STRONTIUM 90 IN MAIZE FIELD, CATTAIL MARSH AND OAKWOOD ECOSYSTEMS

BY J. D. OVINGTON* AND D. B. LAWRENCE

Department of Botany, University of Minnesota, Minneapolis

Cedar Creek Natural History Area is situated 50 km (30 miles) north of Minneapolis, Minnesota, U.S.A. At Cedar Creek, within an area of less than 2000 ha, there is a wide range of natural vegetation types, some of which were sampled intensively in 1959 as part of a research programme designed to obtain data on the biomass and productivity of terrestrial ecosystems (Ovington, Heitkamp & Lawrence 1963). At that time, Mr R. E. Frazier of the State of Minnesota Department of Health was recording strontium 90 in the milk and vegetation from four farms in Minnesota and kindly agreed to determine strontium 90 in some of the plant samples collected at Cedar Creek. Surveys of radioactivity have been done mainly on agricultural crops because of concern about human health with the contamination of food supplies through fallout. Relatively little information is available about strontium 90 in wild ecosystems.

The strontium 90 values given here for plant material collected at Cedar Creek are based on single counts, in which the radioactivity was counted for long enough to ensure that the standard deviation of the total radioactivity count was about 10% or less. The number of samples for which strontium 90 could be determined was limited by financial considerations. Consequently great care was taken to ensure the samples sent for analysis were as representative as possible. For instance, the tree bole sample was composed of sub-samples at 2 m intervals up the trunks of three trees selected to cover the size range of trees in the oakwood. The weights of the sub-samples in the composite sample were adjusted according to the distribution of bole weight in the stand.

The Cedar Creek studies enable tentative comparisons to be made of the strontium 90 contents of an annual field crop, maize, *Zea mays* L., and two natural ecosystems dominated by perennials, a marsh of narrow leaved cattail (reedmace), *Typha angustifolia* L. and an oakwood, chiefly of northern red oak, *Quercus rubra* var. *borealis* Michx. The maize field and adjacent cattail marsh are about a mile from the oakwood and it seems reasonable to suppose that all receive similar amounts of fallout. Although tests of nuclear weapons were suspended in 1958, the fallout rate of strontium 90 was particularly high during the spring of 1959 when the plant sampling began and decreased in the summer (Fig. 1).

ECOSYSTEMS

The soil of the cattail swamp is peat more than a metre deep but the maize field and oakwood are on freely drained, sandy soil. The oakwood soil differs from that of the maize field in being covered with a thick organic mat of litter.

The maize samples were taken from a small experimental plot left after the rest of the field had been harvested for silage on 10 September. When it was sampled on 15 October 1959 the maize biomass had begun to decline from a September maximum. The weight of weeds, mainly *Agropyron repens* L. and *Setaria glauca* L., was about a ninth of that of the maize and was not regarded as excessive for the district.

* Now at the Nature Conservancy, Monks' Wood Experimental Station, Abbots Ripton, Huntingdonshire, England.

The woodland is dense second growth northern red oak, developed naturally after cutting about 57 years ago. When the oakwood was sampled on 24 September, the trees were in full leaf, and just over 17 m tall. The strontium 90 contents of the herb and shrub layers of the oakwood were not determined because these layers constitute only about 0·2% of the biomass of the living plants. Strontium 90 assays were done for dead branches on the trees and the litter layers of the forest floor since they form a large proportion of the organic matter in the woodland.

