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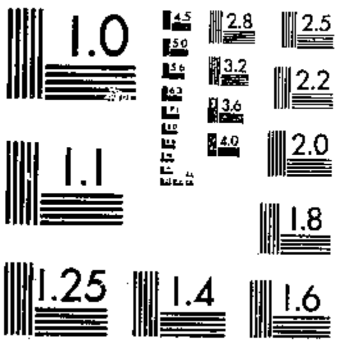

MICROCOPY RESOLUTION TEST CHART
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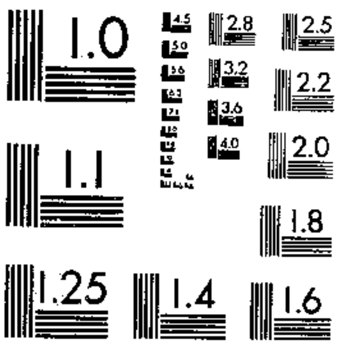

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REDUCTION IN THE PLANT UPTAKE OF Sr-90 BY SOIL MANAGEMENT TREATMENTS

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REDUCTION IN THE PLANT UPTAKE OF Sr-90 BY SOIL MANAGEMENT TREATMENTS

By M. H. Frere, R. G. Menzel, H. Roberts, Jr., D. L. Myhre, M. Amemiya, O. W. Beale, D. R. Timmons, and E. H. Wood, *Soil and Water Conservation Research Division, Agricultural Research Service* [1]

Fallout from intentional or accidental nuclear explosions leads to undesired concentrations of certain radioactive material in agricultural products. Sr-90 is one of the more important radioactive components of fallout, because of its relatively long half-life, 28 years, and its similarity to the nutrient element calcium. Because Sr-90 in fallout is rather soluble (*1*),[2] it is readily available to plants. Its chemical similarity to calcium means that it is concentrated in high-calcium plants such as legumes, secreted into milk, and finally deposited in the bones of man and animals. The long residence time of radioactive Sr in bones involves the hazard of radiation-induced bone cancer and leukemia. The need for investigating methods of reducing the Sr-90 contamination is pressing because of this potential health hazard. The entire problem of controlling the content of Sr-90 in food may be seen in sharper perspective with a knowledge of the possibilities offered by soil and crop management practices.

The present study was conducted to evaluate the effectiveness of deep plowing in conjunction with irrigation and additions of calcium and potassium in the surface soil for reducing uptake of Sr-90. Calcium and potassium were selected for this study because there is ample evidence in the literature that they decrease Sr uptake and because they are commonly used by the farmer. The uptake of Sr-90 was determined from field experiments utilizing Sr-90 already deposited in worldwide fallout. Because of continuing fallout, it was necessary to estimate the amount of Sr-90 deposited directly on the crops.

REVIEW OF LITERATURE

Numerous studies report decreased Sr-90 uptake from deep placement. In studies (*15*) on wheat grown in 2-gallon pots, the same amount of uptake occurred when the Sr-90 was applied at a 5-cm. depth as when it was applied throughout the soil. When the Sr-90 was applied at a 15-cm. depth, a 50-percent reduction in uptake was observed. In lysimeter cultures of barley (*30*), it was observed that as the band of Sr-90 was placed deeper in the soil there was a sharp reduction in uptake until the 24-inch depth was reached. Below this, to a depth of 48 inches, there was little change, with the uptake being about 10 percent of that at the 2-inch depth. Injection of radioactive Ca at different depths (*5*) also has shown a lower uptake from the greater depths.

The effect of different tillage practices has been investigated. Deep plowing to 50 cm. in Russia (*13*) always reduced uptake, but the amount of reduction was highly variable. In England a number of

[1] This study was supported in part by the U.S. Atomic Energy Commission.

[2] Italic numbers in parentheses refer to Literature cited, p. 29.

studies have shown that, in general, the deepest plowing (12 inches) gave least uptake with shallow-rooted crops such as ryegrass and a grass-clover pasture (*2, 25, 29*). However, placement had little effect on the Sr uptake by deep-rooted crops. In the United States, plowing 4 inches deep increased Sr-90 uptake as compared with leaving the Sr-90 on the surface (*3*). In another experiment it was found that the uptake of Sr could be moderately reduced by placing lime with the contaminant at the 15-inch depth (*19*). It was speculated that the uptake of buried Sr could be further reduced if shallow root development were encouraged by applying abundant nutrients and water in the top 12 inches of soil (*19*).

There is little information in the literature on what effect a moist topsoil might have on the uptake of Sr-90 from a buried layer. Several investigations (*3, 32*) have indicated little or no effect of soil moisture on Sr-90 uptake. However, a greenhouse study (*17*) showed more Ca uptake by soybeans from the moist part of the rooting zone than from the dry part.

From the chemical similarity of calcium and strontium, it is logical to expect that calcium additions should reduce Sr uptake. This has been observed in field experiments (*24*), greenhouse studies (*7*), nutrient solution culture studies (*21*), and in short-term ion uptake studies (*6*). In general, the Sr-90 uptake is inversely related to the exchangeable calcium in the soil (*18, 27*). Since soils have finite exchange capacities, overliming has little additional effect; a fourfold reduction of Sr-90 uptake by liming acid soils is generally the most to be expected (*28*).

It has been known for a number of years that potassium reduces the calcium uptake of some plants. It has been reported that potassium also reduces Sr-90 uptake (*16*). Although the results of different experiments are variable, the reduction is usually not so large as with Ca additions. Some plants are more responsive than others, with wheat showing a greater reduction in Sr-90 uptake than peas (*15*). Different potassium salts have different effects (*8, 31*). This may be a result of chemical reactions in the soil or in the plant (*8, 33*).

Direct contamination of plants with fallout contributes greatly to their Sr-90 content during periods of moderate to heavy fallout. For pastures in England and Wales, it was estimated (*2*) that Sr-90 derived from direct contamination would be about equal to that taken up from the soil if the annual fallout rate was only one-eighth to one-fourth of the cumulative deposit in the soil. Wheat grown in Maryland (*22*) retained about 3 percent of that deposited during crop growth and took up about 0.2 percent of that in the soil.

EXPERIMENTAL PROCEDURE

Field experiments utilizing the Sr-90 already deposited in worldwide fallout were started in May 1960. It was recognized that the Sr-90 content of the crops could result from direct deposition of fallout on the growing plant as well as uptake from the soil. At the time this study was planned, the rate of fallout deposition was expected to be small in 1960 and later years; therefore, most of the Sr-90 content of the crops was expected to result from uptake from the soil. The specific activity (Sr-90/Sr) of soil, stubble, and grain was determined for each crop to estimate the contribution of foliar deposition.

The experiments were conducted at four locations with the cooperation of local U.S. Department of Agriculture and State experiment station personnel: The Southern Piedmont Conservation Research Center, Watkinsville, Ga.; the Ankeny Experimental Farm, Ankeny, Iowa; the North Central Soil Conservation Research Center, Morris, Minn.; and the Pee Dee Experiment Station, Florence, S.C. These locations represent widely varying soil and climatic conditions. The sites selected for the experiments had been in grass for at least 5 years. Because Sr-90 movement is slow through undisturbed soil (*10*), the deposited Sr-90 was concentrated in the top few inches.

The same plots were used in 1960, 1961, and 1962. Cultural and fertilization practices common to each crop and location were used, except when they conflicted with experimental variables.

Russian nuclear tests began in the fall of 1961; this led to a large amount of fallout during the 1962 growing season. Since this would obscure most of the treatment effects, only three of the treatments from the 1962 crops were analyzed for Sr and Sr-90.

Design

A modified split-plot design was used at each location, with shallow and deep placement of the surface soil as the two main plots. Minimal and frequent irrigation gave two subplots, and combinations of calcium and potassium at two levels each gave four sub-subplots. The dimensions of the sub-subplots were as large as could be fitted within a 20- by 20-foot area with the equipment that was available for each crop and location. As an example, the plot layout at Ankeny in 1960 is shown in figure 1. The experiment was replicated twice at each location with two series of crops. An outline of the analysis of variance for one crop at one location is as follows:

Source of variation:	*Degrees of freedom*
Replication	1
Placement	1
Replications x placement (Error A)	1
Irrigation	1
Irrigation x placement	1
Replications x irrigation; Replications x irrigation x placement (Error B)	2
Calcium	1
Placement x calcium	1
Irrigation x calcium	1
Placement x irrigation x calcium	1
Potassium	1
Placement x potassium	1
Irrigation x potassium	1
Placement x irrigation x potassium	1
Calcium x potassium	1
Placement x calcium x potassium	1
Irrigation x calcium x potassium	1
Placement x irrigation x calcium x potassium	1
Residual (Error C)	12
Total	31

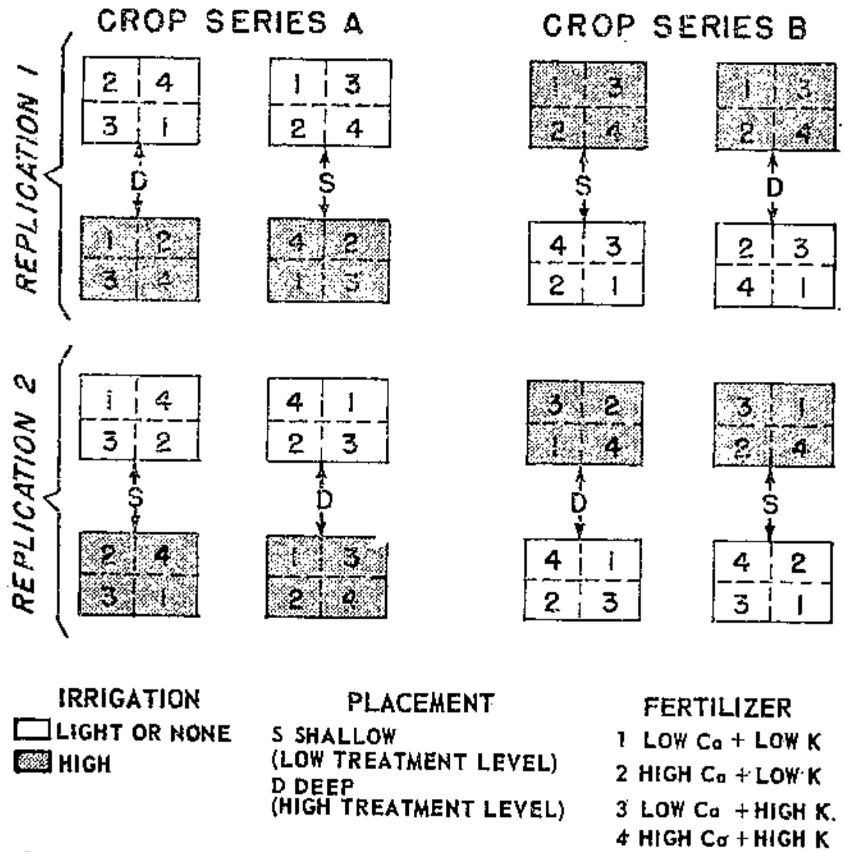

FIGURE 1.—Field plot design. Ankeny Experimental Farm, Ankeny, Iowa.

