Ecological Ramifications of Silver Iodide Nucleating Agent Accumulation in a Semi-Arid Grassland Environment

D. A. KLEIN AND E. M. MOLISE

Department of Microbiology, Colorado State University, Fort Collins 80523

(Manuscript received 28 August 1974, in revised form 20 January 1975)

ABSTRACT

The possible ecological effects of silver iodide accumulation in soil which might result from weather modification were examined by use of a 2.5 year old randomized treatment plot in a semi-arid grassland to define possible threshhold silver levels where changes in decomposer parameters might first be detected. After three growing seasons, silver iodide presence at levels above those which could be expected from weather modification appears to be related to decreased soil oxygen uptake, carbon dioxide evolution, and bacterial glucose mineralization activities. The threshhold for possible observation of decreased mineralization, the most sensitive assay evaluated to date, is in the range of 1–2 $\mu g\ g^{-1}$ silver. In the range of 0–0.6 $\mu g\ g^{-1}$ accumulated silver, no significant changes in this parameter were observed in relation to imposed silver. Silver from silver nitrate did not show equivalent effects. A significant increase in silver-reducing microorganisms was noted only in the high-level silver nitrate treated soils. Analysis of silver distribution between soils and roots in treated plots suggests concentration in the plant root zone, with lesser silver levels in grasses from silver iodide than from silver nitrate. Silver levels present in soils, and which might accumulate as a result of weather modification, appear to be at least 1–2 magnitudes below those where first silver iodide effects on decomposer functions might be seen. A model of silver iodide ecological effects on decomposer function is presented, in which control and treated soils may have equivalent apparent biological activities at a specific time after silver imposition in spite of changed ecosystem functions.

1. Introduction

A major question regarding the short- and long-term effects of weather modification activities concerns the potential effects of silver iodide, used as a nucleating agent in most programs, on soil and aquatic microbiological processes. Although work with other agents is being considered, the major seeding agent of choice, and the agent which appears to warrant maximum confidence among the weather modification profession, is silver iodide. This preference is based on several factors: the long-term use of this seeding agent, its high nucleating efficiency, and the ease of delivery into varied atmospheric systems by use of a wide range of ground-based and airborne procedures.

Since the beginning of operational weather modification activities in 1948–49 (Brown, 1971), silver iodide has been used as a nucleating agent in most programs, and programs have been carried out in most of the states of the western United States since that time.

Concern for the potential ecological effects of AgI on biological systems is based on the well-known and medically useful anti-microbial activity of silver nitrate, used widely in topical treatments. Silver in the ionic form is capable of strongly inhibiting the growth and metabolism of microorganisms (Woodward, 1963) based on its ability to inactivate the sulfhydryl groups of proteins (Snodgrass *et al.*, 1960). Investigations of potential silver biological interactions has been limited by the ability of silver to be adsorbed by organic matter and clays (Cameron, 1973), and to surfaces of flasks and containers where it may no longer influence a test system (Chao *et al.*, 1968).

Based on the bactericidal effect of ionic silver, the medical literature has been utilized in reference to the possible toxic effects of AgI from weather modification in biological systems, including the question of possible biomagnification of silver in higher trophic levels, as can occur with lead and mercury. This possibility has been discussed by Cooper and Jolly (1970), and as noted by these workers, the differences in the physical characteristics of the organic and inorganic forms of silver as opposed to lead and mercury appear to make it unlikely that a similar biomagnification of silver in higher trophic levels might occur. Available summaries of silver physical and chemical characteristics (Gmelin, 1972) tend to confirm this viewpoint.

As reviewed by Cooper and Jolly (1970), the available literature suggests that plant and animal systems would be minimally influenced by the presence of this agent, and that the major point of possible concern would be possible effects on soil and aquatic microorganisms.