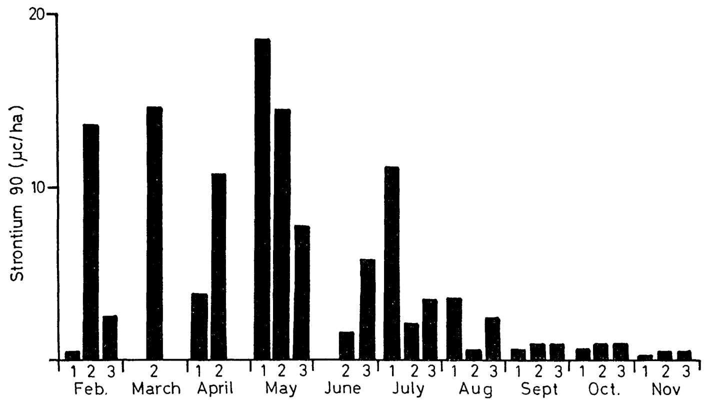

FIG. 1. Monthly fallout in 1959 for the three monitoring stations nearest to Cedar Creek. Monitoring station; 1 = Minnesota, International Falls; 2 = Missouri, Columbia; 3 = Wisconsin, Green Bay.

In hollows within the sandy upland area at Cedar Creek, peat soils have developed and on these waterlogged soils the vegetation frequently consists of a patchwork of stands of narrow leaved cattail, *Typha angustifolia* L. and broad leaved cattail, *T. latifolia* L. Narrow leaved cattails have the greater biomass per unit area, 4227 compared with 3306 kg/ha, and the cattail stand for which strontium 90 was determined is typical of the narrow leaved cattail stands. Associated plants are *Lysimachia thyrsiflora* L., *Potentilla palustris* L. and *Carex comosa* Booth, their biomass being about a third of that of the cattails. Unlike the maize field and oakwood, the lower-lying marsh ecosystem may receive some strontium 90 in water draining from the surrounding areas.

RESULTS AND DISCUSSION

Strontium 90 released into the atmosphere as a fission product of nuclear explosions can form a particulate accumulation on plant surfaces (Romney *et al.* 1963) or may be contained within plant tissues. The various kinds of plant material sampled at Cedar Creek differed greatly in the amount of strontium 90 they contained per kg oven dry weight (Table 1). The strontium 90 content of the oak tree material, in μμc/kg, increased from 99 to 940 in the order: tree trunks, living branches older than 1 year, dead branches, branches younger than 1 year, and leaves. A similar range of strontium 90 values was found in the maize plants, increasing from 31 to 1060 μμc/kg in the order: maize ears (including grain cob and husk), roots, stems and leaves. The shoots of the weeds in the maize field, and the cattails, which were sampled as a whole, were rich in strontium 90. In general higher concentrations of strontium 90 were associated with above-ground plant material which has a large suface area relative to its volume. The small concentration of strontium 90 in the maize ears may be related both to the relatively small surface area and to the fact that the ears develop late in the growing season. This suggests that deposition on plant surfaces and absorption through the shoot, rather than absorption from the soil, may be the main source of accumulation of strontium 90. Nevertheless, data to be published elsewhere indicate that the concentrations of major nutrient elements (such as calcium, Table 1), which are largely absorbed through the roots, parallel those of strontium 90 to some extent. Russell (1960) provides evidence that in periods when the amount of fallout is appreciable relative to the amounts of radio-nuclides in soil, as in 1957–59, the main source of strontium 90 in plants is direct contamination and absorption of material at the shoot bases, rather than absorption through roots from the mineral soil. Gorham (1959) has suggested that the level of radioactivity is higher in mosses and lichens than in angiosperms because they have a greater surface area per unit dry weight of tissue.

Table 1. *Plant biomass and content of strontium* 90 *at Cedar Creek in* 1959

	Oven dry weight (kg/ha)	Calcium (mg/100 g)	Strontium 90 ($\mu\mu$c/kg oven dry weight)	Strontium 90/g Ca ($\mu\mu$c)	Strontium 90 (μc/ha)
Maize field sampled in October					
Maize ears (including grain, cob and husk)	5337	21	31	150	0·17
Maize leaves	1144	370	1060	290	1·21
Maize stems	1567	190	280	140	0·44
Maize roots	472	160	230	140	0·11
Weed shoots	889	380	1120	290	1·00
Maize and weed shoots	8937	–	–	–	2·82
Narrow leaved cattail sampled in September					
Cattail shoots	3272	1460	1360	87	4·45
Oakwood sampled in September					
Oak leaves	3543	720	940	130	3·33
Oak branches formed in 1959	483	960	870	92	0·42
Oak branches formed before 1959	49019	500	400	80	19·61
Oak trunks	111888	380	99	24	11·08
Total for oak shoots	164933	–	–	–	34·44
Dead branches on trees	21838	290	630	220	13·76
Litter layer	31511	1130	2800	240	88·23

