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REVEGETATION FOLLOWING ARTIFICIAL DISTURBANCE

Final Report

for period 1 June 1975 through 30 November 1979

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LIST OF PUBLICATIONS

Fraley Leslie Jr. 1971. Response of shortgrass plains vegetation to chronic and seasonally administered gamma radiation, Ph.D. Thesis, C00-1156-45, Colorado State University, Fort Collins, CO 80523, 170 p.

Fraley Leslie Jr. 1980. Effect of chronic ionizing radiation on the production and viability of Lepidium densiflorum, Schrad. seed, Environmental and Experimental Botany, 20, 7-10.

Fraley Leslie Jr. and Whicker F Ward. 1973. Response of shortgrass plains vegetation to gamma radiation-I. Chronic irradiation, Radiation Botany, 13, 331-341.

Fraley Leslie Jr. and Whicker F Ward. 1973. Response of shortgrass plains vegetation to gamma radiation-II. Short-term seasonal irradiation, Radiation Botany 13, 343-353.

Herron Vicki J. 1979. Ornithogalum virens as a plant assay for beta and gamma radiation effects, M.S. Thesis, C00-2743-5, Colorado State University, Fort Collins, CO 80523, 91 p.

Herron Vicki J, Fraley Leslie Jr. and Stack Stephen M. (in final preparation). Radiation sensitivity (LD_{100} , LD_{50}) of the bulbous species, Ornithogalum virens (Liliaceae), for submission to Environmental and Experimental Botany.

ABSTRACT

Shortgrass plains vegetation was disturbed using ionizing radiation, burning, scraping and rototilling. The vegetation was relatively resistant to radiation and was most sensitive in December. Burning was similar to moderate radiation damage, scraping and tilling similar to severe radiation damage. Recovery was rapid but climax vegetation was not achieved by 8 years after the disturbance.

Seeding trials were conducted at Rocky Flats with only moderate success. Seldom did the seeded species dominate the stand after seeding.

Background

This project started with a contract effective 1 June 1975 between Colorado State University and the U. S. Atomic Energy Commission. The purpose of the study was to look at some of the potential problems associated with reseeding or reclamation in the buffer zone at the Rocky Flats nuclear weapons plant near Golden, Colorado and the potential for movement of soil with low level radio-nuclide contamination during the reclamation process as a result of wind erosion (resuspension). During the course of the study, plots were prepared for seeding and seeded but the associated measurements of soil movement, as originally proposed, were not carried out. This part of the study was omitted because of the time commitment required and the lack of an adequate graduate student to do this part of the study.

During the period of time covered by this report, that part of another contract dealing with the Grasslands Irradiation Site was transferred to the contract. The objectives of the original study were continued. This transfer was made because I had planned and conducted the Grasslands Irradiation study and desired to continue the follow-up and recovery part of the study.

More recently, it was proposed that plant sensitivity to an internal alpha dose, such as might be encountered on Pu contaminated or uranium mine mill tailing contaminated soils, be measured using chromosome aberrations as the end point. A study was initiated to accomplish this objective.

This final report is divided into two subproject reports; one dealing with the Rocky Flats work and one dealing with the grasslands irradiation study.

Literature citations in this report follow the format of Health Physics.

SUBPROJECT 1. THE POTENTIAL FOR RECLAMATION AT ROCKY FLATS FOLLOWING TOPSOIL
REMOVAL OR DISTURBANCE

Introduction

The Rocky Flats plutonium fabrication plant is surrounded by approximately 20 km² of land that serves as a buffer zone to isolate the plant activities from the public. Normal operations at the plant do not result in significant air concentrations or in significant soil contamination. Unusual conditions have existed in the past or may exist in the future that results in soil contamination such that it becomes desirable to remove the contaminated soil. Other plant operations may make it desirable to revegetate significant areas in the buffer zone. Low precipitation, average wind speeds of nearly 4 m/s with peak gusts to at least 45 m/s and rocky soil combine to make the potential for revegetation difficult, especially at a reasonable cost.

The objectives of this study were:

1. To determine a rapid and feasible method of revegetation.
2. Determine a revegetation method such that the vegetation will revert to a "natural" system as rapidly as possible.
3. Develop a predictive model for soil movement by wind during the revegetation period.

Only limited work was done on objective #3.

Materials and Methods

In 1975, an initial effort was made to evaluate a seeding that had been made by Rocky Flats personnel several years earlier. This area was located south of the east portal road and about 500 m east of the east portal. Line transects were established and 25 x 25 cm square quadrats randomly located along the

transect. A species list, ground cover, and percent bare soil was determined for each quadrat. Twenty-five percent of the quadrats were clipped for biomass determination.

Also in 1975, an area was selected in the southwest quadrant of the buffer zone on the top and southeast slope of a ridge (Fig. 1). The ridge was oriented approximately 060° relative to true north. The soil on the ridge was typical of that on the western part of the Rocky Flats buffer zone, i.e., it was rocky. The basic design of the experiment was randomized complete block design within each seeding date with 3 seeding dates, spring, summer and fall; 6 seed mixtures; and seedings in each of 3 years (Fig. 2). The seed mixtures used are listed in Table 1. Due to curtailment of the experiment, no seedings were made in the fall of 1977 or in 1978.

Initially, an attempt was made to prepare a seedbed by plowing the plots with a moldboard plow. The soil in this area of the buffer zone was too rocky and the rocks too large to plow. A landscape tool, a scarifier, was tried and this worked fairly well with repeated scarifying until the soil was fairly loose and the existing vegetation fairly well eliminated. A minimum of 3 scarifyings was necessary.

The soil was too rocky for seeding with a mechanical seeder or any similar tool. Therefore, the seeding rate was doubled and the seed broadcast by hand. In order to give uniform distribution, soil was mixed with the seed to increase the volume and the soil-seed mixture scattered so that each plot was covered twice. In 1977, the scarifier and a chain drag were used on the plots after seeding to cover the seed.