In evaluation of possible AgI ecological effects, a frequent approach has been to assume that if $AgNO_3$

is used, this will exhibit the maximal effects on a test system due to its complete ionization. This approach has been used in rumen studies (Bailey *et al.*, 1973), algal studies (Young and Lisk, 1972), in studies of bacterial survival and respiration in pure culture (Brown and Anderson, 1968; Klein and Sokol, 1973b), in soils (Weaver and Klarich, 1973), and in human toxicity trials (Lawrence and Block, 1968). On the other hand, the use of AgI in test biological systems has been predicated on the literature values for the solubility of this compound in distilled water, usually considered to be approximately 0.03 mg ℓ^{-1} (Merck Index, 1968). This low silver iodide solubility in water suggests that effects on microorganisms will be minimal. However, in more complex biological systems, many additional reactions may occur to give increased AgI availability. For example, the presence of ammonia and amines can lead to increased solubility (Gmelin, 1972). Of interest is the increased solubility of silver iodide in nonpolar solvents in the presence of excess iodide (Gmelin, 1972; Specker and Pappert, 1965) which could lead to increased solubility of AgI in non-polar cellular membranes. An increased inhibitory effect of AgI on glucose radiorespiration in the presence of excess iodide has been observed in laboratory soil systems, suggesting that excess halide may be able to potentiate silver iodide biological effects (Molise and Klein, 1974).

Silver iodide ecological effects are also predicated on measured silver concentrations in precipitation, which are then used to calculate the potential silver accretion which might occur in a given ecosystem over time. Weaver and Klarich (1973) have used this approach to calculate the seeding durations needed before specific effects of added silver from weather modification will be observable in the soil ecosystem, based on short-term whole soil respiration assays carried out in the laboratory. This assumption must be considered in the light of factors which might cause concentration of added silver deposited in soil or water: 1) rainfall over a given area will not be uniform, but may occur in localized zones; 2) wind erosion can be a major factor in the movement of surface soil to more protected areas such as streams and gully areas (Alldredge and Whicker, 1972); and 3) silver uptake by plants (Teller and Klein, 1973) followed by ruminant ingestion can lead to increased localized silver accumulation in fecal material deposition areas.

As an additional factor, short-term field or laboratory experiments will not take into account the ability of plants (Jensen and Kavaljian, 1956) and of microorganisms (Summers and Sugarman, 1974) to cause reduction of free silver ions and silver from silver iodide and silver oxide (Klein and Sokol, 1973b) to metallic silver. The existence of microbially-mediated silver transformations suggests that in any specific situation or environment, added silver should be allowed to equilibrate until the normal distribution of silver forms for a particular environmental condition have been met (Klein and Sokol, 1973a).

The objective of such studies should not be to simply show that effects can be observed by perturbing a system with silver, but to quantify the levels where it will first be possible to observe the effects of accumulated AgI on ecosystem processes. Seasonal primary productivity processes should be allowed to continue for a maximum period to assure that minor changes in ecosystem function can be detected due to the accumulation of specific plant components or by changes in microbial activity parameters which might not be detectable in short-term experiments.

Several approaches are available for the analysis of this problem. It is possible to examine the soils surrounding previously used seeding generator sites where silver gradients have been imposed across plant communities. This approach has the advantage of allowing one to be certain that the silver which was added to the test system was in the burn complex form. The major disadvantage of this approach is that seeding generator sites are not usually placed in locations where the plant and soil community are uniform. As a second approach, specific ecosystem changes can be measured after silver imposition on selected ecosystems where other site characteristics can be assumed to be constant. This second approach allows treatment randomization, and sites can be selected where sufficient background information on community structure and function is available. The major disadvantage of this approach is that the silver forms available for application over the randomized treatment areas will not be the actual silver iodide burn complexes, but will usually be derived from $AgNO_3$ or AgI. It is also difficult to determine when the silver has equilibrated to the final forms which might accumulate in that particular ecosystem.

In this conceptual context, a series of field treatment plots and selected seeding generator site gradients are being studied to evaluate possible threshold silver levels where definitive changes in ecosystem functions can first be observed. In this communication, data from a semi-arid grassland treatment plot are summarized.

2. Materials and methods

a. Sampling site

A field treatment plot installed in March 1972 at the Central Plains Experimental Range, ARS, USDA, at Nunn, Colorado, was used in the field studies reported here. Thirty-six sub-plots in a six by six array were set on 3 m centers. Each sub-plot was 1.5 m^2, with 1.5 m separation. Silver iodide was added to give final Ag concentrations of 100, 10 and 1 μg g^{-1} to a depth of 2 cm. The salt was dissolved with equal parts by weight of sodium iodide in acetone. Silver nitrate was added at the same concentrations of Ag, dissolved in water. Untreated, acetone, sodium iodide and water controls were included. All variables were replicated four-fold.