The physical parameters deep placement and irrigation necessitated the use of this design. It was recognized that the placement and irrigation treatments would require greater differences for statistical significance; small differences in uptake that might result from these treatments are of little practical interest for decontamination.

Treatments

Since all treatments were designed to reduce the Sr-90 uptake, the plots representing the "normal" conditions are considered the control plots, or low level of treatment.

The shallow-placement treatment—considered the control, or low level of treatment—was achieved by conventional plowing to a depth of about 6 inches. In the deep-placement treatment—considered the high level of treatment—the surface 4 inches of soil was buried at a depth of 20 to 24 inches. This was achieved by excavating with a dragline, bulldozer, or scraper and then replacing the soil in layers. The original 14- to 24-inch layer was placed over the 0- to 4-inch layer and finally the 4- to 14-inch layer was replaced to become the new surface soil.

The control plots, or those with minimal irrigation, received sufficient sprinkler irrigation to prevent appreciable drought damage to the crops. The plots with frequent irrigation were irrigated by sprinkler whenever the moisture content of the top 24 inches of soil was reduced by 1 inch of water from its field capacity. This condition was estimated by taking soil samples, by evapotranspiration data, or by tensiometers.

The low-Ca plots, or control plots, received no Ca and the high-Ca plots received sufficient lime to satisfy the lime requirement of the top 7 inches of soil. An exception was made in Minnesota, where calcium was added as gypsum, since the soil had no lime requirement.

The rates of potassium addition to the low-K plots, or control plots, were based on conventional local fertilizer practices. The level sought for the high-K plots was a doubling or tripling of the application to the low-K plots.

Soil and Crop Sampling

Soil samples were taken from the 0- to 4-, 4- to 14-, and 14- to 24-inch layers at each location when the deep-placement pits were excavated. Samples were taken from the 0- to 6-inch layer of soil from both placement treatments at each location in July 1961. In October 1962, a soil core was taken from each sub-subplot and sectioned. The segments were composited to form samples of the soil profile of the deep-placement and shallow-placement treatments at each location.

Samples of grain and stubble (1 to 4 inches above the ground) were collected from the crops grown in 1960 and 1961. The soybean stubble from Watkinsville only was washed lightly with water to remove soil particles before it was dried for analysis. As much direct contamination with fallout as possible was avoided by removal of the leaves and leaf sheaths from the oat and wheat stubble. The entire aboveground part of the plant was collected for the grasses and legumes grown in 1962. All samples were ovendried for yield determinations and ground before analysis. Yields of all grains were calculated on a moisture basis of 13 percent for soybeans, 15.5 percent for corn, and 15 percent for oats and wheat.

Analyses

The soils were characterized by determining pertinent physical and chemical properties. Clay content was determined by a sedimentation procedure (*14*). Types of minerals were identified by the diffraction methods of Jackson (*12*), except that ethylene glycol was used for the solvation of clays.[3] Organic carbon was determined by the chromic acid-ferrous sulfate titration method (*26*). Soil pH was measured electrometrically in a 1:1 soil-water suspension. Exchangeable cations were extracted from the soil with *N* neutral NH_4OAc solution and determined by the following methods: Ca and Mg by EDTA titration

[3] The assistance of the Soil Survey Laboratory, Soil Survey Investigations, Soil Conservation Service, Beltsville, Md., in performing these analyses is gratefully acknowledged.

(*4*); K and stable Sr by flame photometry (*11*). Exchangeable Sr-90 was extracted with $Sr(NO_3)_2$ solution at a normality between one-third and one; the concentration depending on the previously determined exchange capacity of the soil. The Sr-90 contents of the extracts were determined radiochemically (*11*).

The plant samples were dry ashed in a muffle furnace in preparation for determining stable Sr and radioactive Sr-90. The Sr contents of oat grain and stubble, wheat grain and stubble, and the legumes and grasses were determined on samples of the plant ash with X-ray fluorescence (*11*).[4] The ash of the corn stubble and grain and soybean stubble and grain was extracted with dilute HCl. After removal of orthophosphate and other interfering ions by precipitation of zirconyl phosphate and hydroxide at pH 6 (*4*), the Sr was determined by flame photometry (*11*). Since the Sr content of the grain proved to be too low for analysis by this technique, the Ca and Sr in the extracts were precipitated as sulfates and the Sr content was determined by X-ray fluorescence.

Sr-90 in the extract of plant ash was determined by radiochemical procedures. Corrections were made for counting efficiency—determined by using a Sr-90 standard sample—and for decay during the time between harvest and analysis.

The effects of treatments on the yield must be given some consideration, since the deep-placement treatment was a severe modification of the plant root environment. The effects of the treatments on yield and Sr-90 content are reported in the text tables as a percentage change. The percentage change was calculated as the difference between the values at the high and low level of each treatment, divided by the value at the low level of treatment, times 100. The complete data on yield and on Sr-90 content of grain and stubble are listed in the Appendix as the mean of the two replicates.

EXPERIMENTS IN GEORGIA

Procedure

The experimental site at Watkinsville, Ga., was an 8-year-old fescue sod on a Cecil sandy loam with a 2-percent slope. The chemical and physical properties of this soil, which contains kaolinite as the predominant clay mineral, are given in table 1. The analysis showed that the soil was acid and was low in calcium and that the accumulation of Sr-90 was predominately in the top 4 inches of the soil.

Corn and soybeans were planted in early May 1960 and harvested in early and late October 1960, respectively. Oats and wheat were planted soon after the corn and soybean harvest and were harvested in June 1961. Coastal bermudagrass and lespedeza sericea were planted soon after the cereal-grain harvest, and the forage was harvested in June 1962. After the first plowing, 100 pounds of N, 83 pounds of K, and 130 pounds of P were applied per acre and disked into the soil.

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[4] The assistance of the U.S. Plant, Soil and Nutrition Laboratory, Agricultural Research Service, Ithaca, N.Y., in performing these analyses is gratefully acknowledged.

At planting, 500 pounds per acre of 4–5.2–10 fertilizer were applied to all plots. An additional 50 pounds per acre of N as ammonium nitrate were applied to the corn as a side dressing. The high-calcium plots received 1.6 tons per acre of Ca as lime, and the high-potassium plots received 166 pounds per acre of K in addition to the K applied in mixed fertilizer. An additional 0.8 ton per acre of Ca as lime was applied to the high-calcium plots in October 1960.

The corn and soybean plots received 19.5 inches of rain and 7.5 inches of water by irrigation during the growing season. The high-moisture plots were irrigated with an additional 2.5 inches of water in July. The years of 1961 and 1962 were sufficiently wet so irrigation was unnecessary. The oats and wheat plots received 31.2 inches of rain from planting to harvest, with 9.3 inches occurring during April and May 1961. The lespedeza and Coastal bermudagrass plots received 57 inches of rain from planting to harvest, with 9.2 inches occurring during April, May, and June 1962.

Results

The yield and results of the analyses of the plant tissue from control plots, or plots with the low level of all treatments, are given in table 2.

Table 3 presents the percentage change in yield caused by the higher level of each treatment. The apparent 32-percent decrease in corn yield caused by deep placement is not statistically significant because of the few degrees of freedom for testing this treatment. The detrimental effect did not appear in the second year; deep placement even became beneficial, at least for cereal grains under the environmental conditions that prevailed that year.

Table 4 presents a summary of the effect of the treatments on the Sr-90 content of the plant tissue. The deep-placement treatment provided the greatest decrease, as expected, although statistical significance is usually lacking because of the few degrees of freedom in the experimental design. Irrigation was essentially without effect, as would be expected considering the small amount of water applied. Calcium additions provided the second greatest reduction in Sr-90 uptake on this low-calcium soil. Potassium addition also reduced the Sr-90 uptake, although to a lesser extent than calcium. In the experimental design, the calcium and potassium treatments could be statistically tested with more degrees of freedom; thus, the smaller decreases were often statistically significant. The last row in table 4 shows the reduction obtained with a combination of these treatments. A positive interaction of treatments had been expected as a result of greater root growth from application of amendments above the contaminated layer. Although the reduction by the combined treatments was as great as or greater than any individual treatment, the effect was generally less than the interaction effect calculated as the product of the effects of the individual treatments.

The distribution of exchangeable Sr-90 in the soil profile during the experiment is given in table 5. The last column shows that the buried Sr-90 started at about 16 inches and that most of it was contained between 18 and 26 inches. The Sr-90 content of the surface 2 inches of soil increased sharply between July 1961 and October 1962, as a result of fallout accumulation. The surface 6 inches of soil in the deep-

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TABLE 1.—*Chemical and physical properties of the Cecil sandy loam before treatment, Watkinsville, Ga.*

Soil depth (inches)	Clay $<2\mu$	Organic carbon	pH	Exchangeable cations					Sr	Sr-90	
				Ca	Mg	K	H	Total			
	Percent	*Percent*		*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Mg./kg.*	*Pc./kg.*	*µc./acre*
0–4	12	2. 0	4. 8	1. 5	0. 6	0. 2	10. 4	12. 7	1. 3	162. 7	99. 5
4–14	44	. 5	4. 9	1. 1	. 4	. 1	10. 5	12. 1	. 7	6. 6	0. 4
14–24	55	. 2	5. 1	. 7	. 8	. 1	11. 3	12. 9	1. 6	(1)	(1)

[1] Not analyzed.