The original design called for permanent quadrats in each plot to evaluate the seeding. Since the study was terminated prior to completion, this was not done.

Fig. 1. General location and layout of Rocky Flats plant showing boundary prior to purchase of additional buffer area and the seeding plot location.

Fig. 2. Design of the seeding experiment in the Rocky Flats buffer zone. The Fall 1977 and the three 1978 seedings were not done. See Table 1 for the make-up of the seed mixes.

		Block 1						2						3														
Plot No. →		1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6									
Row 1	1976	5	2	Summer		4	6	1	3	5	4	3	6	1	2	3	4	1	2	5	6							
	1977							5	2	Summer		4	6	1	3													
																				Seed mix								
Row 2	1976	2	5	Summer		3	1	6	4	5	6	Spring		3	2	1	4	2	5	Fall		3	1	6	4			
	1977							5	6	Spring		3	1	2	4							1	5	Summer		2	6	3

Table 1. Species in seed mixtures and seeding rates* used at Rocky Flats revegetation trials.

Mix Number	Species in Mix	Seeding Rate	
		g/m ²	lb/acre
1	Crested wheatgrass**	1.4	12
	Western wheatgrass	1.1	10
	Sand dropseed	0.22	2
2	Crested wheatgrass	1.4	12
	Buffalograss	2.2	20
	Sand dropseed	0.22	2
3	Western wheatgrass	1.1	10
	Sideoats grama	0.68	6
4	Crested wheatgrass	1.4	12
	Western wheatgrass	1.1	10
	Sand dropseed	0.22	2
5	Western wheatgrass	1.1	10
	Sand dropseed	0.22	2
	Buffalograss	2.2	20
	Sideoats grama	0.68	6
6	None (plot left bare)		

*Above seeding rates gave approximately 450 seed/m².

**Species. Crested wheatgrass, *Agropyron desertorum* (Agde)

Western wheatgrass, *A. smithii* (Agsm)

Sand dropseed, *Sporobolus cryptandrus* (Spcr)

Buffalograss, *Buchloe dactyloides* (Buda)

Sideoats grama, *Bouteloua curtipendula* (Bocu)

The seeding results were evaluated during the summer of 1979. This was done using a systematic method. A stringline was secured to stakes at each end of a block (Figs. 2 and 3) and the line was marked as shown in Fig. 3. The distance from A to B, AB, was 2.13 m (7 ft), the distances BC, CD, EF and FG were the same as the quadrat dimension, 0.707 m (2.32 ft) and DE was 0.305 m (1 ft). This pattern was repeated for each plot. The quadrat (0.5 m^2) was located as shown in Fig. 3, 4 locations per plot.

The data were collected from 11 through 27 July 1979 and included cover by species, rock and bare ground, and density by species. Species data included all species, whether or not seeded. The data were then summarized to include 1) cover by rock, bare ground, seeded species, and two important cheatgrass invader species, Bromus tectorum and B. japonicum, and density of seeded species and the cheatgrass species. The data were then analyzed by block location (on the top or on the side of the ridge), seed mixture, season of seeding and year of seeding.

A preliminary investigation into the relationship between vegetation cover and wind erosion was conducted in 1978 on an area near the Grasslands Study Site (GIS). Two 10 m circular areas were selected. One was thoroughly rototilled to eliminate all existing vegetation and the other was maintained with vegetation left intact. A Bagnold Catcher (GI 7) was installed in the center of each area. In addition, 3 wet-pot collectors were installed near each Bagnold catcher to compare wind blown soil collection using Bagnold catchers and wet-pot collectors.

Results

The seeding carried out by Rocky Flats personnel was done on topsoil purchased, brought in, and spread on the area to be seeded. The seed was planted using a grain drill in the later summer, 1972. The seed mixture used is in Table 2.

Fig. 3. Quadrat location for the Rocky Flats seeding trials. Quadrat size was 0.707×0.707 m ($= 0.5 \text{ m}^2$).

The seeded areas were irrigated for about 2 years after seeding. No attempt was made by Rocky Flats personnel to evaluate the seeding success on a quantitative basis.

The data (Tables 3 and 4) indicated that revegetation did occur although the diversity is quite low but a look at the species in Table 4 indicated that only one species of the 4 seeded was successful, Agropyron smithii (western wheatgrass). The other two species that showed a significant frequency were Bromus sp. (cheatgrass) and Bromus inermis (smooth brome).

The results of the revegetation trial southwest of the plant are given in Tables 5 and 6. Table 5 gives the results of percent cover and Table 6 of density. Both are broken down by season, seed mix, location and year. Also, both tables give the mean value for a given dependent variable as well as the treatment mean for each and the level of significance of the F statistic as determined by analysis of variance.

Percent cover: Of particular significance was the cover by rock of 51% for an overall average. In addition, there was 11% bare ground so that a total of 62% of the plot surface was accounted for by other than vegetation. Cheatgrass (Bromus japonicus and B. tectorum) varied by species with B. tectorum having larger cover values than B. japonicus. There were differences by season, seed mix, location and year for B. tectorum and by seed mix and location for B. japonicus. The cover by non-seeded species (other in Table 5) not including cheatgrass was approximately 20%. Summing all sources of cover except the seeded species gives an overall average value of 90%. This meant that seeded species had an average cover of 10%. While all seed mixes showed some success, only those mixes with Agropyron desertorum (crested wheatgrass) resulted in significant cover.

Table 2. Seed mixture used at Rocky Flats in late summer 1972 seeding.*

Content	Percent
<i>Andropogon scoparius</i> (little bluestem)	21
<i>A. gerardi</i> (big bluestem)	18
<i>Agropyron smithii</i> (western wheatgrass)	17
<i>Bouteloua curtipendula</i> (sidecoats grama)	10
Other crop	1
Weed	0.4
Inert	33

*Information supplied by Chuck Illsley, Rocky Flats.