TABLE 1. Analysis of regression between silver levels and specific biological parameters in the IBP treatment plots, 0–3 cm data.

Parameter	Original silver form used	Relation of silver to parameter	R^2 value for curve-fitting functions: Linear	Parabolic	Exponential	Power	Number of samples
O_2 uptake	Iodide	Negative	0.130	0.130	0.170	0.104	41
	Nitrate	None	0.000	0.001	0.000	0.008	36
CO_2 evolution	Iodide	Negative	0.150	0.168	0.246	0.201	38
	Nitrate	None	0.000	0.000	0.003	0.001	40
Glucose mineralization	Iodide	Negative	0.215	0.295	0.317	0.494	73
	Nitrate	None	0.001	0.004	0.005	0.004	80
Organic matter—gravimetric	Iodide	None	0.013	0.013	0.001	0.006	39
	Nitrate	Positive(?)	0.197	0.198	0.166	0.060	38
Organic matter—chemical	Iodide	Positive(?)	0.000	0.136	0.001	0.034	34
	Nitrate	None	0.004	0.030	0.013	0.094	40

The treatments were added with spray bottles to cover the entire 1.5 m^2 subplots. The term silver iodide will be used to describe the AgI-NaI complexes which were used in these treatment plots.

b. Field sampling

Duplicate 10 cm diameter, 15 cm depth cores were removed from each of the 40 sub-plots in July 1974, and transported to the laboratory in polyethylene bags for analysis. Surface litter and root crowns were removed, and 0–3 and 3–6 cm depth sub-samples were separated. Each of these depth profile samples were split in two portions, one for the chemical, glucose mineralization, and microbial population assays; and the second portion of each sample in oxygen uptake and carbon dioxide evolution experiments. The samples used in this study were taken three days after a major precipitation event to assure optimal soil moisture conditions.

c. Analytical procedures

Each sub-sample of soil used in biological assays was analyzed for silver content using a persulfate oxidation, atomic absorption analysis procedure carried out by Skyline Laboratories, Wheatridge, Colorado. Plant samples, and samples of separated roots and residual soil were analyzed using the same procedure.

Assays of glucose mineralization, the microbial oxidation of ^{14}C-glucose to $^{14}CO_2$, were made using a modification of the Harrison *et al.* (1971) procedure. Three hundred milligrams of soil were incubated for 20 min. Activity was expressed as counts of $^{14}CO_2$ evolved per 20 min per gram soil (dry weight).

Oxygen uptake and carbon dioxide evolution assays of whole cores were completed using the procedure of Klein *et al.* (1972).

Organic matter in soils and plant materials were estimated by a gravimetric ashing and by dichromate-sulfuric acid chemical oxidation procedures. Dichromate-sulfuric acid organic matter assays, and soluble soil phosphorus, potassium, nitrate, copper, iron and manganese levels were determined using standardized soil testing procedures by the Colorado State University Soil Testing Laboratory.

For enumeration of microbial populations sodium caseinate agar [sodium caseinate (0.2 g), K_2HPO_4 (0.5 g), $MgSO_4 \cdot 7HOH$ (0.2 g), $FeCl_3$ (0.01 g), agar (15.0 g), and 1000 ml distilled water; pH 6.5–7.0] was used for total bacteria and actinomycete counts, and Martin's (1950) Rose Bengal Medium was used for evaluation of fungal populations. Soils were decimally diluted in phosphate buffer and 0.1 ml aliquots were spread on plates in two-fold replications. Plates were read after incubation for five days at 27°C, and a differential count of total bacteria and fungi was made.

After completion of the sodium caseinate agar enumeration the plates were used to assay for the percentage of silver reducing microorganisms by placing 0.75 ml of a 0.4% w/v $AgNO_3$ solution under the agar surface, followed by incubation in the dark at 27°C. After three weeks the plates were examined visually in reflected light for metallic silver deposition around the microbial colonies, and the percentage of silver-reducing microorganisms was calculated.

