, therefore, reports an experimental study to examine behavior of strontium-90 under local environmental conditions of South Korea.

2. Materials and Methods

The plant soybean (*Glycine max*), *Bong-Eui* cultivar, was chosen for the present investigation. Plastic Wagner pots (32 cm in diameter equivalent to 1/1238 a and 24 cm in height) were used for cultivation of the plant under greenhouse conditions.

Three to four plants were grown in each pots filled with sandy loam soil and equal amounts of water were given once a day at a fixed time. Artificial contamination of radionuclide was made through foliage or soil application just after the first flowers were formed. Strontium-90 in the form of strontium nitrate ($^{90}Sr(NO_3)_2$ in 1M HNO_3, carrier free, Radiochemical Centre, Amersham, U.K.) was applied as a pH 6.0 Hoagland solution having an activity level of 0.1 μCi/ml. For foliar contamination, 2-3 ml of the radioisotope solution was carefully applied as a thin film on the upper surface of the leaves using small paint brush of nylon's hair. To improve the adsorption on the leaves, 0.1% of Tween-80 was added into the radioisotope solution. To avoid any possibility of soil contamination during the application steps, the soil surface was covered with a sheet of plastic film. In three pots, one plant each was left uncontaminated and used as a control to detect the possible translocation of strontium-90 from one plant to another across the soil. For soil contamination, 20 ml of ^{90}Sr solution was spread over the surface of the soil as evenly as possible using a dropper.

Plant samples were collected at selected intervals, *e.g.*, 6, 12, 18, 24, 30, 42, and 60 days after the treatment. The whole plant was carefully drawn up from the soil, its root system was lightly washed by dipping into distilled water and blotted with filter paper. The plant was then divided into different portions of leaves, stems, roots, flowers and pods. The fresh weight of each portion was directly measured and dried for two days at 70°C.

The dried samples were ashed in a muffle furnace at 550°C for 20 hours and digested with concentrated nitric acid on a hot plate. When the sample was completely digested, it was evaporated to dryness and dissolved again in 3 ml of 5 N nitric acid. One ml aliquot of these solutions was pipetted onto 1-inch aluminum planchet, dried under an infra-red lamp and counted with a Geiger-Muller counter having 1.5 mg/cm^2 window thickness.

3. Results and Discussion

In foliar treatment of radionuclide solution, it was difficult to apply the same amount of material on the leaves since the surface area of the leaves was different from plant to plant. The radioactivity counted in this experiment for different organs was, therefore, presented as percentages of the whole plant.

The results on the dry weight of plant material and distribution of radioactivity in different parts of soybean plant after foliar treatment with ^{90}Sr are shown in Tables 1 and 2.

Table 1. Dry Weight of Plant Materials After Foliar Treatments with ^{90}Sr

Plant organ	Time after treatment (day)/total dry weight per plant (g)						
	6	12	18	24	30	42	60
Leaves	2.03	2.79	3.50	4.20	4.36	4.13	3.70
Stems	1.67	2.03	2.68	3.07	3.47	3.30	2.62
Roots	0.45	0.28	0.56	0.59	0.66	0.54	0.39
Pods	0.08	0.12	0.31	0.48	0.70	1.91	2.83
Total	4.23	5.22	7.05	8.34	9.19	9.88	9.54

Table 2. Percent Distribution of Radioactivity in the Different Parts of Soybean Plants After Foliar Treatments with ^{90}Sr

Plant organ	Time after treatment(day)						
	6	12	18	24	30	42	60
Leaves	99	99	99	99	99	99	99
Stems	1	1	1	1	1	1	0.5
Roots	—	—	—	—	—	—	—
Pods	—	—	—	—	—	—	0.5

Most of the applied radioactivity remained in the leaves on which the test solution was initially treated and only 1% of the applied activity was translocated from treated leaves to other organs. Roushdy and Abdel Salam[7] observed that the lower part of plant stem took part in the translocation and showed a tendency of ^{90}Sr accumulation. However, the mobility of ^{90}Sr from leaves to other parts was not demonstrated in this experiment.

The results on the radioactivity in the leaves of soybean plant after foliar application of ^{90}Sr are shown in Fig. 1. The total activity in the alive leaves was decreased with growth time and reached 15% of the initial activity from 40th day after treatment. This reduction of the radioactivity in the alive leaves of the plant would be due not to the translocation of the nuclide but to the falling of dead leaves.

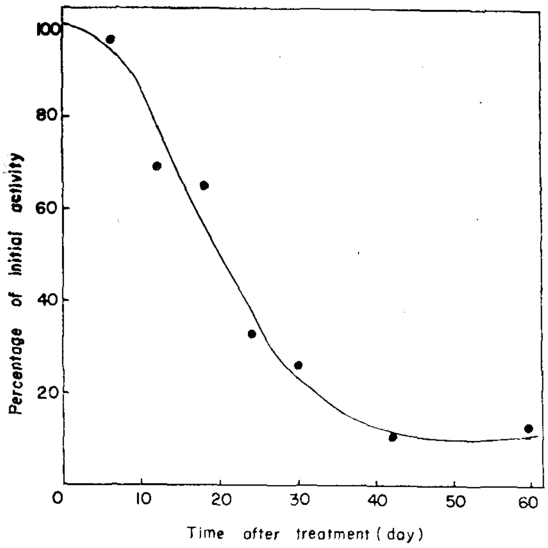

Fig. 1. Radioactivity in the Attached Leaves of Soybean Plants After Foliar Treatment with ^{90}Sr

The activity loss which ranged upto 85% of the treated activity would cause a radiocontamination of the soil and eventually this will become an unavoidable source of contamination in future crops.