The greatest value of strontium 90 found in the samples was 2800 $\mu\mu$c/kg. This was for oak litter which has a higher capacity for holding cations such as strontium and furthermore represents several years' accumulation of litter on the mineral soil. Leaves, branches etc., falling from the plants add more strontium 90 every year to the litter layer which also derives strontium 90 directly from fallout, in rainwater that has washed over the tree crowns, and in animals and their frass which fall from the plants.

The amount of strontium 90 accumulated in the plant biomass per unit area of ecosystem differed considerably between the three areas. Comparing the strontium 90 contents of the above-ground shoot material in μc/ha, the cattail marsh (4·45 μc/ha) contained nearly twice as much as the maize field (2·82 μc/ha) and the oakwood (34·44 μc/ha) over ten times as much. The relatively large amount of strontium 90 in the oakwood plants results from their great biomass, particularly of woody material, rather than from high concentrations of strontium 90. This biomass has a very large area of collecting surface and the older branches and trunks had been exposed to fallout since nuclear testing began.

Some of the strontium 90 accumulated in the ecosystems persists from year to year in the living plants. In the maize field much of the strontium 90 in the maize plants will be removed at harvest since only a small proportion is present in the roots. Part of the removed strontium may be returned later to the field in manure, because the maize is used as winter feed for cattle, and the manure accumulated in winter is spread on the field in spring. In the cattail marsh there will be some carry-over of strontium 90 from year to year in the living plants by way of the rhizomes and roots. In the oakwood the annual carry-over of strontium 90 in the living plants is considerable, over 30 μc/ha in the above-ground shoots, mainly because it persists in (or on) the large mass of trunks and branches. Strontium 90 was not determined in the tree roots but if the concentration is low, as in the maize roots, the total amount within the tree root system would be only a small fraction of that in the branches and trunks, even though there are about 15 000 kg of roots per ha in the oakwood. Large amounts of strontium 90 are present in the oak litter layer, which is the accumulation of several years' litter fall, and in dead branches still attached to the trees. Since these persist from year to year they represent a large carry-over.

The amounts of strontium 90 in the new shoot growth of the three ecosystems are similar: 2·82, 4·45 and 3·75 μc/ha respectively for the maize field, cattail marsh and oakwood. In the cattail marsh much of this will fall on the peat soil in autumn and spring as the cattail plants break up. In the oakwood most of the young branches remain on the trees so that about 10% of the strontium 90 in and on the new shoot production remains in the trees after the leaves have fallen.

It is of interest to compare the Cedar Creek data with those obtained in 1959 in pastures at Brainerd, Minnesota (Anon. 1961), which is only 125 km (80 miles) north-east of Cedar Creek. Strontium 90 levels were determined for permanent pastures at four farms there. The pastures, mainly of the two grasses timothy, *Phleum pratense* L., and bluegrass, *Poa pratensis* L., were on sandy loam or deep marsh peat. In the pastures the concentration of strontium 90 in the grass shoots in November 1959 varied from 1300 to 1930 $\mu\mu$c/kg (oven-dry weight) on marsh soils and from 1610 to 3290 $\mu\mu$c/kg on sandy loam soils. These concentrations are greater than those in the shoots at Cedar Creek but the total amounts in the above-ground pasture vegetation, between 1·2 and 6·6 μc/ha, are similar to the corresponding total values for the maize field and cattail marsh at Cedar Creek. In contrast the total amounts in the pastures are small compared with that in the oakwood at Cedar Creek where the above-ground vegetation contained about 34·4 μc/ha of strontium 90.