The degree of mycorrhizal infection of grasses in relation to silver treatments was carried out by microscopic analysis of 2.0 ml plant root segments following Lactophenol cotton blue staining without KOH clearing. The staining solution consisted of: phenol crystals (20 g), lactic acid (20 ml), glycerol (40 ml), and 20 ml of distilled water, mixed in a hot water bath. After all ingredients were dissolved, 0.05 g of cotton blue was added.

Entire plant roots were soaked in water to loosen the surrounding soil and the individual plants were separated. The plant tops were removed, and the roots were placed in the staining solution at 50°C for 4–5 h or if necessary overnight. Before examinations the roots were rinsed in clear lactophenol, and the root tip areas were cut into 2.0 mm segments and mounted in lactophenol for microscopic examination. The root frag-

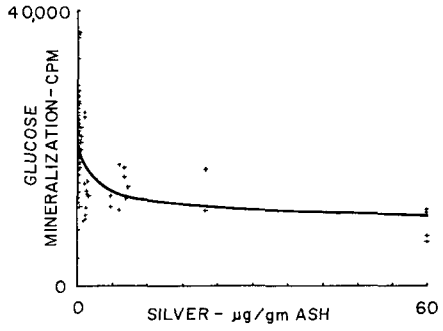

FIG. 1. Regression analysis of microbial glucose mineralization for 0–60 mg g^{-1} residual silver samples in silver-iodide treated sub-plots of a semi-arid grassland soil. Linear, parabolic, exponential and power functions R^2 values were 0.215, 0.295, 0.317 and 0.494, respectively. The power function curve is shown.

ments were scored for the percentage of mycorrhizal fungal infection.

For analysis of silver distribution in plant roots and standing vegetation, standing vegetation clips were made using the 1 m×1 m center areas of control and treated plots, and where possible grass and cactus materials were separated. Silver analyses were made on complete soils, on separated roots which were rinsed in distilled water, and on the soil from which the roots were separated.

3. Results

Relationships of interest between silver levels and biological parameters have been observed (Table 1). However, in the $2\frac{1}{2}$ years since silver was added, it is still possible to differentiate between AgI and $AgNO_3$ treatments.

Silver in the iodide form is related to a decreased relative oxygen uptake, carbon dioxide evolution, and glucose mineralization, whereas no similar relationship is observed with silver imposed in the form of nitrate. The organic matter assays suggest a positive relationship between these parameters and residual silver, although the R^2 values are not particularly strong.

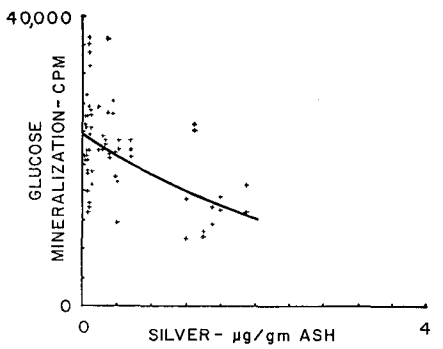

FIG. 2. Regression analysis of zero to 2 µg g^{-1} residual silver samples. Linear, parabolic, exponential and power function R^2 values were 0.269, 0.209, 0.325 and 0.226, respectively. The parabolic function curve is shown.

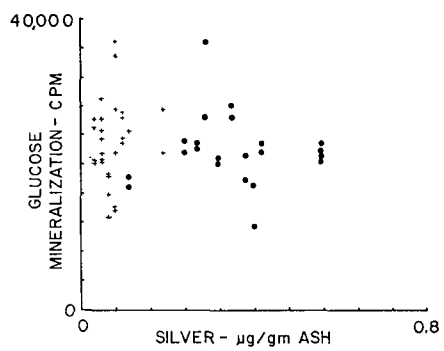

FIG. 3. Regression analysis of zero to 0.56 µg g^{-1} residual silver samples. Linear, exponential, parabolic and power function R^2 values were 0.007, 0.017, 0.004 and 0.002, respectively. The large circles indicate samples to which silver iodide had been added.