With radioactive fallout, direct deposition of fission products may occur on the leaf surface, and the resulting contaminants may be absorbed metabolically by the pland or transferred directly to animals or man that consume the contaminated foliage. It is thus expected that foliar deposition is an important mode of entry of contaminating radioactive substance into food chains of animals and human beings.

In soil treatment of radionuclides, the absorption of ^{90}Sr is complicated by its non-uniform distribution in the soil profile. Most of the strontium deposited by fallout is in the upper 5 cm depth of undisturbed soil.[9] The extent to which a radionuclide is absorbed from the soil by plants seems to depend on the chemical form of the nuclide, the metabolic requirements of the plant and the physico-chemical properties of the soil. Transpiration may play a very

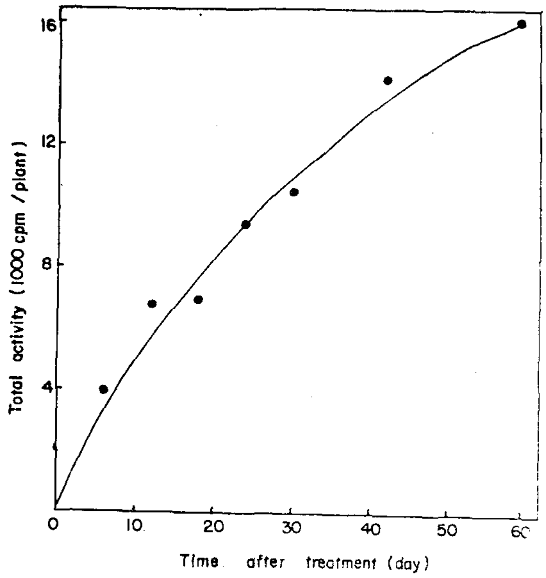

Fig. 2. Radioactivity in the Whole Plants of Soy bean After Soil Surface Treatment with ^{90}Sr

important role in the uptake of strontium through the roots. As shown in Fig. 2, the total radioactivity intaken by the plant increased gradually with time. But it seemed that the growth rate of the plant was much faster than the uptake rate of radionuclide. Therefore the specific activity of the plant increased progressively up to 24th day after treatment and decreased gradually thereafter, as shown in Fig.3.

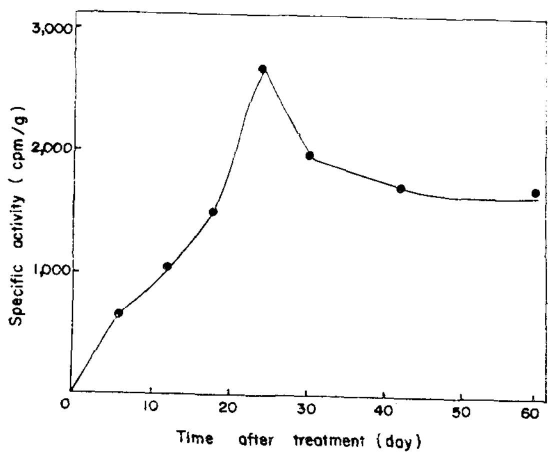

Fig. 3. Radioactivity in the Whole Plants of Soy bean After Soil Surface Treatment with ^{90}Sr

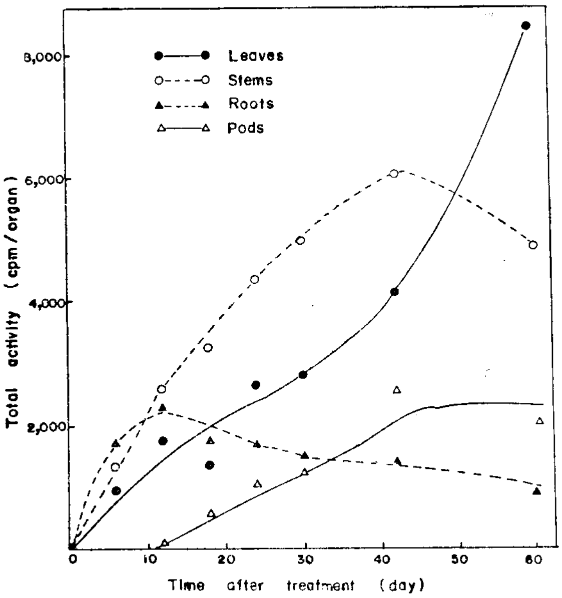

Fig. 4. Radioactivity in the Different Parts of Soybean Plants After Soil Surface Treatment with ^{90}Sr