Table 3. Selected parameters for transects 1 and 2 measured on area reseeded at Rocky Flats.

Transect	Standing crop (g/m ²)	Percent cover	Percent bare soil	Diversity
1	170 ± 56	40 ± 26	12 ± 18	1.2
2	133 ± 64	40 ± 23	22 ± 25	2.3

Table 4. Frequencies for all species sampled in Transects 1 and 2.

n = 21 for transect 1 and 57 for transect 2. Quadrat size was 25 x 25 cm.

Species	Frequency	
	Transect 1	Transect 2
<u>Agropyron desertorum</u> (crested wheatgrass)	--	0.053
<u>A. smithii</u> (western wheatgrass)	0.90	0.81
<u>Bouteloua curtipendula</u> (sideoats grama)	--	0.018
<u>B. gracilis</u> (blue grama)	--	0.075
<u>Bromus inermis</u> (smooth brome)	0.33	0.19
<u>Bromus tectorum</u> (cheatgrass)	0.38	0.58
<u>Liatris punctata</u> (dotted gayfeather)	--	0.035
<u>Sitanion hystrix</u> (bottlebrush squirreltail)	--	0.053
<u>Stipa comata</u> (needle and thread)	--	0.018
<u>Yucca glauca</u> (small soapweed)	--	0.018

Table 5. Average percent cover by bare ground, rock and selected species for Season, Seed Mix, Location and Year Seeded.

	n	Bare Ground	Rock	Brja	Brte	Brsp	Agde	Agsm	Bocu
Overall	240	11.6(5.58)	50.9(15.0)	1.08(2.39)	4.65(9.09)	5.72(9.25)	7.00(9.78)	1.83(4.25)	1.38(4.20)
F		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Season									
F		0.057	0.001	0.562	0.001	0.001	0.001	0.103	0.006
Spring	96	12.3(7.78)	46.6(15.9)	1.23(2.60)	1.53(3.62)	2.8(4.7)	6.0(9.0)	1.5(4.5)	1.8(5.4)
Summer	96	10.2(7.32)	53.2(14.7)	1.15(2.48)	8.00(12.1)	9.1(12.0)	10.0(11.7)	2.6(4.7)	0.60(2.5)
Fall	48	13.0(7.35)	54.9(11.6)	0.625(1.61)	4.17(7.38)	4.8(7.4)	3.0(5.7)	0.81(1.8)	2.0(4.1)
Seed Mix									
F		0.207	0.661	0.002	0.001	0.001	0.001	0.004	0.001
1	40	11.2(7.43)	49.1(13.9)	0.575(1.75)	2.9(6.9)	3.5(6.9)	15.0(10.9)	2.0(2.7)	0.75(3.5)
2	40	10.6(8.10)	49.9(14.6)	0.675(1.12)	2.4(5.3)	3.0(5.1)	14.7(9.8)	0.15(0.36)	0 (0)
3	40	12.8(7.33)	52.1(14.9)	0.500(0.877)	3.7(6.7)	4.2(6.7)	0.85(2.7)	3.4(6.6)	3.7(6.9)
4	40	12.4(7.38)	52.8(14.0)	0.950(1.84)	2.9(6.7)	3.9(6.6)	11.2(10.4)	1.6(2.6)	1.2(3.7)
5	40	10.0(5.55)	52.0(14.6)	1.85(3.31)	9.3(13.6)	11.2(13.3)	0.07(0.27)	1.8(2.1)	2.0(4.3)
6	40	12.7(9.20)	49.6(18.3)	1.90(3.66)	6.7(10.8)	8.6(11.2)	0.18(0.81)	2.0(6.5)	0.62(2.6)
Location									
F		0.001	0.001	0.001	0.001	0.001	0.779	0.827	0.540
Ridge Top	120	3.28(5.04)	57.4(13.8)	1.52(2.68)	1.45(3.10)	3.0(4.4)	7.2(10.3)	1.9(4.2)	1.5(3.9)
Ridge Side	120	1.50(8.21)	44.4(13.3)	0.633(1.96)	7.84(11.7)	8.5(11.7)	6.9(9.7)	1.8(4.3)	1.2(4.5)
Year									
F		0.001	0.001	0.205	0.001	0.001	0.353	0.001	0.020
1976	144	13.3(7.72)	49.1(14.4)	0.875(2.16)	2.6(5.5)	3.5(5.8)	6.6(9.9)	0.87(2.3)	1.1(3.2)
1977	96	9.16(6.67)	53.7(15.6)	1.38(2.68)	7.7(12.1)	9.0(12.0)	7.6(10.2)	3.3(5.9)	1.8(5.4)

Values in parentheses are one standard deviation

F values are from an SPSS AOV

Other represents all other species combined cover

Table 5 (Con't)