TABLE 2.—*The yield and plant analyses of control plots (low level of all treatments), Watkinsville, Ga.*

[Average of 2 replicates for corn and soybeans, 4 replicates for others]

Yield and plant analysis	Corn		Soybean		Oats		Wheat		Lespedeza	Coastal bermudagrass
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble		
Yield kg./acre	2, 884	--------	904	--------	552	--------	916	--------	511	524
Sr-90 pc./kg	3. 4	420	230	960	96	200	46	190	2, 780	1, 480
Sr mg./kg	0. 03	33	8. 4	44	3. 3	6. 4	1. 6	5. 2	31	16. 6
Specific activity pc. Sr-90/mg. Sr	110	13	27	22	29	31	29	36	90	89

TABLE 3.—*Percentage change in yield caused by the higher level of each treatment, Watkinsville, Ga.*

Treatment	Corn	Soybean	Oats	Wheat	Lespedeza	Coastal bermudagrass
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Placement	−32	−13	+15	[1] +18	+3	+8
Irrigation	0	+4				
Calcium	[1] −12	[1] +9	+2	−5	+19	+2
Potassium	+9	+2	+4	+1	0	[1] −15

[1] Statistically significant at the 0.95 probability level.

placement treatment showed fallout accumulation between May 1960 and July 1961—the final content of 18 pc. per kg. as compared with an initial content of 7 pc. per kg. The Sr-90 fallout deposits corresponding to these increases in soil content were 10 μc. per acre from May 1960 to July 1961 and 17 μc. (for the shallow-placement treatment) or 28 μc. (for the deep-placement treatment) per acre from July 1961 to October 1962.

EXPERIMENTS IN IOWA

Procedure

The experimental site at Ankeny, Iowa, was a sod of pasture grasses on Nicollet silt loam with a 2- to 4-percent slope. The chemical and physical properties of this soil, which contains montmorillonite as the predominant clay mineral, are given in table 6. The analysis showed that the soil had a medium calcium content, and a weakly acid reaction and that the accumulation of Sr-90 was predominantly in the top 4 inches of soil.

Corn and soybeans were planted during the last week of May 1960 and harvested in the middle of October 1960. Oats and wheat were planted in the middle of April 1961 and harvested in the middle of July the same year. Alfalfa and bromegrass were planted on the wheat plots, and red clover and timothy were planted on the oat plots; the seed was broadcast the day after the cereal grains were planted. The forages were harvested in the middle of June 1962.

Before seedbed preparation, 2.4 tons per acre of Ca as lime were applied on the high-calcium plots and 500 pounds per acre of K as KCl were applied on the high-potassium plots. At planting time, broadcast applications of nitrogen as ammonium nitrate were made at the rates of 200 pounds per acre on the areas planted to corn and of 40 pounds per acre on areas planted to soybeans. Three hundred pounds per acre of 4–7–6.6 fertilizer were applied on the rows. In April 1961, 87 pounds per acre of P as treble superphosphate were applied to all plots, 333 pounds per acre of K as KCl were applied to the high-potassium plots, and 0.8 ton per acre of Ca as lime was applied to the high-calcium plots.

TABLE 4.—*Percentage change in the Sr-90 content of crops caused by the higher level of each treatment or treatment combination, Watkinsville, Ga.*

Treatment	Corn		Soybean		Oats		Wheat		Lespedeza	Coastal bermudagrass
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Placement	−57	−73	−14	−38	−20	[1] −26	[2] −20	[1] −37	−15	−23
Irrigation	+1	−18	−16	−4	---	---	---	---	---	---
Calcium	[1] −29	[1] −20	[1] −43	−12	[2] −16	[1] −22	[1] −17	[2] −8	---	---
Potassium	[3] −14	[1] −16	−8	−22	−16	−9	[2] −12	−1	---	---
P x I x C x K [4]	−62	−86	−56	−47	−40	−49	−41	−35	---	---

[1] Statistically significant at the 0.99 probability level.
[2] Statistically significant at the 0.95 probability level.
[3] Statistically significant at the 0.90 probability level.
[4] P, placement; I, irrigation; C, calcium; K, potassium.

TABLE 5.—*Distribution of Sr-90 in the Cecil sandy loam profile during the experiment with different placement treatments, Watkinsville, Ga.*

Soil depth (inches)	Sr-90 content [1]				
	Before treatment, May 1960	Shallow placement		Deep placement	
		July 1961	October 1962	July 1961	October 1962
	Pc./kg.	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*
0–2	} 163	} 50	120	} 18	111
2–4			48		} 18
4–6	} 7		40		
6–8		-	36	-	} 16
8–10		-	41	-	
10–12		-	} 22	-	} 14
12–14		-		-	
14–16	-	-	} 9	-	15
16–18	-	-		-	26
18–20	-	-	} 5	-	42
20–22	-	-		-	55
22–24	-	-		-	51
24–26	-	-	} 3	-	37
26–28	-	-		-	20

[1] The 2-inch layers within brackets were composited before analysis.

The corn and soybeans received 19.5 inches of rain and 2 inches of water by irrigation at the low-moisture level. The high-moisture plots received an additional 6.3 inches of irrigation water. The wheat crop received 8 inches of rain, and the high-moisture plots received an additional 8 inches of water by irrigation. The oats received only 6.4 inches of rain, as they were harvested 2 weeks earlier than the wheat. The high-moisture plots received an additional 2.4 inches of water by irrigation. Since the forages were planted at the same time as the cereal grains, they received all the moisture that the grains did plus the precipitation from July 1961 to June 1962. However, since the growing season is only from about April through September, the difference in moisture levels was computed for these months. The low-moisture plots of alfalfa-brome received about 31.9 inches of rain, and the high-moisture plots received an additional 13.4 inches of water by irrigation. The low-moisture red clover-timothy plots received a supplemental irrigation in July 1961, so the total was 32.7 inches; the high-moisture plots received an additional 7.9 inches of water by irrigation.

Results

The yield and results of the analyses of the plant tissue from control plots, or plots with the low level of all treatments, are given in table 7. Comparison of these values with those for Georgia (table 2) shows that the Sr-90 content was lower in Iowa crops than in Georgia crops, as expected with crops grown on soil containing more Ca. In

Table 6.—*Chemical and physical properties of the Nicollet silt loam before treatment, Ankeny, Iowa*

Soil depth (inches)	Clay $<2\mu$	Organic carbon	pH	Exchangeable cations					Sr	Sr-90	
				Ca	Mg	K	H	Total			
	Percent	*Percent*		*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Mg./kg.*	*Pc./kg.*	*μc./acre*
0–4	20	3.1	5.6	8.6	3.4	0.6	10.2	22.8	10.5	161.1	73.9
4–14	22	2.1	5.5	8.4	3.2	.4	9.9	21.9	11.4	8.0	10.6
14–24	22	1.4	5.8	8.3	3.8	.3	7.3	19.7	12.7	([1])	([1])

[1] Not analyzed.

Table 7.—*The yield and plant analyses of control plots (low level of all treatments), Ankeny, Iowa*

[Average of 2 replicates]

Yield and plant analysis	Corn		Soybean		Oats		Wheat		Alfalfa	Brome	Red clover	Timothy
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble				
Yield — kg./acre	3,680	------	1,050	------	1,580	------	1,020	------	730	870	990	620
Sr-90 — pc./kg	0.8	55	37	260	14.2	63	13.1	68	2,310	1,760	2,730	1,250
Sr — mg./kg	0.07	20	3.8	30	1.8	3.7	1.2	3.9	39	8.4	39	9.1
Specific activity — pc. Sr-90/mg. Sr	11	3	10	9	8	17	11	17	59	215	70	135

addition, the natural Sr content is also lower than in the Georgia crops even though the Sr/Ca ratio is somewhat higher in the Iowa soil than in the Georgia soil. The Sr-90 contents and specific activities of the four crops grown in 1962 provide a contrast in ranking a crop. The Sr-90 content of the legumes may be nearly twice that of the grasses, but the specific activity of the grasses may be twice that of the legumes.

The effects of the treatments on yield are given in table 8. These data are similar to those from Georgia (table 3). Deep placement was most detrimental to the corn yield. Whether this is a result of a more sensitive crop or a result of planting in the recently disturbed soil is not known. The difference in amounts of water applied at the high and low levels of the irrigation treatment was greater in Iowa than in Georgia; thus, a greater effect is observed in the yield data. Since the last four crops were grown as mixtures of alfalfa-brome and red clover-timothy, consideration must be given to plant-competition effects. Thus, the decrease in clover yield with increase in moisture may be solely caused by a greater response by timothy to additional moisture.

Table 9 presents a summary of the effects of the treatments on the Sr-90 content in plant tissue. Comparision of these data with the similar data from Georgia (table 4) shows a similar effect for placement. The percentage change was greatest for corn and soybeans—first-year crops—and decreased in the crops of succeeding years. Irrigation showed somewhat greater effects in Iowa than in Georgia, because of the greater irrigation differential. Although calcium additions consistently caused reductions, the magnitude was small because of the relatively high calcium content of the soil. Potassium additions caused small changes in either direction and, therefore, can be considered as without effect. An estimate of the maximum effect of treatment combination is given in the last row of the table. These results also indicate that the maximum effect is usually less than the product of the individual effects. The data for wheat grain are limited because of an insect infestation that destroyed some samples before the analyses could be completed.

The distribution of exchangeable Sr-90 in the soil profile during the experiment is given in table 10. The last column shows that the buried Sr-90 started at about 14 inches and that most of it was contained between 16 and 24 inches. The Sr-90 content of the surface soil increased during the experiment as it did at Watkinsville. The Sr-90 fallout deposits corresponding to these increases in soil content were 13 μc. per acre from May 1960 to July 1961 and 21 μc. (for the shallow-placement treatment) or 24 μc. (for the deep-placement treatment) per acre from July 1961 to October 1962.

EXPERIMENTS IN MINNESOTA

Procedure

The experimental site at Morris, Minn., was a sod of 9-year-old brome-bluegrass mixture on a Brookings silt loam. The chemical and physical properties of this soil, which contains montmorillonite as the predominant clay mineral, are given in table 11. The analysis

TABLE 8.—*Percentage change in yield caused by the higher level of each treatment, Ankeny, Iowa*

Treatment	Corn	Soybean	Oats	Wheat	Alfalfa	Brome	Red clover	Timothy
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Placement	−42	−26	−12	−10	+11	−8	−1	−2
Irrigation	+6	+11	+6	+4	−9	0	[1] −48	+55
Calcium	−1	+6	+1	+2	+2	−2	+18	−10
Potassium	−3	+2	+3	+4	+4	+6	−11	+19

[1] Statistically significant at the 0.95 probability level.

TABLE 9.—*Percentage change in the Sr-90 content of crops caused by the higher level of each treatment or treatment combination, Ankeny, Iowa*

Treatment	Corn		Soybean		Oats		Wheat		Alfalfa	Brome	Red clover	Timothy
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble				
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Placement	−18	−60	−65	−56	−13	0	+8	+11	−12	−17	−5	0
Irrigation	−13	−8	−17	−14	−15	+12	+24	−9	+6	−13	−21	−3
Calcium	−13	−9	−7	[1] −6	−5	−4		−6				
Potassium	+11	[1] −9	+5	−4	+9	+3		−13				
P x I x C x K [2]	−50	−64	−70	−67	−25	+8		−35				

[1] Statistically significant at the 0.95 probability level.