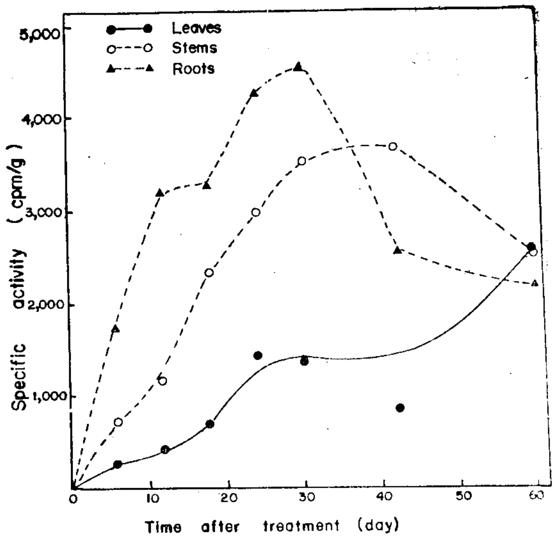

Fig. 5. Radiactivity in the Different Parts of Soybean Plants After Soil Surface Treat ment with ^{90}Sr

It was also estimated that about 5% of the total radioactivity treated was absorbed into the plant at 60th day after treatment.

The radioactivities in different parts of soybean plants after soil treatment of ^{90}Sr are shown in Fig. 4 and 5. The total activity of the leaves was gradually increased with time, and 52% of the total absorbed activity resided in the leaves at 60th day after treatment. As shown in the foliar treatment, the reduction in the amount of radioactvity in the leaves of the plant was not attributed to the translocation of the nuclide but to the activity loss falling of leaves. Many workers could demonstrate a clear translocation of the activity and a specific distribution to different regions within the metabolic paths by means of autoradiography.[4,7] The activity loss by dead leaves increased significantly with time and it ranged up to 76% of the whole leaves at 60th day after treatment. The activity of the stems was slightly higher than that of the leaves, with an increase up to 42nd day after treatment and a gradual decrease thereafter. It seems that the reduction of activity is due to translocation to other organs. As shown in Table 4, 30% of the total plant activity was remained in the stems at 60th day after treatment. The activity loss by the dead stems was not great but it was increased to reach 24% of the total stems activity at 60th day after treatment.

As shown in Fig. 5, the specific activity of the roots was the greatest among different organs. The activity of the roots decreased significantly with time, and reached 6% of total activity at 60th day after treatment as shown in Table 2. The activity associated with this organ is probably composed of adsorbed as well as absorbed strontium. The activity of the pods was increased with time and reached 12% of the total activity at 60th day after treatment.

The general trend for the distribution of radioactivities in the plant parts could, therefore, be described in the decreasing order of leaves> stems> pods> roots. This result agreed with the experiment of Roshdy who investigated the

Table 3. Dry Weight of Plant Materials After Soil Treatments with ^{90}Sr

Plant organ	Treatment*	Time after treatment (day)/total dry weight per plant (g)						
		6	12	18	24	30	42	60
Leaves	1	2.97	3.11	2.38	1.43	2.15	2.29	2.54
	2	—	—	—	—	—	2.80	3.41
Stems	1	2.24	2.48	1.58	1.48	1.50	1.85	2.10
	2	—	—	—	—	—	2.07	2.77
Roots	1	0.97	0.72	0.53	0.40	0.33	0.55	0.42
	2	—	—	—	—	—	0.33	0.60
Pods	1	0.12	0.15	0.15	0.23	1.34	1.18	1.48
	2	—	—	—	—	—	1.10	1.50
Total	1	6.30	6.46	4.64	3.54	5.32	8.24	9.51
	2	—	—	—	—	—	6.30	8.29

* Treatment 1 was the lot of one-time application just before flowering.
Treatment 2 was the lot of two-times application just before flowering and 30 days after first treatment.

Table 4. Percent Distribution of Radioactivity in the Different Parts of Soybean Plants After Soil Surface Treatments with ^{90}Sr

ant organ	Treatment*	Time after treatment (day)						
		6	12	18	24	30	42	60
Leaves	1	24	26	20	25	27	29	52
	2	—	—	—	—	—	25	33
Stems	1	33	38	47	46	48	43	30
	2	—	—	—	—	—	24	34
Roots	1	43	34	25	18	14	10	6
	2	—	—	—	—	—	25	11
Pods	1	—	2	9	11	12	18	12
	2	—	—	—	—	—	26	22

* Treatment 1 was the lot of one-time application just before flowering.
Treatment 2 was the lot of two-times application just before flowering and 30 days after first treatment.

absorption of ^{90}Sr by cucumber under greenhouse conditions. The results obtained can possibly reflect the importance of physiological activity of the different organs and those such as roots and fruits are apparently less important in this aspect. During the experiment, the activity levels of leaves decreased gradually towards the end of the experiment. This could be explained by the losses associated with the falling of dead leaves which depended on the time between spraying and harvesting, and the growing condition.

As already expected from the immobility of ^{90}Sr, there was no translocation of the nuclide from one plant to another across the soil media. Also the absorption of strontium should be concerned with the system of the roots. Therefore, experiments in pot culture do not necessarily indicate the situation which will occur in the field.

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