	Buda	Sper	Other	MIX 1	MIX 2	MIX 3	MIX 5
Overall	1.01(3.99)	0.246(2.39)	20.39(16.44)	9.07(10.9)	8.01(10.7)	2.07(4.91)	4.46(7.38)
F	0.001	0.029	0.001	0.001	0.001	0.001	0.001
Season							
F	0.007	0.245	0.001	0.001	0.001	0.643	0.016
Spring	1.9(6.0)	0.54(3.7)	26.9(17.9)	8.1(10.3)	7.9(11.1)	2.1(6.0)	5.8(9.7)
Summer	0.44(1.2)	0.01(0.10)	13.4(14.3)	12.6(11.9)	10.4(11.5)	2.6(4.7)	3.7(5.4)
Fall	0.42(1.5)	0.12(0.73)	21.3(11.2)	4.0(6.4)	3.4(5.8)	0.94(2.1)	3.4(4.7)
Seed Mix							
F	0.001	0.070	0.008	0.001	0.001	0.017	0.001
1	0.10(0.30)	0.02(0.16)	17.8(14.9)	17.0(11.8)	15.1(10.9)	2.0(2.7)	2.8(4.1)
2	3.2(6.4)	0.02(0.16)	18.6(15.9)	14.8(9.8)	17.9(10.8)	0.18(0.38)	3.4(6.4)
3	0 (0)	0 (0)	23.4(17.3)	4.3(7.4)	0.85(2.66)	3.4(6.6)	7.2(8.8)
4	0 (0)	1.3(5.7)	16.0(15.8)	14.0(11.7)	11.2(10.4)	2.8(6.5)	4.0(7.0)
5	2.8(6.7)	0.15(0.80)	20.8(16.2)	2.0(2.5)	2.8(6.7)	2.0(2.5)	6.7(8.7)
6	0.02(0.16)	0 (0)	25.6(17.4)	2.2(6.5)	0.20(0.82)	2.0(6.5)	2.6(7.4)
Location							
F	0.053	0.089	0.853	0.869	0.556	0.465	0.243
Ridge Top	0.62(2.1)	0 (0)	20.5(15.8)	9.0(11.0)	7.7(10.3)	1.9(4.2)	4.0(6.4)
Ridge Side	1.4(5.2)	0.49(3.4)	20.2(17.2)	9.2(10.8)	8.3(11.1)	2.3(5.5)	4.9(8.3)
Year							
F	0.001	0.087	0.001	0.057	0.357	0.001	0.001
1976	1.0(4.0)	0.04(0.42)	26.2(15.9)	7.5(10.1)	6.9(9.8)	0.91(2.4)	2.3(4.0)
1977	0.30(1.1)	0.55(3.7)	11.7(13.1)	11.4(11.6)	9.6(11.7)	3.8(6.9)	7.7(9.7)

Values in parentheses are one standard deviation
F values are from an SPSS AOV
Other represents all other species combined cover

Table 6. Average density by species or seed mix for Season, Seed Mix, Location, and Year Seeded.

	n	Brja	Brte	Brsp	Agde	Agsm	Bocu	Buda	Spcr	Other
Overall	240	5.09(10.66)	17.87(29.54)	22.96(31.22)	10.23(18.31)	5.90(10.56)	0.700(1.990)	1.03(2.94)	0.175(1.262)	23.90(16.78)
F		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Season										
F		0.410	0.001	0.001	0.001	0.002	0.005	0.026	0.086	0.001
Spring	96	4.8(10.5)	6.4(13.6)	11.2(19.0)	5.3(7.8)	4.4(9.5)	0.94(2.5)	1.5(4.1)	0.35(1.9)	30.0(18.8)
Summer	96	6.5(12.4)	29.4(37.6)	35.8(38.0)	19.0(25.3)	8.8(12.1)	0.35(1.3)	0.67(1.5)	0.02(0.20)	17.5(15.1)
Fall	48	3.0(5.9)	17.8(25.7)	20.8(26.2)	2.6(4.7)	3.1(7.8)	0.92(1.8)	0.88(2.0)	0.12(0.64)	24.5(9.9)
Seed Mix										
F		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.007	0.007
1	40	2.1(5.8)	13.3(26.9)	15.4(26.9)	21.2(24.4)	7.2(7.8)	0.20(0.99)	0.30(0.97)	0.005(0.32)	24.1(20.3)
2	40	3.4(10.0)	9.4(21.9)	12.8(22.7)	18.6(21.0)	0.7(2.0)	0 (0)	3.0(3.9)	0.005(0.32)	21.6(15.2)
3	40	2.7(4.4)	15.2(26.5)	18.0(26.6)	1.4(3.2)	10.0(16.0)	1.8(2.7)	0 (0)	0 (0)	26.0(16.2)
4	40	5.0(9.8)	11.8(26.0)	16.7(26.3)	18.8(21.3)	5.0(7.4)	0.40(1.0)	0 (0)	0.80(2.9)	19.4(13.3)
5	40	7.6(10.9)	34.6(36.4)	42.2(36.8)	0.55(2.2)	8.4(10.6)	1.6(3.4)	2.8(5.1)	0.15(0.70)	23.4(16.2)
6	40	9.8(16.9)	23.0(31.3)	32.8(35.8)	0.85(3.9)	4.2(11.7)	0.20(0.76)	0.005(0.32)	0 (0)	29.0(17.9)
Location										
F		0.001	0.001	0.001	0.001	0.269	0.007	0.073	0.013	0.001
Ridge Top	120	7.6(11.9)	6.2(14.0)	13.9(21.3)	13.0(23.6)	6.5(10.8)	0.98(2.5)	0.77(1.9)	0 (0)	21.4(14.7)
Ridge Side	120	2.6(8.6)	29.5(35.8)	32.0(36.6)	7.5(10.1)	5.3(10.3)	0.42(1.2)	1.3(3.7)	0.35(1.8)	26.4(18.4)
Year										
F		0.004	0.001	0.001	0.676	0.001	0.003	0.001	0.018	0.001
1976	144	3.5(7.5)	10.8(19.6)	14.3(20.7)	8.7(16.3)	2.9(6.3)	0.50(1.3)	0.56(1.5)	0.04(0.37)	30.9(16.1)
1977	96	7.5(13.8)	28.4(37.8)	35.9(39.1)	12.5(20.8)	10.4(13.7)	1.0(2.7)	1.8(4.2)	0.38(1.9)	13.4(11.6)

Values in parentheses are one standard deviation

F values are from an SPSS AOV

Other represents the sum of the densities of all other species not listed in column headings

Table 6 (Con't)