[2] P, placement; I, irrigation; C, calcium; K, potassium.

TABLE 10.—*Distribution of Sr-90 in the Nicollet silt loam profile during the experiment with different placement treatments, Ankeny, Iowa*

Soil depth (inches)	Sr-90 content [1]				
	Before treatment, May 1961	Shallow placement		Deep placement	
		July 1961	October 1962	July 1961	October 1962
	Pc./kg.	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*
0–2			206		123
2–4	161	97	103	27	25
4–6			87		
6–8		—	54	—	
8–10	8	—	12	—	14
10–12		—		—	
12–14		—	4	—	9
14–16	—	—		—	22
16–18	—	—	2	—	60
18–20	—	—		—	66
20–22	—	—	2	—	60
22–24	—	—		—	36
24–26	—	—		—	25
26–28	—	—	2	—	16

[1] The 2-inch layers within brackets were composited before analysis.

showed that the soil had a neutral reaction and was high in calcium and Sr content and that the accumulation of Sr-90 was predominantly in the top 4 inches of the soil.

Corn and soybeans were planted the last of May 1960 and harvested the last of October. Oats and wheat were planted the first of May 1961 and harvested the last of July. Alfalfa-brome and red clover-timothy mixtures were planted at the same time as the grains. The red clover-timothy mixture germinated poorly, probably because of insufficient soil moisture,[5] and was reseeded in August after the grain harvest. The late planting resulted in a high degree of winterkilling of red clover.

Before the corn and soybeans were planted, 250 pounds of K per acre as KCl were applied to the high-potassium plots and 1.2 tons per acre of Ca as gypsum ($CaSO_4$) were applied to the high-calcium plots. Gypsum was used at this location because the application of lime to the soil with a neutral reaction would not provide additional soluble Ca and would raise the pH above the desired level. At the time of the corn planting, 100 pounds of 16–8.7–0 fertilizer per acre were applied. An additional 33 pounds of N per acre as ammonium nitrate were applied at the second cultivation. Soybeans were supplied with 9 pounds of P per acre as superphosphate at planting. Before the oats and wheat were planted, 33 pounds per acre of N as ammonium nitrate and 40 pounds per acre of P as treble superphosphate were applied to

[5] The source of irrigation water was inadequate to provide all the water necessary for both high irrigation and minimal irrigation plots during this extremely dry growing season.

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TABLE 11.—*Chemical and physical properties of the Brookings silt loam before treatment, Morris, Minn.*

Soil depth (inches)	Clay $<2\mu$	Organic carbon	pH	Exchangeable cations					Sr	Sr-90	
				Ca	Mg	K	H	Total			
	Percent	*Percent*		*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Mg./kg.*	*Pc./kg.*	*μc./acre*
0–4	25	4. 4	6. 8	20. 6	8. 7	0. 6	8. 8	38. 7	86. 8	178. 9	69. 4
4–14	23	2. 1	7. 0	18. 1	8. 8	. 4	5. 7	33. 0	91. 8	2. 0	2. 2
14–24	22	. 7	7. 8	15. 3	7. 4	. 3	3. 5	26. 5	85. 2	[1]	[1]

[1] Not analyzed.

TABLE 12.—*The yield and plant analyses of control plots (low level of all treatments), Morris, Minn.*

[Average of 2 replicates]

Yield and plant analysis	Corn		Soybean		Oats		Wheat		Alfalfa	Brome	Red clover	Timothy
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble				
Yield kg./acre	1, 136	------	250	------	582	------	234	------	1, 312	127	99	875
Sr-90 pc./kg.	1. 6	35	20	320	13	42	13	22	4, 058	1, 544	2, 803	1, 840
Sr mg./kg.	0. 2	27. 1	15. 1	39. 9	1. 6	4. 6	0. 9	3. 1	40. 6	6. 3	45. 3	4. 4
Specific activity pc. Sr-90/mg. Sr	8	1. 3	1. 3	8	8	9	14	7	55	245	62	418

all plots. The high-potassium plots received an additional 250 pounds per acre of K as KCl. No fertilizer was applied in 1962.

The corn and soybeans received 15 inches of rain and 2.2 inches of water by irrigation at the low-moisture level. The high-moisture plots received an additional 31.5 and 32.3 inches of irrigation water on the first and second replications, respectively. The low-moisture plots of oats and wheat received 5.9 inches of precipitation, and the high-moisture plots received an additional 27.8 inches of water by irrigation. Since the alfalfa-brome mixture was planted with the grains, only the moisture received during the growing season—that is, May–September 1961 and May–June 1962—is considered. This was 22.9 inches of precipitation for the low-moisture level with additional supplemental irrigations of 41 inches of water applied to the high-moisture plots. Since the red clover-timothy mixture was reseeded in August 1961, only the moisture from that time on was considered. The 4.1 inches in September plus the 10.3 inches in the following May and June gave 14.4 inches of precipitation for the low-moisture plots; an additional 11.6 inches of water was applied to the high-moisture plots in 1962.

Results

The averages of the yield and plant analysis for the two replicates of the control plots, or plots with the low level of all treatments, are given in table 12. The major difference between this location and Iowa (table 7) appears to be lower yields. The lower yields probably are a result of the more northern climate. The Sr and Sr-90 contents of the plant material are usually similar to those of Iowa even though the Ca and Sr contents of this soil are twofold and eightfold higher, respectively, than of the Iowa soil. However, it is possible that the difference between the "available" Ca and Sr in the two soils is actually less, since some free calcium carbonate with its Sr impurities may have been dissolved in the exchangeable cation determination for the Minnesota soil. The differences between Sr-90 contents and specific activities of grasses and legumes are again demonstrated at this location.

The treatments had no significant effects on yield of the first 2 years' crops (grains) (table 13). However, the values might be used as an indication of trend; thus, it could be concluded that if there was a detrimental yield effect in the first year's crops, it is eliminated in the second year. The differences in yield due to irrigation were greater at this location than at any other, as would be expected since the irrigation differential was greater. Considering the four crops (forages) grown in 1962, several treatments had significant effects. However, in interpreting these results, consideration must be given to several extenuating circumstances, such as crop competition and the extremely poor development of the red clover. Thus, the magnitude of the effect of placement and irrigation on alfalfa and brome may be a result, to a large extent, of plant competition. The same considerations probably apply to the red clover-timothy mixture, because of the poor growth of red clover.

A summary of the effect of the treatments on the Sr-90 content of plant tissue is given in table 14. The data from this location are the most variable of those from the four locations. A contributing factor

TABLE 13.—*Percentage change in yield caused by the higher level of each treatment, Morris, Minn.*

Treatment	Corn	Soybean	Oats	Wheat	Alfalfa	Brome	Red clover	Timothy
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Placement	−18	−7	+3	+39	[1]+34	−31	+6	−10
Irrigation	+25	+36	+71	+2	[2]+23	−40	[1]+265	[1]−24
Calcium	+2	−9	−10	+12	0	−30	[2]+51	−9
Potassium	+4	−3	+1	+13	−3	−5	[3]+78	−16

[1] Statistically significant at the 0.90 probability level.
[2] Statistically significant at the 0.95 probability level.
[3] Statistically significant at the 0.99 probability level.

TABLE 14.—*Percentage change in the Sr-90 content of crops caused by the higher level of each treatment or treatment combination, Morris, Minn.*

Treatment	Corn		Soybean		Oats		Wheat		Alfalfa	Brome	Red clover	Timothy
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble				
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Placement	+21	−4	−22	−38	+10	−12	−18	−12	−14	+12	−3	+7
Irrigation	−45	−27	+3	−11	+48	−12	[1]+58	−3	−13	+11	+3	+10
Calcium	0	0	−11	+12	+13	−12	----	+12	----	----	----	----
Potassium	[1]−31	−10	+7	−4	−12	−9	+10	−7	----	----	----	----
P x I x C x K [2]	−69	−20	−8	−35	+187	−40	+90	+9	----	----	----	----

[1] Statistically significant at the 0.95 probability level.
[2] P, placement, I, irrigation; C, calcium; K, potassium.

may be the shallow distribution of the Sr-90 in the deep-placement treatment, as shown in table 15. This location had the highest moisture differential; yet the grain of soybeans, oats, and wheat showed an increase in Sr-90 content with increase in irrigation. This may indicate that the sprinkler irrigations aided in translocaton of foliar-deposited fallout. The high natural Ca and Sr content of this soil preclude any effect of added Ca. With the exception of corn grain, the potassium additions were also without effect. The data for the wheat grain are limited because of an insect infestation that destroyed the samples before the analyses could be completed. Since it was obvious from the results of the corn and soybean crops that the Ca treatment would have little or no effect, the samples of wheat grain from the two Ca treatments were combined for analysis. The effects of the combined treatments on Sr-90 content were quite variable, ranging from large increases in oats and wheat grain to a considerable decrease in corn grain.

The distribution of exchangeable Sr-90 in the soil profile during the experiment is given in table 15. The last column shows that the buried Sr-90 started between 10 and 14 inches and that most of it was contained between 14 and 24 inches. The Sr-90 content of the surface 2 inches of soil increased during the experiment as it did at the other locations. The Sr-90 fallout deposits corresponding to these increases in soil content were 14μc. per acre from May 1960 to July 1961 and 18μc. (for the shallow-placement treatment) or 30μc. (for the deep-placement treatment) per acre from July 1961 to October 1962.

TABLE 15.—*Distribution of Sr-90 in the Brookings silt loam profile during the experiment with different placement treatments, Morris, Minn.*

Soil depth (inches)	Sr-90 content [1]				
	Before treatment, May 1960	Shallow placement		Deep placement	
		July 1961	October 1962	July 1961	October 1962
	Pc./kg.	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*
0–2	179	146	334	26	187
2–4			120		23
4–6	2		77		
6–8			24		14
8–10			6		
10–12			2		32
12–14					
14–16			2		73
16–18					
18–20			2		25
20–22					61
22–24					53
24–26			2		4
26–28					1

[1] The 2-inch layers within brackets were composited before analysis.

