Table IV. Ca and Sr^{90} Contents of Cowpeas Grown in Greenhouse in Soils Listed in Table III

(Average of three replicates)

Soils	Yield, Grams Dry Wt.	Ca, Meq./Gram	Sr^{90}, $\mu\mu c$./Gram	Sr^{90}/Ca, $\mu\mu c$./Meq.
Lynchburg-Greene No. 2	41.0	0.89	0.89	1.00
Dunbar-Greene No. 3	44.9	0.77	0.88	1.14
Dunbar-Greene No. 4	33.5	0.55	0.55	1.00
Lynchburg-Edgecomb No. 1	43.2	0.48	0.56	1.17
Lynchburg-Edgecomb No. 3	45.3	0.79	1.03	1.30
Dunbar-Edgecomb No. 4	44.8	0.69	0.65	0.94
Error, std. dev.	1.8	0.027	0.045	

Possibly the HCl extraction did not remove all of the Sr^{90} remaining in the soil after extraction with $Sr(NO_3)_2$. Up to 15 or 20% more Sr^{90} has been found in extracts obtained by fusing soil samples with Na_2CO_3 than in extracts obtained by treatment with 6*N* HCl at room temperature (*15*). If part of the Sr^{90} in soils is not extracted with HCl, it would not be expected to be available to plants, especially since the evidence indicates that nonexchangeable Sr^{90} is not available to plants.

The possibility that Sr^{90} is incompletely extracted from soils by HCl digestion was emphasized by analyses of six Lynchburg and Dunbar soil samples obtained from eastern North Carolina at the same time that the four samples from Pitt County were taken. These samples were also used in the greenhouse experiment with cowpeas, and were treated in the same way as those from Pitt County, except that the soil extractions were not made until December 1959. The samples from Pitt County had been extracted in February 1959 at nearly the same time as the aliquots of soil were prepared for the greenhouse experiment. An average of only 38 $\mu\mu c$. of exchangeable Sr^{90} per kg. of soil was found in the soils extracted at the later time (Table III), compared to an average of 52 $\mu\mu c$. in the soils extracted at the earlier time. Yet the plant uptake of calcium and Sr^{90} indicated that all of the soils contained about the same amount of available Sr^{90} (Table IV), that is, with equal calcium contents in the soil, the plants contained the same ratios of Sr^{90} and Ca. The efficiency of the HCl extractions is now being checked by fusing the soils with Na_2CO_3.

The results indicate that about 15 $\mu\mu c$. of Sr^{90} per kg. of soil was fixed during storage in the laboratory and that it was not extracted by HCl digestion. If the exchangeable Sr^{90} analyses for all 10 soils had been comparable, a more definite statement about the difference between slopes of the regression lines in Figure 1 could probably have been made. At present, all that can be said is that nonexchangeable Sr^{90} appears not be taken up appreciably by cowpeas.

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Depth of Feeding as It Affects the Concentration of Radioactivity within the Plant

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In the early reports of Project Sunshine, Libby and coworkers (*4*) expressed a belief that strontium-90 from fallout was concentrated in the top $2^1/_2$ inches of soil. Since that time, the nuclides have moved downward and it has been shown by others (*1*) that they have penetrated to greater depths probably even in virgin soil. Plowing and other agricultural practices have certainly placed surface concentrations to depths of 6 to 8 inches. Percolation of strontium-90 through the soil occurs more rapidly when the calcium content of the soil is high (*3*).

Root penetration varies markedly with the crop, rainfall, type of soil, locale of growth, food, and other factors, and ranges from 10 inches for some garden plants to well over 10 feet for alfalfa (*5*).

The depth to which a plant extends its root system and obtains nutrients should have a direct effect upon the plant's concentration of a radionuclide if that nuclide is concentrated at or near the soil surface. In a sense the nuclide absorbed near the surface is diluted by elemental species obtained at greater depths. Since both top and root growth respond to the presence of nutrients, the placement of fertilizers will stimulate root development in the zone of application and an increase in nutrient absorbed from that zone will result. A fertilizer placed in a zone which contains a radionuclide will increase the uptake of that radionuclide because of stimulation of plant growth. A calculated discrim-

In any study of fallout uptake by plants the depth at which the plant receives its nutrients at different time of growth is important. This study shows that in grass, alfalfa, and lettuce the roots were feeding below 20 inches after 46 days and since the fallout is concentrated near the soil surface, only a small portion of the fallout material will be translocated to the plant. This indicates that the major portion of fallout material in plants is due to foliar absorption. This study also shows that the projection of concentration of radionuclide in soil to concentration of radionuclide in man is quite difficult since the uptake of the radionuclide by plant and hence, to man, can vary by a factor of 2 or 3, depending on the depth of feeding of the plant.

ination for a plant growing in nature is in truth an apparent discrimination which is biased by its root depth.