	MIX 1	MIX 2	MIX 3	MIX 5	Total	Number of sp.	MIX 1	
							n	
Overall	16.31(21.49)	11.27(18.32)	6.079(10.73)	7.813(11.23)	64.91(32.18)	7.66(2.30)	240	16.31(21.49)
F	0.001	0.001	0.001	0.001	0.001	0.001		0.001
Season								
F	0.001	0.001	0.005	0.073	0.001	0.001		0.001
Spring	10.1(11.6)	6.8(8.8)	4.8(9.8)	7.2(10.8)	53.7(26.1)	8.1(2.1)	96	10.1(11.6)
Summer	27.8(27.4)	19.6(25.2)	8.8(12.1)	9.8(12.5)	82.1(31.9)	7.0(2.4)	96	27.8(27.4)
Fall	5.9(10.1)	3.5(5.0)	3.2(8.3)	5.0(8.5)	53.0(28.6)	8.0(2.2)	48	5.9(10.1)
Seed Mix								
F	0.001	0.001	0.001	0.001	0.001	0.308		0.001
1	28.4(28.0)	21.4(24.3)	7.3(7.9)	7.8(7.8)	68.4(32.8)	8.0(2.6)	80	26.5(25.6)
2	19.3(22.1)	21.6(20.3)	0.75(2.0)	3.8(4.2)	56.6(25.7)	7.4(2.2)	40	19.3(22.1)
3	11.5(17.4)	1.4(3.2)	10.0(16.0)	11.9(16.5)	57.3(27.9)	7.9(2.4)	40	11.5(17.4)
4	24.6(23.2)	18.8(21.3)	5.8(8.4)	6.2(8.2)	61.0(30.2)	7.2(2.2)		
5	9.1(11.3)	3.4(5.6)	8.5(10.9)	12.9(11.9)	79.0(36.8)	8.0(2.2)	40	9.1(11.3)
6	5.0(12.0)	0.90(3.9)	4.2(11.7)	4.4(11.9)	67.1(34.6)	7.6(2.3)	40	5.0(12.0)
Location								
F	0.001	0.001	0.445	0.442	0.001	0.561		0.001
Ridge Top	19.5(26.2)	13.8(23.4)	6.5(10.8)	8.2(11.6)	56.5(27.3)	7.7(2.4)	120	19.5(26.2)
Ridge Side	13.2(14.9)	8.8(10.6)	5.7(10.7)	7.4(10.9)	73.3(34.5)	7.6(2.2)	120	13.2(14.9)
Year								
F	0.001	0.226	0.001	0.001	0.001	0.001		0.001
1976	11.7(18.2)	9.3(16.2)	3.0(6.5)	4.0(6.7)	58.0(25.4)	8.5(2.1)	144	11.7(18.2)
1977	23.2(24.2)	14.2(20.8)	10.7(13.8)	13.5(14.0)	75.3(38.1)	6.4(2.1)	96	23.2(24.2)

Values in parentheses are one standard deviation

F values are from an SPSS AOV

Other represents the sum of the densities of all other species not listed in column headings

Density

Table 6 gives the density results as well as the total number of species per plot (which is a rough measurement of diversity). The same general pattern emerges as with percent cover: percent cover

Cheatgrass (Bromus japonicus and B. tectorum) and other non-seeded species made a major contribution to the total density, 72%, with the seeded species contributing 18%. While there were differences between treatments, Agropyron desertorum (crested wheatgrass) contributed most to the density of all seeded species and Agropyron smithii (western wheatgrass) was second in density. The other 3 species Bouteloua curtipendula (sideoats grama), Buchloe dactyloides (buffalograss), and Sporobolus cryptandrus (sand dropseed) made minor contributions.

In general, mix 1 (and mix 4, which was identical) gave the best results. Seed mixes which did not include crested wheatgrass resulted in a low density of seeded species.

Several other interesting features can be gleaned from Tables 5 and 6. One of these is the relationships between the 2 Bromus species. Location was a major factor as to which species dominated.

Soil mass collection: The data in Table 7 are presented for general information only. The data are too sketchy to indicate more than general values. Although not broken out in Table 7, the ratio of the masses collected in the top section of the Bagnold Catchers (bare/vegetated at 60 to 75 cm above ground level) was 1.8. This indicated that there was much less difference in soil movement between the bare and vegetated areas 60 to 75 cm above the ground than there was near the ground. For all levels above the ground combined, the bare to vegetated ratio was 95.

Table 7. Soil mass collected by Bagnold Catchers and dry cups in bare and vegetated areas.

Collection Period	Average Wind Speed (m/s)	Mass collected (mg)				Rate of mass collection (µg/s)			
		Bagnold*		Dry Pots		Bagnold		Dry Pots	
		Bare Area	Vegetated Area	Bare Area	Vegetated Area	Bare Area	Vegetated Area	Bare Area	Vegetated Area
1-8 Apr 76	2.8	708	99	--	--	1.21	0.17	--	--
8-13 Apr 76	3.1	1 103	48	--	--	2.56	0.11	--	--
13-18 Apr 76	4.2	1 321	54	--	--	3.02	0.12	--	--
18-29 Apr 76	3.8	1 377	110	--	--	1.43	0.11	--	--
19 & 20 May 76	2.8	225	30	--	--	2.60	0.35	--	--
8-14 Feb 77	--	--	--	157	20	--	--	0.30	0.039
14-21 Feb 77	--	897	0.0	10	13	1.51	0.0	0.017	0.022
21-28 Feb 77	5.8	33 153	142	--	--	55.5	0.24	--	--
28 Feb-8 Mar 77	--	1 348	26	--	--	1.95	0.038	--	--
8-15 Mar 77	--	60 838	581	--	--	101	0.96	--	--

*Fraction of mass in ground creep cup (0 to 1 cm above ground level). Average = 42%.

--Data not available

Discussion

The appearance of only one seeded species in the 1972 seeded area indicated that the mixture used was probably not satisfactory for the conditions that existed at the time of seeding. The other two species that had a high frequency of occurrence probably had seed that came in with the soil or, in the case of Bromus sp., cheatgrass, probably blew in from adjacent areas since cheatgrass is common throughout the buffer zone and was observed as the primary invader along roads and firebreaks. The other species that appear in Table 4 are common to the grassland community on Rocky Flats. The biomass was similar to that found by Little (1976) in a nearby natural system but was composed mostly of non-native species.