EXPERIMENTS IN SOUTH CAROLINA

Procedure

The experimental site at Florence, S.C., was a 5-year-old sod of Coastal bermudagrass on a Dunbar sandy loam. The chemical and physical properties of this soil, which contains kaolinite as the predominant clay mineral, are given in table 16. The analysis showed that the soil was acid and was low in calcium. The Sr-90 was initially contained mainly in the top 4 inches of the soil; although more Sr-90 was found deeper in this soil than in the profiles at other locations.

The corn and soybeans were planted in late May and early June and harvested in middle October and late November 1960, respectively. Oats were planted in late October 1960 and harvested the following early June; whereas, the wheat was planted in late December 1960 and harvested the following late June. Coastal bermudagrass and lespedeza sericea were planted in July 1961. The grass was harvested in late June 1962, except for the second replication of the shallow-placement plots where very little grass grew because of heavy weed infestations. The deep-placement plots of lespedeza were harvested in late June 1962, but the shallow-placement plots were much slower growing and were not harvested until late July.

Before the seedbed was prepared, 1.2 tons per acre of Ca as lime were applied to the high-calcium plots and 83 pounds per acre of K as KCl were applied to the high-potassium plots. At planting, 300 pounds of 4–5.2–10 fertilizer per acre were applied to all plots. During the summer, an additional 100 pounds per acre of N as ammonium nitrate and 16 pounds per acre of P as superphosphate were applied to all corn plots. The P application was also made on the deep-placement plots planted to soybeans. A mixture of minor elements was applied to all plots. All oats and wheat plots were fertilized with 700 pounds per acre of 4–5.2–10 fertilizer at planting. An additional 0.4 tons per acre of Ca as lime was applied to the high-calcium plots. The following spring, 60 pounds per acre of N as ammonium nitrate were applied to all plots. At planting, the lespedeza received 400 pounds per acre of 4–5.2–10 fertilizer. The following spring, 50 pounds per acre of K as KCl were applied to the high-potassium plots of both crops and an additional 80 pounds per acre of N as ammonium nitrate were applied to the grass.

The 3 years of the study at this location were "wet" years, and the irrigation differential was smaller than that at the other locations. The corn received 22.1 inches of rain, and an additional 2.6 inches of water was applied to the high-moisture plots. The soybeans received 19 inches of rain, and an additional 1.8 inches of water was applied to the high-moisture plots. The oats and wheat were not irrigated. The oats received 24.2 inches of rain and the wheat 27 inches. In 1962, the bermudagrass plots received 5.6 inches of rain, and an additional 3.5 inches of water was applied to the high-moisture plots between the first of May and harvest. All lespedeza plots were irrigated with the same amount of water, but, because of the different harvest dates, 5.5 inches of rain fell on the deep-placement plots and 10.3 inches on the shallow-placement plots.

Results

The yield and results of the analyses of the plant tissue from the control plots, that is, the plots with the low level of all treatments, are given in table 17. The yields are similar to those from Georgia (table 2), except that corn yield was considerably lower in South Carolina than in Georgia. The Sr-90 and the Sr contents are, in general, a little lower in the South Carolina crops.

The effects of the treatments on the yield are given in table 18. Although the deep-placement treatment was very detrimental to the corn yield, its effect on the other crops was much smaller. The data for the Coastal bermudagrass were affected by the presence of weeds on the shallow-placement plots. The calcium treatment is the only other variable that shows a major effect, and this would be anticipated for legumes—with high-calcium requirements—on this acid soil.

The effect of the treatments on the Sr-90 content of the plant tissue is given in table 19. The placement treatment at this location had a larger and more consistent effect than at any other location. Possibly this indicates more uniform depth of placement of the buried Sr-90 at this location. The calcium treatment also gave consistent reduction in Sr-90 content, except for wheat grain. This effect might be expected on this low-calcium soil. The soil analyses (table 20) indicated a somewhat lower rate of fallout in South Carolina than at the other locations, which would have resulted in larger observed effects from the soil treatments. The last row in table 19 shows that the combined effect of all treatments seldom exceeds that from placement alone.

The distribution of exchangeable Sr-90 in the soil profile during the experiment is given in table 20. The last column shows that the buried Sr-90 started at about 16 inches and that most of it was contained between 16 and 24 inches. The Sr-90 content of the surface 2 inches of soil increased during the experiment as it did at the other locations. The Sr-90 fallout deposits corresponding to these increases in Sr-90 content are 9 μc. per acre from May 1960 to July 1961 and 12μc. (for the shallow-placement treatment) or 14 μc. (for the deep-placement treatment) per acre from July 1961 to October 1962.

CONTAMINATION FROM FALLOUT DEPOSITED ON THE PLANT

When the experiment was designed, it was recognized that the Sr-90 content of the grain could arise from two sources—soil uptake and direct deposition of fallout on the plant. A small rate of fallout deposition was expected, at least in comparison with preceding years. However, the relative contamination from these two sources was not known. The contamination from direct fallout was estimated by measuring the specific activity of strontium in the grain and in the lower section of the stem—the part that was expected to be least contaminated by direct deposition. This decision was based on the hypothesis that the specific activity of the strontium from the soil, integrated over the growing season, would be the same in both plant parts. Thus an increase in the specific activity in the grain could be attributed to direct deposition.

TABLE 16.—*Chemical and physical properties of the Dunbar sandy loam before treatment, Florence, S.C.*

Soil depth (inches)	Clay $<2\mu$	Organic carbon	pH	Exchangeable cations					Sr	Sr-90	
				Ca	Mg	K	H	Total			
	Percent	*Percent*		*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Meq./100g.*	*Mg./kg.*	*Pc./kg.*	*μc./acre*
0–4	9	1.5	5.2	1.7	0.5	0.2	6.6	9.0	2.7	117.0	70.2
4–14	26	.4	5.1	1.6	.8	.1	6.2	8.7	2.5	8.0	11.9
14–24	31	.3	4.8	1.0	.7	.1	7.6	9.4	2.6	1.4	2.2

TABLE 17.—*The yield and plant analysis of control plots (low level of all treatments), Florence, S.C.*

[Average of 2 replicates except for Coastal bermudagrass]

Yield and plant analysis	Corn		Soybean		Oats		Wheat		Lespedeza	Coastal bermudagrass
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble		
Yield kg./acre	1,866	------	940	------	887	------	804	------	665	379
Sr-90 pc./kg.	1.4	102	118	556	82	126	68	150	1,594	646
Sr mg./kg.	0.11	22	5.1	12	2	3.2	1.4	4	17	7.2
Specific activity pc. Sr-90/mg. Sr	13	4.6	23	46	41	39	48	38	94	90

TABLE 18.—*Percentage change in yield caused by the higher level of each treatment, Florence, S.C.*

Treatment	Corn	Soybean	Oats	Wheat	Lespedeza	Coastal bermuda-grass
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Placement	[1]−56	−1	0	[2]−15	−19	+29
Irrigation	+6	−5	------	------	+34	+8
Calcium	−9	[3]+16	−12	+7	[1]+49	[3]−28
Potassium	+7	+7	+5	+1	−7	+4

[1] Statistically significant at the 0.99 probability level.
[2] Statistically significant at the 0.90 probability level.
[3] Statistically significant at the 0.95 probability level.

TABLE 19.—*Percentage change in the Sr-90 content of crops caused by the higher level of each treatment or treatment combination, Florence, S.C.*

Treatment	Corn		Soybean		Oats		Wheat		Lespedeza	Coastal bermuda-grass
	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble		
	Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Placement	−33	[1]−62	−37	−40	[2]−60	[2]−53	[2]−39	−2	+1	+22
Irrigation	−7	+4	+6	+6	------	------	------	------	0	+154
Calcium	[3]−12	−8	−12	−2	[1]−10	−6	[1]+17	−4	------	------
Potassium	+7	+3	0	+5	−3	+16	[1]−12	+11	------	------
P x I x C x K[4]	−21	−67	------	−30	−68	−54	−39	+20	------	------

[1] Statistically significant at the 0.95 probability level.
[2] Statistically significant at the 0.99 probability level.
[3] Statistically significant at the 0.90 probability level.
[4] P, placement; I, irrigation; C, calcium; K, potassium.

TABLE 20.—*Distribution of Sr-90 in the Dunbar sandy loam profile during the experiment with different placement treatments, Florence, S.C.*

Soil depth (inches)	Sr-90 content [1]				
	Before treatment, May 1960	Shallow placement		Deep placement	
		July 1960	October 1962	July 1961	October 1962
	Pc./kg.	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*
0–2	}	}	131	}	71
2–4	} 117	} 70	66	} 18	} 14
4–6	}	}	53	}	}
6–8	}	---	44	---	}
8–10	} 8	---	26	---	} 8
10–12	}	---	}	---	}
12–14	}	---	} 11	---	} 5
14–16	}	---	}	---	13
16–18	}	---	} 4	---	58
18–20	} 1	---	}	---	35
20–22	}	---	}	---	76
22–24	}	---	} 2	---	43
24–26	---	---	}	---	18
26–28	---	---	}	---	6

[1] The 2-inch layers within brackets were composited before analysis.

The average specific activities for the deep- and shallow-placement plots at each location are given in table 21. The specific activities in the plant parts are generally higher than the average specific activity for the top 14 inches of soil on which they were grown. Every exception occurs with the shallow placement in Georgia or with the corn stubble. A small error in the determination of the very low strontium content of Cecil sandy loam could be responsible for the discrepancy in Georgia. The low specific activity of corn stubble indicates that it is least contaminated by direct fallout.

The fact that specific activities of corn stubble were lower than those of soil may reflect systematic analytical errors or, with shallow placement, that a large amount of strontium uptake was from deeper than 14 inches. But with deep placement, uptake of strontium from the buried surface soil layer at 14 to 24 inches should result in increased specific activity.