The strongest relationships were observed between silver added originally in the iodide form, and the decreased ability of the soil microflora to oxidize glucose to carbon dioxide. Further analyses of these data were carried out to determine the lowest silver levels where definitive relationships with glucose mineralization could be detected. Over the 60 µg g^{-1} silver range, with increased AgI levels, the glucose mineralization activities appeared to be decreased (Fig. 1). To further analyze this relationship, a separate analysis of data obtained in the 0–2 µg g^{-1} silver range was completed (Fig. 2). Under these conditions, it is still possible to observe decreased mineralization with increasing residual silver concentrations, based on the R^2 values and the line slope which were derived. Finally, the 0–0.8 µg g^{-1} data were analyzed (Fig. 3). Under these conditions it was no longer possible to differentiate between the added silver (noted by large circles), and residual soil silver. These results would suggest that silver in the range of 0.5–0.8 µg g^{-1} will not show detectable effects on glucose mineralization within the time frame of the experiment. Above this accumulation level, possible effects on the soil microorganism biological activities may be observable.

Additional correlations of glucose mineralization versus other biotic and abiotic parameters have been completed (Table 2). These results suggest a possible inverse relationship between iron and copper levels, in comparison with glucose mineralization activity. To attempt to interpret this observation, the copper and iron levels in control and treated soils were compared with mineralization activities. The copper and iron levels in the treated soils were not significantly higher than in controls, whereas the glucose mineralization activities in the high-level treatment soils were significantly decreased. Analysis of glucose mineralization in control soils in relation to copper and iron levels did not show a possible causal relationship. These preliminary considerations suggest that the relationship between decreased glucose mineralization and increased copper and iron levels may reflect a secondary soil response to AgI imposition.

TABLE 2. Relationship of glucose mineralization activity to abiotic parameters in the IBP site AgI treatment plots.

Parameter	Relation to mineralization	R^2 value for curve-fitting regressions				N*
		Linear	Parametric	Exponential	Power	
Copper	Negative	0.229	0.243	0.280	0.285	33
Mn^{++}	None	0.039	0.043	0.033	0.044	33
K^+	None	0.047	0.083	0.036	0.047	32
Fe^{++}	Negative	0.166	0.184	0.205	0.220	32
Zinc	None	0.003	0.004	0.000	0.000	62
Nitrate ion	None	0.003	0.014	0.004	0.005	64
Control plot silver	None	0.017	0.021	0.000	0.000	63

* Number of sample pairs analyzed.

The evaluation of percent mycorrhizal colonization of grass roots showed no discernable differences between control and high-treatment level plot root systems.

The microbial populations and percent silver reducing microorganisms in the test plots were enumerated in relation to silver impositions. Only the high-level and intermediate-treatment-level plots were examined, and no significant changes in total microbial populations were observed in relation to the silver treatments (Table 3). The percentage of silver-reducing microorganisms in the high $AgNO_3$ treatment plot was significantly increased over the controls, suggesting that this silver reduction capability had been stimulated in the presence of the added $AgNO_3$. No such increase in silver-reducing organisms was observed in the AgI treated soils.

In a further analysis of silver localization within the soil-grass community, an examination of silver levels in treated intact soils, and in separated soil and roots was completed (Table 4). The highest relative silver concentration appears to be associated with the plant roots. With sample variability, this difference was only significant at the 10% level. In additional analyses of above-ground vegetation, grasses had higher relative silver concentrations than cactus, but for AgI treatments these silver levels were approximately one-tenth of below-ground concentrations (Table 5). In the $AgNO_3$ treated soils, the grasses tended to have higher silver concentrations than the corresponding soils, indicating the greater mobility of silver from $AgNO_3$ even after $2\frac{1}{2}$ years of soil contact.

Our results to date suggest that radioactive glucose mineralization is a very sensitive assay for the study of silver iodide-microbe interactions. This sensitivity appears to be based on the short-term nature of the assay, where changes due to laboratory manipulations can be minimized, and maximum ecological relevance can be achieved. Using this procedure in conjunction with other assays, our work to date indicates that it may be possible to detect effects of residual silver at as low as 1–2 $\mu g\ g^{-1}$ levels.

It is of interest to note that silver originally added in iodide or nitrate forms still shows differences in soil responses after three growing seasons have been completed. Thus, one may not be able to assume that silver added to soils in differing forms will eventually equilibrate to a similar series of compounds, at least within the time frame of this experiment. The possible formation of stable AgI-NaI complexes such as $(Na\ Ag\ I_2)_x$ or additional burn mixture complexes (Davis, 1969) may lead to accumulation of silver forms in soils which may differ from forms derived when AgI or $AgNO_3$ would be used.