Results of the revegetation trials conducted southwest of the main plant site indicated that the method and seed mixes used were not satisfactory except for the inclusion of crested wheatgrass. Only with mixes that contained crested wheatgrass was some degree of success achieved. Even in those plots, non-seeded species contributed more to density and cover than the seeded species.

Several questions have been raised about the use of crested wheatgrass in this type of situation. Success is generally considered good but it is a long lived species and persists for many years after it has become established and an area seeded to crested wheatgrass may only slowly revert to native vegetation. Areas on the Idaho National Engineering Laboratory (INEL) in southeastern Idaho that were seeded to crested wheatgrass in 1958 are still dominated with crested wheatgrass and appear to still be in the original rows (personal observation). Also, it has been reported that behavior of some animal species was altered in areas seeded to crested wheatgrass and that faunal diversity was reduced in crested wheatgrass stands (Re78).

Data on the population dynamics of crested wheatgrass are sparse and more information is needed on the longevity of individuals, rates of seed production, success of self-seeding in an established stand, and the incorporation of seedlings into the adult population. Studies addressing some of the questions have recently been started at INEL (Ma78). Until more information is available, it would not be prudent to use crested wheatgrass, especially in those areas where it is desirable to have the vegetation revert to native species as quickly as possible.

The conditions that exist at Rocky Flats, especially the rocky soil, will make seedbed preparation and seeding by conventional methods impractical or impossible. At best, seeding will be expensive and chances for success small regardless of the species seeded. The steep slopes on many of the ridges will prevent the use of farm type tractors and some type of tracked tractors will have to be used. The rocks necessitate the use of a scarifying type tool for seedbed preparation rather than a moldboard plow. The seeding will have to be done by broadcasting, perhaps from an airplane, which decreases the chance of success.

Importing topsoil along with irrigation can be used to alleviate some of the above mentioned problems. However, this would be expensive and may be impossible to do on some of the steeper slopes. Results from previous seedings with or without topsoil and irrigation, however, do not indicate a high degree of success.

The data from the Bagnold Catchers indicate that bare areas pose more of a potential for wind erosion and resuspension than does vegetated soil. This has been known for several decades and was investigated in the Central Plains of the United States following the Dust Bowl of the 1930s. Most of the soil,

however, moved very close to the ground (ground creep) with approximately 42% of the total amount collected in the ground creep fraction. An additional 32% of the total collected was in the 1 to 15 cm fraction whether the catcher was located in the bare or vegetated area. These fractions contain larger particles that are less subject to long distance movement (Gi74). For heights greater than 30 cm up to 75 cm above the ground, the difference between the amount collected in the bare area compared to the vegetated area decreased significantly. (At 60 to 75 cm, the amount collected during the entire sampling period was 35 mg and 19 mg for the bare and vegetated areas, respectively.) At this level, a major fraction of the material collected was probably the result of long distance movement.

SUBPROJECT 2 EFFECTS OF IONIZING RADIATION ON SHORTGRASS PLAINS VEGETATION

INTRODUCTION

This research was initiated in 1967. The original objectives were to:

1. Determine the radiosensitivity of native shortgrass plains vegetation.
2. Compare the effect of long-term chronic irradiation to short-term irradiation.
3. Determine radiosensitivity by season.
4. Determine species radiosensitivity.

METHODS

Experimental design

The basic experimental design and early results have been published (Fr71;Fr73a;Fr73b). Six sectors were established in a circular pattern around the ¹³⁷-Cs source (8 750 Ci as of Sept 1968). The treatments were; Control, Chronic irradiation, Chronic irradiation, Spring irradiation (April), Summer irradiation (July), and Late-fall irradiation (December) for sectors 1,2,3,4,5 and 6, respectively. The irradiation of the

chronic sectors was initiated 3 April 1969 and continued until 1 July 1978. The irradiation of the seasonal sectors was for thirty days in 1969 during the month stated.

In addition to the plots established in the irradiation field, 75 plots were established in an area adjacent to the irradiation field to evaluate damage and recovery following disturbance by severe burning, scraping off the upper 2 cm of soil, and rototilling.

Recent data collected from the irradiated and artificially disturbed plots were limited to density by species except for blue gramma (Bouteleua gracilis, Bogr). For Bogr, basal cover was estimated. Data were taken from the initiation of the experiment through 1979. These data were converted to Diversity, D , using the equation

$$D = -k \sum p_i * \ln(p_i)$$

where:

p_i was the probability of sampling the i th species, and k was the ratio of base 2 to base e logarithms

and to Coefficient of Community, CC , using the equation

$$CC = 2C / (A + B)$$

where:

A was the number of species in the control plot

B was the number of species in the treated plot, and

C was the number of species shared by the two plots.

More detail about the calculations was reported by Fraley (Fr71).

Bogr cover was also used as an independent measure of radiosensitivity since this species was the dominant species in the study area.

RESULTS AND DISCUSSION

Short-term, seasonal irradiation

The result of the irradiation was the establishment of three zones regardless of the end point used to measure the effect or the season of irradiation. The zone closest to the source resulted in total elimination of the vegetation. Next to that, and further from the source, was a zone where some species and/or some individuals were eliminated. Still further from the source, no effects were measured. The boundaries of these zones (in R/h) varied, depending on the end point being measured and the season of irradiation. For the middle (transition) zone, an estimate of the 50 % (D50) effect was made and this value was used to compare between seasons (Table 8). For the two species, spiderwort (Tradescantia occidentalis, abbreviated Troc) and buckwheat

(Eriogonum effusum, abbreviated Eref), an estimate of the exposure rate required to produce 100 % lethality (LD100) was made since the density was too low to estimate 50 % effects (Table 8). The density of other species was too low to give reasonable survival estimates.