Large amounts of strontium 90 are present within the pasture root mats, i.e. the horizon immediately overlying the soil, which consists of surface roots, bases of stems and decaying litter. At Brainerd, strontium 90 in the root mats in 1959 varied from 2·5 to 24·7 μc/ha. Comparisons of strontium 90 levels in root mats cannot be made with the Cedar Creek data except for the oakwood, where the litter corresponds approximately to the root mat horizon. The oak litter has 88·2 μc/ha of strontium 90, much more than root mats at Brainerd.

Unfortunately strontium 90 was not determined in the soils of the Cedar Creek ecosystems. At Brainerd estimates of strontium 90 from hydrochloric acid extracts, or indirectly from ratios of strontium 90 to caesium 137, give values of 58–111 μc/ha for mineral soils within the top 5 cm (2 in.) and 180–244 μc/ha for peat soils. The greater values for the peat soils may result from transport of strontium 90 in water flowing in from the surrounding uplands. Inclusion of deeper soil layers would increase these values, but not very greatly if, as is usual, strontium 90 is held mainly in the surface soil.

The removal of strontium 90 from the pastures by grazing animals, estimated from feeding rates (Anon. 1961), is a small fraction of 1% of the total in the ecosystem. It seems probable that the amount of strontium 90 per unit area in each complete ecosystem at Cedar Creek is within the range found in the Brainerd pastures. The strontium 90 contents of the soil in the maize field and cattail marsh would then be twenty to fifty times greater than those of the living organic matter. In contrast a relatively large fraction of the strontium 90 in the woodland would be in living plants and litter.

No data are available for income of strontium 90 fallout in 1959 at Cedar Creek but an approximate value can be obtained from data published for the three nearest monitoring sites (Fig. 1) with fairly complete records for the year (Hardy, Rivera & Collins 1963). Strontium 90 in the 1959 precipitation collections at International Falls, Minnesota amounts to 46 μc/ha, at Green Bay, Wisconsin 50 μc/ha and at Columbia, Missouri, 66 μc/ha. For the growing season, i.e. May to September, the respective fallouts in the precipitation are 21, 41 and 20 μc/ha. Dry fallout is less important than fallout in precipitation, which is from five to twenty times as large (Alexander *et al.* 1961). If fallout of

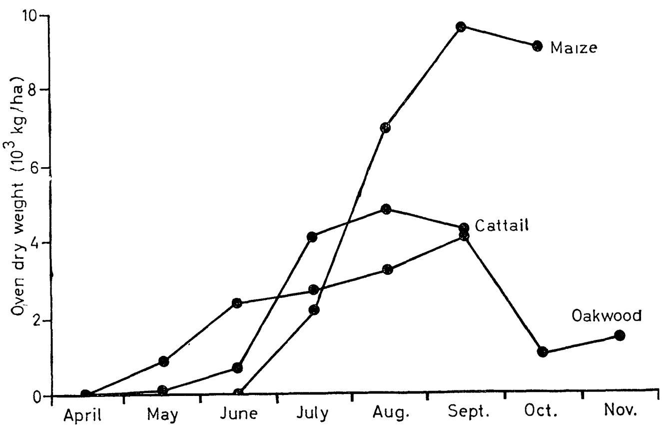

FIG. 2. Growth of maize, cattail and oakwood (new branches and leaves) shoots in 1959.

strontium 90 at Cedar Creek during the growing season 1959 was also in the range of 20–40 μc/ha it greatly exceeded strontium 90 in the 1959 plant growth in all ecosystems, as well as the total for all plant material (excluding the peat soil) in the cattail and maize ecosystems. In the oakwood, strontium 90 in the plant material of the ecosystem, i.e. 136 μc/ha for oakwood trees (excluding roots), dead branches on trees and the litter layer, is several times greater than the 1959 fallout.

The dominant plants of each ecosystem have been subjected to different amounts of fallout because of differences in phenology (Figs. 1 and 2). The upland sandy soils warm up rapidly and spring growth of the oak trees is well advanced before the peat soil of the cattail marsh thaws out. The field of maize was planted on 19 May and the maize plants did not fully cover the ground until late July. Consequently, the new shoots of the oak trees were more exposed to the heavy spring fallout than the cattail shoots and the maize plants virtually missed it completely.