The observation of a possible increased percentage of silver-reducing microorganisms in soils in response

TABLE 3. Microbial populations and percentage of silver-nitrate-reducing microorganisms in control and treated soils.

Treatment	Total populations		Silver reducers	
	Population ($\times 10^{-6}\ g^{-1}$)	Significance[a]	Percent of total	Significance[a]
AgI —High level[b]	28±16[d]	—	10.1±3.8	—
—Intermediate[c]	42±28	—	11.8±6.4	—
$AgNO_3$—High level	38±13	—	22.4±8.53	**
—Intermediate	31±24	—	11.5±5.3	—
Controls, untreated and sodium iodide sub-plots	30±26		11.2±4.1	

[a] T test of possible significant difference of treated plot results in relation to controls: —, $P>0.05$; **, $P<0.025$.
[b] High-level treatments were originally at 100 $\mu g\ g^{-1}$ silver in the 0–2 cm soil layer.
[c] Intermediate-level treatments were originally at 10 $\mu g\ g^{-1}$ silver in the 0–2 cm soil layer.
[d] Standard deviation.

TABLE 4. Added silver distribution in the soil-root system of a semi-arid grassland.[a]

Treatment	Entire soil	Root-free soil	Roots
AgI	6.2±6.2[b]	4.0± 2.4	40.2±29.4[c]
$AgNO_3$	16.2±9.1	15.2±21.0	105.3±87.8[c]

[a] Expressed as silver in $\mu g\ g^{-1}$ of materials on a dry-weight basis.
[b] Standard deviation.
[c] Difference from entire soil value only significant at 10% level.

to higher silver nitrate additions suggests that some of the soil microflora may have the ability to shift their enzymatic capabilities to respond to the presence of this metal. This could also occur with silver iodide in microenvironments, as has been observed with laboratory cultures (Klein and Sokol, 1973b).

The increased relative silver concentrations in the vicinity of the roots in the silver-treated soil-plant systems implies that there may be a distinct silver localization in the plant root zone. The ability of plants to cause silver reduction in root tip cells (Jensen and Kavaljian, 1956) would tend to strengthen this hypothesis. Specific work on localization of immoblized silver in plant materials is planned.

Additional studies of silver movement in grass, spruce and aspen communities have shown results similar to those observed in this study (Klein and Sokol, 1974). Silver from $AgNO_3$ will be taken up by plants to a greater extent than from AgI, but that with increasing soil silver concentration there could be a relative exclusion of silver from the above-ground plant components. These trends suggest that after three years, the plant root zone may be the site of the highest silver concentrations in this semi-arid grassland environment.

TABLE 5. Comparison of soil, grass and cactus silver contents in a semi-arid grassland treatment plot.

Treatment	Silver levels ($\mu g\ g^{-1}$ dry weight) Soil[a]	Grass[b]	Cactus[b]
AgI —High level	20.53	3.58	0.84
—Intermediate level	1.05	0.40	(c)
—Low level	0.285	0.01	0.03
$AgNO_3$—High level	16.61	46.5	1.74
—Intermediate level	1.99	0.32	0.04
—Low level	0.483	1.8	0.10
Solvent controls			
AgI	0.083	0.008	0.03
$AgNO_3$	0.077	0.070	0.02
Untreated controls	0.058	0.060	0.04

[a] Average of eight values.
[b] Only single values available.
[c] Datum not available.

TABLE 6. Modeling of silver iodide ecological effects on decomposer functions in a terrestrial ecosystem.

Primary productivity Annual cycle	Organic matter index with primary production input Start	In-put	Out-put[a]	End	Microbial activity index[b]
−1	100	10	10	100	100
0 (silver imposition)	100	10	9	101	95
+1	101	10	9	102	96.9
+2	102	10	9	103	97.85
+3	103	10	9	104	98.8
+4	104	10	9	105	99.75
+5	105	10	9	106	100.70
+6	106	10	9	107	101.65

[a] As a result of silver imposition, 10% of input organic matter assumed not to be dissimilated.
[b] Silver imposition assumed to decrease microbial activity to 95% of original, based on 100 organic matter units. This percentage activity per unit organic matter present assumed to remain constant over time.