In general, the shortgrass plains vegetation was resistant to ionizing radiation and similar to that of old fields (Wh74). Troc was one of the most sensitive species of the shortgrass plant community as measured by phenological development. A chronic exposure rate of > 1 R/h resulted in a loss of seed production. However, the estimated total 30 d exposure needed to eliminate the species was 13 kR during its most sensitive period (late fall). Part of the reason for this apparent lack of sensitivity was probably because of the growth characteristics of the species. Troc is a monocotyledon (Commelinaceae family (Fe50; Ha64)) and, during most of the year, the meristem is approximately 5 cm below the soil surface. The most sensitive portion of the plant, then, was shielded by soil during the major portion of its life cycle.

For all end points measured, the vegetation was most sensitive during the late fall (December), least sensitive in the summer (July), and intermediate in sensitivity in the spring (April). This was different than reported by Miller (Mi68). Sparrow and others (Sp63; Sp70; Wo63) reported an increase in sensitivity of plant species for short term exposures during semi-dormant periods because of the slow turnover rate of the

Table 8. Total exposure (kR) needed to produce selected D50 results in short-term, seasonally irradiated native shortgrass vegetation.

Season of Exposure	Coefficient of Community	Diversity Index	Standing crop		Bogr Cover	LD100	
			All spp	Grass		Troc	Eref
Spring	140	65	52	48	50	32	133
Summer	175	160	81	81	55	83	225
Late fall	86	53	22	16	30	13	49

meristem cells which allowed for the accumulation of a greater radiation dose and, therefore, radiation damage. The same effect was not true for acute exposures. Under acute conditions, vegetation was most sensitive during the rapid growing phase of the plant. Under field conditions, this would normally be in the spring.

Chronic irradiation

The pattern that developed in the chronically irradiated plots was similar to the seasonally irradiated plots except that the "total lethality" zone extended further from the source (lower exposure rate). The changes in diversity and coefficient of community were similar so only the diversity data are reported. The major changes came during the first 2 years with only a slow regression after that until the irradiation was terminated on 1 July 1978 (Figs. 4 & 5 and Table 9). Fig. 4 shows the diversity surface response for the first two years (April 1969 through June 1971) with the vegetation sampling dates of 4-69 (straight line), 6-69, 9-69, 4-70, 6-70 and 6-71. Fig. 5 shows the 4-69 diversity and the diversity for June of each year thereafter through 1978. The diversity D50 values are given in Table 9. There appeared to be a significant decrease in the 1978 D50 value as compared to the previous several years. Bogr cover did not show a similar decrease for 1978 (Table 10).

These results indicate that the vegetation quickly equilibrated with the stressing agent (ionizing radiation).

Fig. 4. Diversity surface response as a function of time and exposure rate for the first two years of irradiation of shortgrass plains vegetation. Irradiation was initiated 3 April 1969. Exposure rates varied from 650 R/h ($\log 650 = 2.81$) to 1.0 R/h ($\log 1.0 = 0.0$).

Fig. 5. Diversity surface response as a function of time and exposure rate for shortgrass plains vegetation. Irradiation was initiated 3 April 1969 and was continuous until 1 July 1978. Vegetation was sampled in late June of each year. Exposure rates varied from 650 R/h ($\log 650 = 2.81$) to 1.0 R/h ($\log 1.0 = 0.0$).

Table 9. Exposure rate required to reduce diversity to 50 % of the 'no effects' value for native shortgrass vegetation. The irradiation was initiated 3 April 1969 and terminated 1 July 1978.

Sampling date	Exposure Rate (R/h)		
	-2 s.e.	D50	+2 s.e.
6-69	34	47	65
6-70	7.7	11	16
6-71	9.8	15	22
6-72	10	14	20
6-73	15	20	28
6-74	7.9	12	19
6-75	11	15	22
6-76	13	17	22
6-77	11	15	19
6-78	6.5	8.5	11

Table 10. Exposure rate required to reduce Bogr (blue grama) cover to 50 % of the 'no effects' value. Irradiation was initiated 3 April 1968 and terminated 1 July 1978.

Sampling date	Exposure Rate (R/h)		
	-2 s.e.	C50	+2 s.e.
6-69	20	35	62
6-70	5.9	9.2	14
6-71	3.3	6.0	11
6-72	3.5	5.2	7.6
6-73	2.9	4.0	5.6
6-74	3.2	4.6	6.4
6-75	2.1	3.3	5.2
6-76	0.54	1.2	2.8
6-77	1.5	2.7	4.8
6-78	2.4	3.1	4.1

However, what these data do not show are the changes that took place in the vegetation during the several year time interval. Different species-increased-and-decreased-(Fr80) and the plant community was dynamic during that time. Overall, however, in the effects zone, the more sensitive species were eliminated (all shrubs, plains prickly pear (Opuntia polyacantha, Oppo), Troc and mid-grasses). Some species increased in density; sedges, pepperweed (Lepidium densiflorum, Lede), and Russian tumblethistle (Salsola kali, Saka). Other species, such as Bogr, decreased in density but without being eliminated.

The diversity D50 decrease in 1978 may have been due to the combined effect of ionizing radiation stress and enhanced moisture stress due to a drought condition that existed during the previous fall, winter and spring. It is possible that a plant community that is in equilibrium with one stress may be synergistically effected by an additional stress. Since the irradiation was terminated on 1 July 1978, it was not possible to investigate that possibility for the shortgrass plant community.

Burning, scraping and rototilling

The plots that were artificially disturbed by burning, scraping or rototilling were given their treatment by seasons corresponding to the seasons of the short-term irradiation and over a two year period. The resulting diversity and Bogr cover were not found to be different by season or year so data from all

plots disturbed in the same manner were combined. Scrapping and rototilling resulted in decreased diversity but were not statistically different from the burn or control plot diversity values (Fig. 6).

Bogr cover was eliminated in the scrapped and rototilled plots and was decreased in the burned plots as compared to the control plots (Fig. 7).