In Britain, many pastures were assessed for strontium 90 content in 1959 (Agricultural Research Council 1961a). These show a range of values for total strontium 90, the Minnesota pastures having values intermediate between those of the British medium and high productivity pastures (Table 2). The general distribution pattern for strontium 90 differs in that the British pastures have more strontium 90 in their litter mats; more litter tends to accumulate in British than in Minnesota pastures. In the Minnesota oakwood, where the litter layer is well developed, the strontium 90 content of the litter corresponds more closely to that of the litter mats of British pastures.

The larger amount of strontium 90 persisting in (or perhaps on the surface of) the bulky trees means that it will probably reach the soil much more slowly than in herbaceous systems. When fallout is no longer detectable in the living organic matter of herbaceous communities, forest organisms will retain some strontium 90, of which an increasingly large fraction will remain in circulation in the living matter of the biosphere.

Table 2. *Comparative values* ($\mu c/ha$) *of strontium* 90 *in* 1959

		Plant shoots	Litter mat	Soil	Total
Cedar Creek	Maize field	3	0	–	–
	Cattail	5	–	–	–
	Oakwood	34	88	–	–
Brainerd pastures (a)	23 M	7	11	180	198
	25 L	6	12	194	212
	27 U	6	3	103	112
	31 L	1	7	111	119
British pastures (b)	Low productivity (1)	11	325	75	411
	Medium productivity (2)	4	195	92	291
	High productivity (3)	1	66	24	91

(a) From Anon. (1961); M = marsh, L = lowland, U = upland.
(b) From Agricultural Research Council (1961a, b).
(1) Stations 3, 4, 8, 9, 11, 13.
(2) Stations 1, 6, 7, 10, 12, 16, 17, 23.
(3) Station 24.

At Cedar Creek, the actual levels of strontium 90, even after the unusually heavy fallout of 1959, represented less radioactivity than the natural potassium present in the same samples. By comparison with standards of contamination which most people take for granted from natural materials, the present samples would not seem particularly hazardous even if they were involved in food chains leading to man. The ratios of strontium 90 : calcium (Table 1) were lower at Cedar Creek than in the herbage of most British pastures, though they were higher than those found in most vegetable crops (Agricultural Research Council 1961b).

On the other hand, if more intensive contamination of the environment were to arise from a nuclear catastrophe (such as an industrial accident, or local fallout from an atomic bomb), woodland organic matter might retain contamination for many years longer than agricultural crops and grasslands. The future of strontium 90 in marshes would depend upon the nature of their organic soils, and the extent of import by runoff from the uplands.

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SUMMARY

In Minnesota in late 1959, the above-ground parts of cattail and maize ecosytems at Cedar Creek contained 4·4 and 2·8 μc/ha of strontium 90 respectively, much less than the annual fallout. These amounts are similar to those found in the vegetation of Minnesota pastures. In the pastures, the quantity of strontium 90 in the vegetation was only a few per cent of that in the root mat and top 5 cm of soil, so that it seems likely that much of the strontium 90 in the maize field and cattail marsh also is in the soil and not in the living plants. In contrast, the trees of the oakwood contain much more strontium 90 (48·2 μc/ha) than the living plants of the other ecosystems. The total strontium 90 (136 μc/ha) in the organic matter in the oakwood at Cedar Creek is in the range reported for the total strontium 90 in the vegetation, root mat and surface soil of pastures under roughly comparable rainfalls in Minnesota and Britain. Since the accumulation of strontium 90 in terrestrial ecosystems is fairly uniform for comparable localities, much of the strontium 90 in the woodland is likely to be in the organic matter and relatively little in the mineral soil. The oakwood clearly differs greatly from the herbaceous ecosystems in respect of the distribution and anticipated rate of movement of strontium 90. Oak leaves contain only 3·33 μc/ha of strontium 90, much less than the more persistent living branches, trunks, dead branches and litter (20·03, 11·08, 13·76 and 88·23 μc/ha respectively).

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