The possible threshold levels for first detection of changes in decomposer functions suggested by these studies (1–2 $\mu g\ g^{-1}$) must be considered in light of the silver levels which have been observed in soil and plants in control and impact areas in weather modification programs, and in other studies of silver levels in plant materials and soils.

Analyses of silver contents of plants in urban and forest areas (Horovitz *et al.*, 1974; Warren and Delavault, 1950) show that higher silver levels can be found in other geological areas. The former workers found some plant silver levels in the 5–10 $\mu g\ g^{-1}$ range, and the latter workers detected silver in the range of 0.1 to 1.4 $\mu g\ g^{-1}$ in plants in British Columbia.

In studies related specifically to weather modification in the San Juan Ecology Project, over a three-year period no significant changes in silver levels have been observed (Teller *et al.*, 1974). Highest relative silver levels have been found in litter and soil, with lower levels in plant materials in spruce, aspen and grass communities. The highest silver levels observed in 1973 were in aspen litter, being 0.09±0.26 $\mu g\ g^{-1}$. The high standard deviations are typical for analyses of these materials, and indicate that silver levels approaching 0.3–0.4 $\mu g\ g^{-1}$ can occasionally be detected.

With the possibility of silver iodide imposition on a semi-arid grassland ecosystem being related to a slight diminution of soil respiration indexes, a predictive model of possible ecological ramifications of silver iodide accumulation can be developed. Several assumptions are made in this preliminary model: 1) primary productivity will not be influenced by silver imposition; 2) silver accumulation above a certain level will result in measurable decrease in whole soil carbon dioxide evolution, and oxygen uptake, and of bacterial glucose mineralization, as examples of biological activity parameters; and 3) the organic matter retained in the

decomposer compartment will increase as a result of this decreased mineralization activity.

With these assumptions, silver addition to the decomposer compartment will cause an initial decrease in microbial activity parameters (Table 6). However, with the gradual accretion of organic matter through undiminished primary productivity, eventually the apparent microbial activity will return to the control soil value. At this "equivalence point," silver imposition effects may only be recognized by increased organic matter levels. Beyond this time, both the organic matter and microbial activity values should be higher than those observed in untreated soils. This model will be subject to additional refinements to include factors such as added silver dilution by increased organic matter accumulation, and perhaps other physical limitations, but this may provide a starting point for a more critical analysis of AgI effects on a decomposer ecosystem.

This model predicts that possible AgI accumulation effects in the decomposer compartment may not be detected, depending on the assay techniques used and the time of sampling. The time at which such a biological "equivalence point" for control and treated soils is reached will depend on the primary productivity rate and the forms and levels of silver present. Thus, evaluation of silver iodide effects in ecosystems of varying productivities should include periodic analyses to follow possible gradual changes in carefully selected decomposer parameters.

In summary, related studies to date indicate that the silver levels which have been detected in two weather modification programs where silver monitoring is being carried out have not shown significant changes in relation to seeding activities. The silver levels detected are at least 1–2 orders of magnitude below where possible interactions between accumulated silver iodide and changes in decomposer functions might be observed. The trend toward silver concentration in or on plant roots points out the need to further examine microbial functions in root environments in relation to possible silver concentration in this area. In addition, the available treatment plots and seeding generator silver gradients should continue to be monitored, to extend the time scale over which silver iodide accumulation ecological effects can be predicted. Hopefully, this will allow us to further refine our definition of seeding agent accumulation thresholds where biological responses are first observed. This information is of direct interest in management of weather modification programs.

Acknowledgments. This research was performed under Grant GI-38716 as a part of the research on societal utilization sponsored by the Weather Modification Program, Research Application Directorate, National Science Foundation. Related weather modification project seeding agent monitoring and biological studies cited in this report were supported by the National Center for Atmospheric Research and the Bureau of Reclamation. Consultations with H. L. Teller and Richard Sokol, and the technical assistance of Patricia Mayeux, Mart Westbrook, Sallie Jepson, Laurie Winslow and Pamela Gilheany are gratefully acknowledged. Dr. Darwin Davidson, University of Wyoming, provided the mycorrhizal staining procedure.

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