Deep placement reduced the Sr-90 content in corn stubble more than that in corn grain (tables 4, 9, 14, 19). The other management treatments generally had nearly the same effect on Sr-90 content in stubble as they did in grain. These effects are difficult to explain unless (1) a large part of the strontium found in the grain was taken up from the surface soil much later than that found in the stubble, and (2) the Sr-90 content of the surface soil increased markedly during the growing season because of fallout contamination. Thus, it may be concluded that fallout contamination affected mainly the response

TABLE 21.—*The average specific activity of Sr in soils (0- to 14-inch layer) and crops as affected by the placement treatment at 4 locations*

Location and placement	Specific activity (Sr-90/Sr)									
	Soil		Corn		Soybean		Oats		Wheat	
	May 1960	July 1961	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble
	Pc./mg.	*Pc./mg.*	*Pc./mg.*	*Pc./mg.*	*Pc./mg.*	*Pc./mg.*	*Pc./mg.*	*Pc./mg.*	*Pc./mg.*	*Pc./mg.*
Georgia:										
Shallow	59. 0	44. 0	44. 0	7. 2	31. 0	20. 0	31. 0	28. 0	29	33. 0
Deep	5. 4	17. 0	28. 0	2. 2	24. 0	14. 0	26. 0	21. 0	32	28. 0
Iowa:										
Shallow	4. 6	4. 7	9. 3	2. 7	6. 9	7. 8	6. 8	10. 3	12	13. 0
Deep	. 5	1. 5	5. 1	1. 6	2. 2	3. 3	5. 6	7. 2	13	12. 0
Minnesota:										
Shallow	. 6	. 7	1. 8	1. 2	7. 8	9. 8	15. 0	6. 8	20	7. 6
Deep	. 02	. 3	18. 3	1. 4	5. 2	8. 8	16. 0	5. 5	18	8. 0
South Carolina:										
Shallow	15. 0	17. 0	20. 0	3. 4	28. 0	48. 0	38. 0	46. 0	45	40. 0
Deep	2. 4	4. 5	13. 0	1. 3	18. 0	31. 0	15. 0	18. 0	32	41. 0

to the deep-placement treatment and does not seriously interfere with the interpretation of results from this study. Recent work (*20*) shows that reduction in uptake of Sr-85 from placements 20 inches deep is about the same as was observed in this study.

Effects of the management treatments were smaller with oats and wheat grown in 1961 than with corn and soybeans grown in 1960. With the deep-placement treatment, this resulted in large part from the fallout of about 10μc. per acre Sr-90 on the surface soil between the time the treatments started in 1960 and the time the oats and wheat were harvested in 1961. Nevertheless, the deep-placement treatment gave 50 percent reduction in Sr-90 concentration in oats grown in South Carolina and smaller reductions in both oats and wheat grown in Georgia. Additions of calcium also reduced Sr-90 concentration in the crops grown in Georgia (table 4). Fallout of Sr-90, either in the soil surface or directly on the crops, may have obliterated other effects.

Contamination of the wheat grain by direct fallout can be estimated from other data. Observations of others (*9, 23*) indicate that most contamination occurs after heading, which occurs approximately 6 weeks before harvest. Measurements have indicated that approximately 1 percent of the Sr-90 fallout during this period was retained in wheat grain (*22*). An estimate of the Sr-90 fallout was obtained by multiplying local rainfall by the concentration of Sr-90 in rain at the nearest fallout collection station of the AEC (*34*). The 1-percent retention figure was adjusted for low yield of grain at Florence, S.C., and Morris, Minn., to two-thirds and one-half percent, respectively. The estimated direct contamination is shown in table 22. By comparison with observed concentrations, the estimated direct contamination ranges from about one-third of the total Sr-90 content in grain from Georgia and South Carolina to all the Sr-90 content in grain from Minnesota. Errors in the estimated percentage retention may arise from unknown effects of rainfall intensity or differences in wheat varieties.

Most of the Sr-90 content in the forage crops grown in 1962 arose from direct fallout contamination. At the nearest AEC fallout collection stations, the Sr-90 deposited from April through June 1962 ranged from 10μc. per acre at Columbia, S.C., to 37μc. per acre at Vermillion, S. Dak. The amounts in legumes ranged from 1μc. per acre in lespedeza

TABLE 22.—*Data for estimating and estimated direct contamination of wheat grain by Sr-90 fallout at 4 locations*

Location	Rainfall for 6 weeks before harvest	Estimated Sr-90 fallout	Sr-90 retained in grain	Yield of grain	Sr-90 content of grain from direct contamination
	Inches	*µc./acre*	*µc./acre*	*Kg./acre*	*Pc./kg.*
Georgia	3.65	1.43	0.0143	1,250	11
South Carolina	7.08	2.21	.0147	800	18
Minnesota	2.65	1.45	.0072	550	13
Iowa	2.94	.92	.0092	1,200	8

grown at Watkinsville, Ga. to 3μc. per acre in alfalfa grown at Morris, Minn. The amounts in grasses were generally lower. Thus, about 10 percent of the fallout during the growing period was retained on some of the crops.

MAIN TREATMENT EFFECTS AND INTERACTIONS OF TREATMENTS

The uptake of Sr-90 from about 20 inches below the soil surface was reduced as much as 75 percent in corn stubble at Georgia and 65 percent in soybean grain in Iowa when compared with the uptake from the conventional plow layer. There was great variability between locations, part of which may be attributed to variation in direct deposition of fallout. In addition, the deep-placement treatment in Minnesota was shallower than at other locations. In general, the 1961 crops (oats and wheat) showed less reduction by deep placement than the previous year's crops (corn and soybeans). This is probably a result of fallout deposited on the surface of the deep-placement plots during the first year.

The difference in irrigation levels was small or nonexistent at the locations other than Minnesota, and the effects of irrigation on Sr-90 uptake were small. In Minnesota, corn showed a sizable reduction in Sr-90 uptake from irrigation, but the interaction of placement-irrigation was not significant.

As expected, the calcium treatment showed the greatest effect at the two southern locations, which have low-calcium soils. The maximum reduction in Sr-90 uptake achieved was 43 percent in soybean grain at Georgia.

In general, the effect of potassium was small or negligible with the exception of a 31-percent reduction in Sr-90 uptake in corn grain at Minnesota.

Eleven treatment interactions were tested for each crop and location, except wheat at Iowa and Minnesota. Out of 154 interactions tested, only 1 was significant at the 1-percent level and 19 at the 5-percent level; and of the significant interactions, only 3 showed positive effects, that is, that the effect of the combined treatments was greater than the product of the individual treatments. Thus, in general, the effects of irrigation, liming, and potassium additions were no better, and sometimes poorer, on the deep-placement plots than on the shallow-placement plots.

The yield of corn was greatly reduced at all locations by the deep-placement treatment. Since the oats and wheat showed increases or only small reductions in yield when grown in the second year, possibly the reduction in corn yield by deep placement would be smaller with time.

CONCLUSIONS

The burial of Sr-90 deeper in the soil profile reduced the Sr-90 content of corn and soybean grain at most about 60 percent and of oat and wheat grain about 20 percent. There was much variability among locations and crops. The magnitude of the measured reduction is less than the true value, because some fallout was deposited on the plant during the growing season. In addition, the value for oats and wheat is low because fallout was deposited on the deep-placement plots during the previous year. Irrigation, calcium, and potassium additions did not enhance the reduction by deep placement, although the calcium addition, alone, did cause a reduction of approximately 20 percent in the two Southern States. Fallout after the establishment of the deep-placement plots and during the growing season obscured any treatment effects with the grasses and legumes. No means were found to accurately assess the contribution of foliar deposition to the Sr-90 content of the plants.

LITERATURE CITED

(1) Bryant, E. A., Cowan, C. A., Heald, W. R., Menzel, R. G., and others. 1960. BIOLOGICAL AVAILABILITY OF STRONTIUM-90 FROM ATOMIC TESTS. Science 132: 327–330.

(2) Burton, J. D., Milbourn, G. M., and Russell, R. S. 1960. RELATIONSHIP BETWEEN RATE OF FALLOUT AND THE CONCENTRATION OF SR-90 IN THE HUMAN DIET IN THE UNITED KINGDOM. Nature 185: 498–500.

(3) Cline, J. F., and Hungate, F. P. 1956. EFFECT OF STRONTIUM AND CALCIUM IN SOIL ON UPTAKE OF SR-90 BY BARLEY PLANTS. U.S. Atomic Energy Comn. HW 41500: 7–13.

(4) Derderian, M. D. 1961. DETERMINATION OF CALCIUM AND MAGNESIUM IN PLANT MATERIAL WITH EDTA. Analyt. Chem. 33: 1796–1798.

(5) Ellis, F. B., Newbould, P., and Taylor, R. 1962–63. UPTAKE OF NUTRIENTS FROM DIFFERENT DEPTHS IN SOIL BY PLANTS. [Gt. Brit.] Agr. Res. Council Radiobiol. Lab. Rpt. 10: 92–96.

(6) Epstein, E., and Leggett, J. E. 1954. THE ABSORPTION OF ALKALINE EARTH CATIONS BY BARLEY ROOTS: KINETICS AND MECHANISM. Amer. Jour. Bot. 41: 785–791.

(7) Evans, E. J., and Dekker, A. J. 1962. THE INFLUENCE OF SOIL PROPERTIES AND SOIL AMENDMENTS ON THE SR-90 CONTENT OF OATS GROWN IN SELECTED CANADIAN SOILS. Canad. Jour. Soil Sci. 42: 23–30.

(8) ——— and Dekker, A. J. 1963. THE EFFECT OF POTASSIUM FERTILIZATION ON THE SR-90 CONTENT OF CROPS. Canad. Jour. Soil Sci. 43: 309–315.

(9) ——— and Dekker, A. J. 1965. FOLIAR, FLORAL, AND ROOT ADSORPTION OF SR-90 BY CROPS. Agron. Jour. 57: 82–83.

(10) Frere, M. H., Larson, K. H., Menzel, R. G., and others. 1963. THE BEHAVIOR OF RADIOACTIVE FALLOUT IN SOILS AND PLANTS. Natl. Acad. Sci., Natl. Res. Council Pub. 1092, Wash., D.C.

(11) Heald, W. R., Menzel, R. G., Roberts, H., Jr., and Frere, M. H. 1965. METHODS OF SOIL AND PLANT ANALYSIS WITH SPECIAL REFERENCE TO STRONTIUM-90 CONTAMINATION. U.S. Dept. Agr. Agr. Handb. 288, 23 pp.

(12) Jackson, M. L. 1956. SOIL CHEMICAL ANALYSIS. ADVANCED COURSE. Univ. Wis., Madison, published by the author, 991 pp.

(13) Kachanova, G. F. 1962. [SR-90 UPTAKE FROM SOIL INTO PLANTS GROWN UNDER FIELD CONDITIONS.] Izv. Timiryazev. S.-Kh. Akad. 4: 105–110. [Abstract in Chem. Abs. 59: 1929d. 1963.]

(14) Kilmer, V. J., and Alexander, L. T. 1949. METHODS OF MAKING MECHANICAL ANALYSIS OF SOILS. Soil Sci. 68: 15–24.