This paper reports the results of a study of the effect of depth of radionuclide on its concentration within the plant. The study reports on only one set of conditions, hence the results are not necessarily applicable to specific conditions in the field. Reference to literature on root distribution and nutrient uptake was not included, as the material given is concerned with another approach to the problem of nutrient uptake only as it relates to depth of feeding.

Materials and Methods

Eighteen metal culverts, each 2 feet in diameter and 5 feet deep, were set in a trench (Figure 1). A local soil was uniformly mixed with barnyard manure and placed in the culverts up to the predetermined level. A portion of the same soil was "spiked" with Cs^{137}—i.e., a solution of the radionuclide was added—and mixed in a $^1/_2$-yard concrete mixer. This mixture was then placed on top of the unspiked soil in the culverts at levels of $2^1/_2$, 5, 10, 20, and 60 inches (the cross-hatched zone in Figure 1). One culvert for each crop received no nuclide; this was used as the control. Cesium-137 was chosen since it had been shown (*2*) previously that this nuclide is well fixed in the soil and would remain in place. The concentration of Cs^{137} was 2000 ± 65 c.p.m. per gram of soil. Water was used to assist in packing the soil; however, some results suggest that more care should have been used in water addition since uneven water concentration could affect root growth and lead to some of the variations noted.

The plots were seeded with lettuce, grass, and alfalfa on May 29, 1958; five crops were harvested in the 1958 growing season with the last harvest on October 30. No attempt was made to harvest the crops at any particular stage in growth but rather only when it appeared that at least 100 grams of cut weight could be obtained from each plot. Cut crops were ashed and the concentration of Cs^{137} was determined in a gamma pulse height analyzer. Each determination was corrected by the amount of activity in the control plot. Approximately 2 grams of ash were counted for each determination; the activity varied from 30 to 300 c.p.m. The amount of Cs^{137} in the plant ash at each of the five depths of spiked soil for each harvest is expressed as a percentage of that found in the ash from plants which were grown on the 60-inch, or fully-spiked plot. There is a decrease in the potassium requirement of a plant as it ages, and a similar phenomenon was demonstrated in this study. By referring all of the results to the full plot, at each harvest, any difference in plant potassium requirement is eliminated.

Results

The results obtained from the 1958 crops of alfalfa are shown graphically in Figure 2. At the time of harvesting the first crop, at a plant age of 46 days, the concentration of Cs^{137} in plants growing in the $2^1/_2$-inch nuclide depth plots was only one third that in the 60-inch depth plots. Thus, about two thirds of the nutrient supply of the plant is assumed to be obtained below the $2^1/_2$-inch level even at this early age. The 5- and 10-inch levels of spiked soil are contributing about 60 and 70% of the plant nutrient, respectively. There is some indication that the plant root is feeding below 20 inches; however, more than 85% of its nutrient is obtained above that level. The rapid penetration of roots is rather surprising and may not take place in an undisturbed native soil. Such a soil would be more compact and root penetration might be inhibited.

Although data were not obtained from these experiments to warrant the

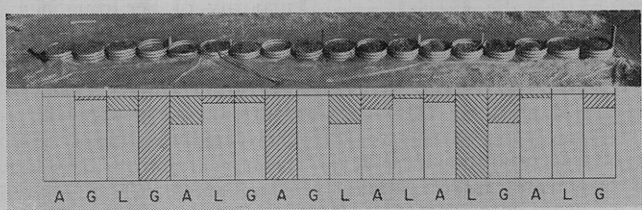

Figure 1. Plot layout and depth of cesium-137

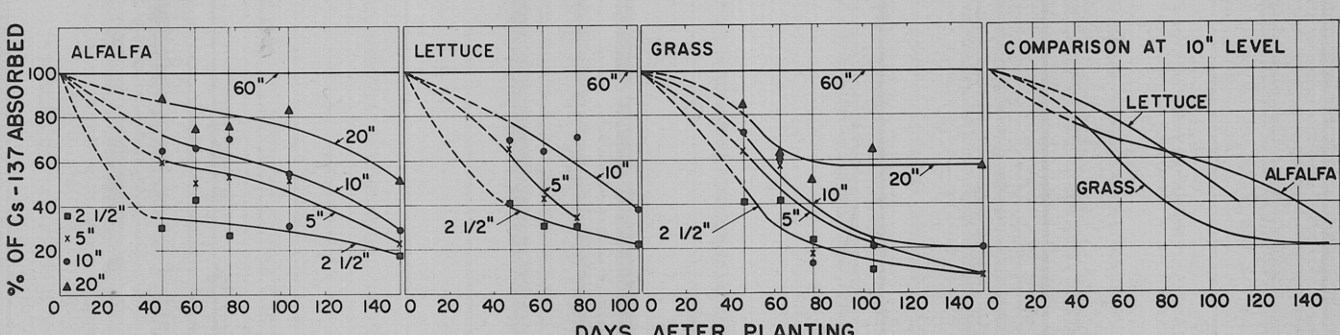

Figure 2. Percentage of cesium-137 absorbed at various root depths as related to time after planting