(15) Klechkovskii, V. M., ed. 1955. ON THE BEHAVIOR OF RADIOACTIVE FISSION PRODUCTS IN SOIL, THEIR ABSORPTION BY PLANTS AND THEIR ACCUMULATION IN CROPS. Transl. from Russian, U.S. Atomic Energy Comn., AEC–TR–2867, 227 pp.

(16) Lee, C. C. 1962. UPTAKE OF STRONTIUM M-85 BY ALFALFA. Science 138: 41–42.

(17) Masujima, H. 1963. SOIL-MOISTURE SYSTEM IN RELATION TO PLANT GROWTH. THE EFFECTS OF PARTIAL MOISTURE CONDITIONS IN THE ROOTING ZONE ON PHOSPHORUS AND CALCIUM ABSORPTION BY SOYBEAN PLANTS. Hokkaido Natl. Agr. Expt. Sta. Res. Bul. 82: 36–39.

(18) Menzel, R. G. 1954. COMPETITIVE UPTAKE BY PLANTS OF POTASSIUM, RUBIDIUM, CESIUM, AND CALCIUM, STRONTIUM, BARIUM FROM SOIL. Soil Sci. 77: 419–425.

(19) ——— 1960. RADIOISOTOPES IN SOILS: EFFECT OF AMENDMENTS ON AVAILABILITY. *In* Radioisotopes in the Biosphere, pp. 37–46, ed. by R. S. Caldecott and L. A. Snyder, Univ. Minn., Center for Continuation Study.

(20) MENZEL, R. G., ECK, H. V., and CHAMPION, D. F.
1967. EFFECT OF PLACEMENT DEPTH AND ROOT-INHIBITING CHEMICALS ON UPTAKE OF STRONTIUM-85 BY FIELD CROPS. Agron. Jour. 59: 70–72,

(21) ——— and HEALD, W. R.
1955. DISTRIBUTION OF POTASSIUM, RUBIDIUM, CESIUM, CALCIUM, AND STRONTIUM WITHIN PLANTS GROWN IN NUTRIENT SOLUTIONS. Soil Sci. 80: 287–293.

(22) ——— MYHRE, D. L., and ROBERTS, H., JR.
1961. FOLIAR RETENTION OF STRONTIUM-90 BY WHEAT. Science 134: 559–560.

(23) MIDDLETON, L. J.
1960. RADIOISOTOPES IN PLANTS: PRACTICAL ASPECTS OF AERIAL CONTAMINATION WITH STRONTIUM-90 AND CESIUM-137. *In* Radioisotopes in the Biosphere, pp. 86–96, ed. by R. S. Caldecott and L. A. Snyder, Univ. Minn., Center for Continuation Study.

(24) MILBOURN, G. M.
1960. THE UPTAKE OF RADIOACTIVE STRONTIUM BY CROPS UNDER FIELD CONDITIONS IN THE UNITED KINGDOM. Jour. Agr. Sci. 55: 273–282.

(25) ——— ELLIS, F. B., and RUSSELL, R. S.
1959. THE ABSORPTION OF RADIOACTIVE STRONTIUM BY PLANTS UNDER FIELD CONDITIONS IN THE UNITED KINGDOM. Reactor Sci. 10: 116–132.

(26) PEECH, M., ALEXANDER, L. T., and DEAN, L. A.
1947. METHODS OF SOIL ANALYSIS FOR SOIL FERTILITY INVESTIGATIONS. U.S. Dept. Agr. Cir. 757, 25 pp.

(27) REITEMEIER, R. F., and MENZEL, R. G.
1960. RELATION OF RADIOACTIVE CONTAMINATION OF CROPS TO SOIL FERTILITY. 7th Internatl. Cong. Soil Sci. Trans. III: 35–45.

(28) RUSSELL, R. S.
1960. THE PASSAGE OF THE RADIOACTIVE SUBSTANCES THROUGH FOOD CHAINS INTO THE HUMAN DIET: GENERAL REVIEW. *In* Sup. to the Rpt. of an FAO Expert Comm. on Radioactive Materials in Food and Agriculture, pp. 18–49. Rome, 1959.

(29) ——— and MILBOURN, G. M.
1957. RATE OF ENTRY OF RADIOACTIVE STRONTIUM INTO PLANTS FROM SOILS. Nature 180: 322–324.

(30) SCHULTZ, R. K., MOBERG, J. P., and OVERSTREET, R.
1959. SOME EXPERIMENTS ON THE DECONTAMINATION OF SOILS CONTAINING SR-90. Hilgardia 28: 457–475.

(31) SHIRSHOVA, R. A.
1962. [EFFECT OF POTASSIUM FERTILIZERS ON UPTAKE OF RADIOACTIVE STRONTIUM BY THE PLANT.] Pochvovedenie 3: 36–43.

(32) STEWART, J. D.
1960. INFLUENCE OF SOIL MOISTURE ON ION UPTAKE BY BEAN PLANTS. U.S. Atomic Energy Comm. HW–65500: 37–41.

(33) TSELISHCHEVA, C. N.
1963. [THE REACTION OF STRONTIUM ABSORBED BY THE SOIL WITH POTASSIUM PHOSPHATE.] Izv. Timiryazev. S-Kh. Akad. 84: 332–338.

(34) UNITED STATES ATOMIC ENERGY COMMISSION, NEW YORK OPERATIONS OFFICE.
1964. HEALTH AND SAFETY LABORATORY, FALLOUT PROGRAM QUARTERLY SUMMARY REPORT (Dec. 1, 1963–Mar. 1, 1964). HASL–144, 209 pp.

APPENDIX

TABLE 23.—*Sr-90 content of crops at Watkinsville, Ga.*

Treatment [1]				Corn [2]		Soybean [2]		Oats [3]		Wheat [3]		Coastal bermuda-grass	Lespe-deza
P	I	C	K	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble		
				Pc./kg.	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*
1	1	1	1	3.4	420	230	960	96	200	46	190	[3] 1,480	[3] 2,780
1	1	1	2	2.5	400	210	820	88	170	36	190	-----	-----
1	1	2	1	3.0	450	140	750	93	140	32	170	-----	-----
1	1	2	2	1.8	340	120	800	81	140	31	160	-----	-----
2	1	1	1	2.0	150	280	700	98	140	33	120	[2] 1,150	[2] 2,360
2	1	1	2	1.5	130	180	560	69	120	28	110	-----	-----
2	1	2	1	.8	84	100	500	62	120	28	110	-----	-----
2	1	2	2	.9	92	130	660	58	100	27	120	-----	-----
1	2	1	1	3.5	430	240	950	-----	-----	-----	-----	-----	-----
1	2	1	2	4.0	360	190	1,030	-----	-----	-----	-----	-----	-----
1	2	2	1	2.4	300	110	720	-----	-----	-----	-----	-----	-----
1	2	2	2	2.0	250	130	930	-----	-----	-----	-----	-----	-----
2	2	1	1	1.0	120	140	430	-----	-----	-----	-----	-----	-----
2	2	1	2	1.0	86	150	530	-----	-----	-----	-----	-----	-----
2	2	2	1	1.0	92	88	420	-----	-----	-----	-----	-----	-----
2	2	2	2	1.3	61	100	500	-----	-----	-----	-----	-----	-----

[1] P, placement; I, irrigation; C, calcium; K, potassium; 1, shallow placement or low level of irrigation or amendments; 2, deep placement or high level of irrigation or amendments.

[2] Average of 2 replications.

[3] Average of 4 plots since no irrigation was applied.

TABLE 24.—*Sr-90 content of crops at Ankeny, Iowa*

Tr atment[1]				Corn[2]		Soybeans[2]		Oats[2]		Wheat		Alfalfa[2]	Brome[2]	Red clover[2]	Timothy[2]
P	I	C	K	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain[3]	Stubble[2]				
				Pc./kg.	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*
1	1	1	1	0. 8	55	37	260	14. 2	63	13. 1	68	2, 310	1, 760	2, 730	1, 250
1	1	1	2	. 8	68	32	220	14. 0	50	13. 1	46	--------	--------	--------	--------
1	1	2	1	. 8	50	35	210	13. 6	40	13. 1	54	--------	--------	--------	--------
1	1	2	2	. 8	66	31	210	15. 5	60	13. 1	40	--------	--------	--------	--------
2	1	1	1	. 6	30	15	110	13. 8	58	15. 5	62	2, 030	1, 460	2, 590	1, 250
2	1	1	2	. 6	25	16	90	14. 0	59	15. 5	44	--------	--------	--------	--------
2	1	2	1	. 7	26	12	100	11. 4	54	15. 5	46	--------	--------	--------	--------
2	1	2	2	. 6	28	18	90	13. 0	52	15. 5	56	--------	--------	--------	--------
1	2	1	1	. 5	63	27	190	11. 8	56	17. 8	38	2, 460	1, 530	2, 150	1, 210
1	2	1	2	. 6	66	30	200	13. 7	68	17. 8	46	--------	--------	--------	--------
1	2	2	1	. 4	53	22	190	12. 4	59	17. 8	44	--------	--------	--------	--------
1	2	2	2	. 8	59	29	190	13. 5	66	17. 8	42	--------	--------	--------	--------
2	2	1	1	. 8	22	13	80	10. 8	72	17. 9	54	--------	--------	--------	--------
2	2	1	2	. 8	20	17	90	11. 7	46	17. 9	52	--------	--------	--------	--------
2	2	2	1	. 3	16	15	90	9. 4	54	17. 9	59	--------	--------	--------	--------
2	2	2	2	. 4	20	11	90	10. 6	68	17. 9	44	--------	--------	--------	--------

[1] P, placement; I, irrigation; C, calcium; K, potassium; 1, shallow placement or low level of irrigation or amendments; 2, deep placement or high level of irrigation or amendments.

[2] Average of 2 replications.

[3] Average of a composite of 2 replications of 4 treatments.