conclusion, there is probably an increase in root mat after the initial rapid penetration. Such a mat would support the top growth physically and nutritionally. The fact that the Cs^{137} concentration in plants grown on the $2^1/_2$-inch spiked soil decreases by only 15% 104 days after the first harvest, while those grown on the 20-inch spiked soil decreased 35% in concentration, indicates that a root mat develops near the surface. As the tap-type root ages, say to a 2 or 3 year plant, the root mat may move downward. Such a movement would further decrease the plant's uptake of near surface fallout. Hence, specific concentrations of radionuclides absorbed from the soil would be much lower in older plants than in younger plants.

The results for lettuce are also shown in Figure 2. Here only four harvests were available since the lettuce died out in the fall. The data for the 20-inch depth plots are not reported; subsequent investigation indicated that an error had been made in filling this particular plot. The pattern is fairly similar to that for alfalfa.

The results for grass are shown in Figure 2. The scatter of the points is much more pronounced than in the case of either alfalfa or lettuce. However, the curves which have been drawn indicate that the grass roots penetrated quite rapidly and to a somewhat greater depth than either lettuce or alfalfa in the early stages of growth. After 154 days the grass was apparently receiving less than 10% of its nutrient from the 5-inch level and only 20% from the 10-inch level. This was a mixture of deep-rooting pasture grasses and not lawn grass.

Figure 2 shows a comparison of the three plants grown at the 10-inch level. The lettuce did not send down early roots as deep as did grass and alfalfa, but the roots were deeper at the third and fourth harvest than were those of alfalfa. If one projects the curves, however, it will be noted that the alfalfa roots will soon be deeper than the lettuce.

The slope of the curve indicates that grass roots penetrate more rapidly than those of either of the other two crops, but penetration levels off after about 100 days, indicating it is approaching maximum depth; the alfalfa feeder roots apparently continue to penetrate to greater depths. The tap-type root of alfalfa is apparently slower in penetrating than the grass root and perhaps the plant receives a great deal of its nutrients near the surface during the formation of the lower tap root, while the grass roots are feeding throughout their depth.

The few surviving grass and alfalfa plots were harvested in the spring of 1959. The activity found in these crops was quite uniform and higher than in the harvest of 1958. This suggests that as the ground warms up the plant sends out numerous feeder roots which feed intensively in the zone of warm, damp soil.

Numerous investigators (*5*) have shown an elevated potassium requirement in young plants. The increase in Cs^{137} activity over older crops may be explained on this basis and points out the metabolic relationship between cesium and potassium. Later harvests indicated a return to the levels and pattern observed in 1958.

A practical, though anomalous, example of the effect of root depth on plant uptake of radionuclides is given by speculating on the probability of an increasing concentration of radionuclide in pasture-land supporting dairy cattle. Is it not possible that the feeding of imported grains and roughage is increasing the surface contamination in these pasture lands where such an increase is most undesirable? This follows since the foods imported for feeding dairy cattle contain radioactivity and only a small amount of this is retained by the animal. The remainder is deposited on the soil in feces and urine. As a result the surface contamination continues to increase on pasture soils from which the cow is obtaining the majority of her roughage. Plants are said to be feeding below the level of fallout; yet, because the feces and urine provide a source of concentrated plant nutrient, the roots will probably feed more avidly just below this material and hence will absorb the relatively concentrated nuclide which builds up from continued deposition. This reemphasizes the fact that fallout is never eliminated, since it is recycled over and over.

Discussion

This was a preliminary study only. Although the points represent from one to five analyses, their scatter on the curve indicates that replication of plots would be highly desirable. Root penetration has been known to continue during the first year of growth to support the above-ground plant, but it was somewhat surprising that the roots penetrated as deeply and rapidly as they did.

This study further points out the difficulty in projecting from soil concentration of nuclide to concentration in man since depth of root feeding could affect the uptake of a nuclide by a factor of 2 or 3.

Because, at least in unfertilized soils, the roots of plants are generally feeding well below the depth of penetration of fallout, only a small portion of the activity in the soil will be translocated to the plant. This lends further credence to the supposition that at present most of the radioactivity found in plants arises from foliar absorption rather than root absorption from the soil. As the reservoir of nuclides above the earth is depleted, absorption from the soil will become the major factor contributing to concentration of the radionuclide in the plant.

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