TABLE 25.—*Sr-90 content of crops at Morris, Minn.*

Treatment [1]				Corn [2]		Soybeans [2]		Oats [2]		Wheat		Alfalfa [2]	Brome	Red clover	Timothy [2]
P	I	C	K	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain [3]	Stubble [2]				
				Pc./kg.	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*
1	1	1	1	1.6	35	20	320	13	42	13.1	22	4,060	[4] 1,540	[2] 2,800	1,840
1	1	1	2	1.4	40	25	310	24	37	12.6	18	--------	--------	--------	--------
1	1	2	1	.8	58	26	470	21	28	13.1	24	--------	--------	--------	--------
1	1	2	2	.8	54	27	390	20	38	12.6	35	--------	--------	--------	--------
2	1	1	1	1.0	66	20	190	28	30	11.6	40	3,470	[2] 1,570	[4] 2,730	1,960
2	1	1	2	.8	50	31	210	23	28	9.3	32	--------	--------	--------	--------
2	1	2	1	3.1	64	19	220	14	40	11.6	20	--------	--------	--------	--------
2	1	2	2	.9	30	14	190	21	30	9.3	36	--------	--------	--------	--------
1	2	1	1	.8	40	29	310	37	42	24.8	34	3,520	[2] 1,720	[2] 2,890	2,020
1	2	1	2	.6	42	32	300	9	32	29.3	18	--------	--------	--------	--------
1	2	2	1	.5	33	26	260	36	28	24.8	36	--------	--------	--------	--------
1	2	2	2	.8	48	23	230	34	26	29.3	18	--------	--------	--------	--------
2	2	1	1	1.0	34	18	210	33	30	20.0	17	--------	--------	--------	--------
2	2	1	2	.8	37	20	200	24	31	25.0	30	--------	--------	--------	--------
2	2	2	1	.7	28	22	240	33	26	20.0	36	--------	--------	--------	--------
2	2	2	2	.5	28	19	210	37	25	25.0	24	--------	--------	--------	--------

[1] P, placement; I, irrigation; C, calcium; K, potassium; 1, shallow placement or low level of irrigation or amendments; 2, deep placement or high level of irrigation or amendments.

[2] Average of 2 replications.

[3] Average of a composite of 2 replications and 2 calcium treatments.

[4] Only 1 replication.

TABLE 26.—*Sr-90 content of crops at Florence, S.C.*

Treatment [1]				Corn [2]		Soybean [2]		Oats [3]		Wheat [3]		Coastal bermuda-grass	Lespe-deza [2]
P	I	C	K	Grain	Stubble	Grain	Stubble	Grain	Stubble	Grain	Stubble		
				Pc./kg.	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*	*Pc./kg.*
1	1	1	1	1. 4	102	118	560	82	126	68	150	[4] 650	1, 590
1	1	1	2	2. 2	82	113	490	75	151	48	168	------	------
1	1	2	1	1. 5	78	93	440	73	148	57	160	------	------
1	1	2	2	1. 4	90	95	480	74	148	63	156	------	------
2	1	1	1	1. 3	44	76	280	31	59	33	166	[2] 790	1, 600
2	1	1	2	1. 6	38	79	320	37	95	25	156	------	------
2	1	2	1	. 9	29	64	310	31	54	44	118	------	------
2	1	2	2	1. 8	35	81	340	25	58	42	180	------	------
1	2	1	1	2. 4	84	143	560	------	------	------	------	[4] 1, 640	1, 610
1	2	1	2	1. 8	110	131	540	------	------	------	------	------	------
1	2	2	1	2. 0	96	107	510	------	------	------	------	------	------
1	2	2	2	1. 2	90	104	520	------	------	------	------	------	------
2	2	1	1	1. 0	32	73	290	------	------	------	------	------	------
2	2	1	2	1. 2	35	52	280	------	------	------	------	------	------
2	2	2	1	. 8	36	66	250	------	------	------	------	------	------
2	2	2	2	1. 1	34	82	390	------	------	------	------	------	------

[1] P, placement; I, irrigation; C, calcium; K, potassium; 1, shallow placement or low level of irrigation or amendments; 2, deep placement or high level of irrigation or amendments.

[2] Average of 2 replications.

[3] Average of 4 plots.

[4] Only 1 replication.

Table 27.—*Yields at Watkinsville, Ga.*

[1 kg.=0.039 bu. of corn, 0.037 bu. of soybeans or wheat, 0.069 bu. of oats, and 2.2 lb. of forage]

Treatment [1]				Corn [2]	Soybeans [2]	Oats [3]	Wheat [3]	Coastal bermuda-grass [3]	Lespedeza [3]
P	I	C	K						
				Kg./acre	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*
1	1	1	1	2, 884	904	552	916	524	511
1	1	1	2	3, 088	877	640	854	433	520
1	1	2	1	2, 788	874	680	814	552	632
1	1	2	2	3, 172	783	530	867	472	627
2	1	1	1	2, 516	722	667	1, 069	599	554
2	1	1	2	2, 548	584	703	1, 015	484	537
2	1	2	1	1, 561	777	624	933	550	626
2	1	2	2	1, 767	831	764	1, 050	510	636
1	2	1	1	2, 814	760	---	---	---	---
1	2	1	2	3, 038	878	---	---	---	---
1	2	2	1	3, 256	907	---	---	---	---
1	2	2	2	3, 126	990	---	---	---	---
2	2	1	1	2, 142	668	---	---	---	---
2	2	1	2	2, 545	786	---	---	---	---
2	2	2	1	1, 496	819	---	---	---	---
2	2	2	2	1, 909	844	---	---	---	---

[1] P, placement; I, irrigation; C, calcium; K, potassium; 1, shallow placement or low level of irrigation or amendments; 2, deep placement or high level of irrigation or amendments.

[2] Average of 2 replications.

[3] Average of 4 plots since no irrigation was applied.

TABLE 28.—*Yields at Ankeny, Iowa*

[Average of 2 replications. 1 kg. = 0.039 bu. of corn, 0.037 bu. of soybeans or wheat, 0.069 bu. of oats, and 2.2 lb. of forage]

Treatment[1]				Corn	Soybeans	Oats	Wheat	Alfalfa	Brome	Red clover	Timothy
P	I	C	K								
				Kg./acre	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*
1	1	1	1	3, 678	1, 054	1, 577	1, 025	733	874	987	620
1	1	1	2	3, 452	1, 114	1, 678	1, 066	677	956	790	705
1	1	2	1	3, 579	1, 136	1, 596	1, 114	508	818	1, 015	451
1	1	2	2	3, 576	1, 140	1, 622	1, 128	677	987	956	508
2	1	1	1	1, 991	629	1, 340	931	649	846	902	620
2	1	1	2	2, 081	708	1, 384	1, 037	733	1, 015	677	677
2	1	2	1	2, 234	715	1, 388	905	818	733	902	592
2	1	2	2	2, 062	719	1, 417	1, 032	846	902	956	790
1	2	1	1	3, 960	1, 021	1, 626	1, 100	620	1, 072	423	956
1	2	1	2	3, 658	1, 104	1, 646	1, 152	677	818	367	1, 128
1	2	2	1	3, 885	1, 159	1, 720	1, 127	620	1, 015	451	987
1	2	2	2	3, 912	1, 152	1, 692	1, 134	592	902	479	1, 043
2	2	1	1	2, 494	883	1, 540	1, 022	620	790	508	848
2	2	1	2	2, 231	913	1, 532	984	620	846	338	1, 100
2	2	2	1	2, 000	988	1, 436	1, 024	705	790	592	705
2	2	2	2	2, 104	958	1, 592	1, 034	677	902	564	931

[1] P, placement; I, irrigation; C, calcium; K, potassium; 1, shallow placement or low level of irrigation or amendments; 2, deep placement or high level of irrigation or amendments.

TABLE 29.—*Yields at Morris, Minn.*

[Average of 2 replications. 1 kg.=0.039 bu. of corn, 0.037 bu. of soybeans or wheat, 0.069 bu. of oats, and 2.2 lb. of forage]

Treatment [1]				Corn	Soybean	Oats	Wheat	Alfalfa	Brome	Red clover	Timothy
P	I	C	K								
				Kg./acre	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*
1	1	1	1	1, 136	250	582	234	1, 312	127	99	875
1	1	1	2	729	238	493	178	1, 213	212	113	889
1	1	2	1	934	144	373	181	1, 028	109	56	593
1	1	2	2	1, 265	164	442	209	1, 115	56	240	734
2	1	1	1	726	349	621	228	1, 792	99	56	1, 044
2	1	1	2	740	250	400	280	1, 679	113	99	494
2	1	2	1	627	217	367	341	1, 862	99	113	889
2	1	2	2	867	276	314	366	1, 397	70	296	847
1	2	1	1	1, 582	398	593	204	1, 467	113	268	706
1	2	1	2	1, 396	368	735	252	1, 411	70	607	720
1	2	2	1	1, 358	377	767	201	1, 552	85	409	832
1	2	2	2	1, 480	369	762	245	1, 764	70	635	466
2	2	1	1	826	281	772	204	1, 919	56	480	564
2	2	1	2	1, 098	202	829	383	1, 975	42	268	564
2	2	2	1	1, 037	244	697	323	1, 990	42	310	593
2	2	2	2	880	323	836	304	2, 046	56	945	381

[1] P, placement; I, irrigation; C, calcium; K, potassium; 1, shallow placement or low level of irrigation or amendments; 2, deep placement or high level of irrigation or amendments.

TABLE 30.—*Yields at Florence, S.C.*

[1 kg.=0.039 bu. of corn, 0.037 bu. of soybeans and wheat, 0.069 bu. of oats, and 2.2 lb. of forage]

Treatment [1]				Corn [2]	Soybeans [2]	Oats [3]	Wheat [3]	Coastal bermudagrass	Lespedeza [2]
P	I	C	K						
				Kg./acre	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*	*Kg./acre*
1	1	1	1	1, 866	940	887	804	[4] 379	665
1	1	1	2	1, 630	1, 101	916	809	[4] 360	297
1	1	2	1	1, 620	1, 198	728	729	[4] 284	686
1	1	2	2	1, 805	1, 257	825	768	[4] 304	772
2	1	1	1	684	896	811	574	[2] 474	503
2	1	1	2	746	1, 049	962	590	[2] 465	416
2	1	2	1	584	1, 164	858	764	[2] 398	461
2	1	2	2	710	1, 192	734	725	[2] 408	596
1	2	1	1	1, 830	944	--------	--------	[4] 341	609
1	2	1	2	1, 854	1, 059	--------	--------	[4] 512	621
1	2	2	1	1, 432	1, 074	--------	--------	[4] 209	1, 117
1	2	2	2	1, 794	1, 044	--------	--------	[4] 398	898
2	2	1	1	910	965	--------	--------	[2] 740	465
2	2	1	2	934	976	--------	--------	[2] 455	546
2	2	2	1	708	1, 101	--------	--------	[2] 313	808
2	2	2	2	822	1, 156	--------	--------	[2] 351	817

[1] P, placement; I, irrigation; C, calcium, K, potassium; 1, shallow placement or low level of irrigation or amendments; 2, deep placement or low level of irrigation or amendments.
[2] Average of 2 replications.
[3] Average of 4 plots since no irrigation was applied.
Only 1 replication because of weed infestation.

END