Other immediate effects of burning were the elimination of some semi-shrub, forb and grass species such as Eref, Oppo and red threeawn (Aristida longiseta, Arlo). This happened to those species that were dependent on intact above ground stem and/or crowns for continued existence. Those species that had underground perennating organs were burned off but not killed. Bogr was not killed and recovered, at least partially, in the very short time period of 2 to 6 weeks.

Scrapping removed the crown of many species and completely eliminated all species that did not have underground perennating organs, such as Bogr.

Rototilling completely eliminated all vegetation. In addition, it left a well-prepared seedbed, by agricultural standards, and partially planted the plant parts of some species, such as the lobes of Oppo. A well prepared seedbed, however, is probably dependent on the species and different species probably react favorably to different types of seedbed preparation. See

Fig. 6. Diversity as a function of time for recovery of shortgrass plains vegetation disturbed by burn, scrape and rototill treatments.

Fig. 7. Blue grama (Bogr) cover (percent of control) as a function of time for recovery of shortgrass plains vegetation disturbed by burn, scrape and rototill treatments.

the discussion in the "Recovery" section for species related data.

Recovery

Recovery was a continuing process that started soon after the completion of the disturbing insult, whether ionizing radiation or other artificial disturbance. The patterns of recovery depended on the nature of the insult (type and amount) and, at least for early recovery, on the season. The latter was particularly true for the irradiated plots. In general, recovery was rapid when measured by diversity but the recovering plant community was a different community than the original community. In those plots that were heavily damaged by the radiation, only those perennial species that had underground perennating organs returned quickly - within 2 months for the vegetation irradiated in the spring. Other species appearing during early recovery were invader annuals typical of the first seral stage of secondary succession.

In those plots that were moderately damaged but in which *Bogr* was not eliminated, succession was more like an intermediate seral stage of secondary succession. There was an increase in the number of annuals, but also many perennials were present.

Recovery in the spring and summer irradiated plots was similar in both pattern and timing. Recovery in the late fall irradiated plots was similar in pattern to recovery in the spring

and summer plots but delayed over a longer period of time, up to 1 year.

Recovery in the chronic irradiated sectors had only been in progress for one year, 1 July 1978 through June 1979. Even within that time period, there was a rapid increase in diversity. The six plots closest to the source (exposure rate of 650 down to 45 R/h), which had had nearly all of the original vegetation eliminated, had an average diversity in 1979 of 1.7 compared to a diversity of essentially zero at the end of the irradiation period (Fig. 8). In plots further from the source the diversity was essentially the same in 1979 as at the time the irradiation ceased.

The recovery in the first 6 to 8 plots was due primarily to Saka, slimleaf goosefoot (Chenopodium leptophyllum, Chle) and scarlet gaura (Gaura coccinea, Gaco). Gaco is a perennial that had never been completely eliminated from these plots and apparently had underground perennating organs that made for rapid recovery of the species after irradiation was terminated. The continual existence of this species in the irradiated plots was probably due to the presence of larger clones and, therefore, part of an individual plant was growing outside of the radiation zone. This would not happen for chronically irradiated plots that covered larger areas.

Recovery in the burned, scraped and rototilled plots depended on the method of disturbance and the method of evaluation of the

Fig. 8. Diversity as a function of exposure rate for shortgrass plains vegetation. The 1978 data are for the end of a 9 year chronic exposure period. Irradiation was terminated 1 July 1978 and the 1979 data are after a 1 year recovery period.

recovery.

For diversity (Fig. 6), there was a rapid increase to an average value of 1.3 in 1970 and it remained at that value until 1974. There was little difference between types of treatment. From 1975 through 1979, the diversity fluctuated somewhat with the burn diversity being lower than the scrape, rototill and control diversity from 1975 through 1977. For 1978 and 1979, the scrape diversity was lower than the diversity for the other treatments. Overall, there was a general increase in diversity from 1970 through 1979.

Since diversity, as calculated in this study, is dependent on the number of species present and their density and dispersion, plots that have the same diversity do not necessarily have the same plant community nor are they in the same seral stage of succession. The scrape and rototill plots were very similar and were characteristic of early secondary succession. The burn and control plots were similar in that both had a high frequency of *Bogr* although the burn plots had few *Oppo* and few shrub species. This was attributed to the effect of the fire.

When the recovery was determined by measuring the *Bogr* cover, as a percent of the control, a different picture emerged (Fig. 7). The burn plots went from 36 to 75 % from 1970 until 1974. From 1975 until 1979, the *Bogr* cover on the burn plots fluctuated but averaged about 100 % of the control plot values. On the other hand, the *Bogr* cover in the scrape and rototill plots

remained low during the entire period although the trend was to increase slightly. There was an indication of Bogr seedlings in the scrape and rototill plots the last few years although the actual presence of these seedlings was limited to a very few plots.

The effect of the treatments as it related to an inadequate seedbed for recovery purposes depended on the species used to indicate success. Two specific species densities were evaluated for comparison purposes, Oppo and Arlo. Both were present in the general area prior to the disturbance but specific plot densities were not recorded.

For Oppo, the rototilled plots had a more rapid recovery than either the burn or scrap plots (Table 11). The density was higher in the rototill plots than in the scrape and burn plots and lower in the rototill plots than in the control plots. The burn and scrape plot densities were the same and both were lower than the control plot density. (All differences reported in this and the next paragraph reflect the result of TWOSAMPLE t-tests, $\alpha = 0.10$ (Ry76).)

For Arlo, the scrape plot density was higher than the other three treatments. The rototill plot density was higher than the burn plot density but not higher than the control plot density. There was no difference between the burn and control density values.

Table 11. Density of Opuntia polyacantha (Oppo) and Aristida longiseta (Arlo) in the artificially disturbed plots in 1978, 8 years after disturbance.

Species	Treatment			
	Burn	Scrape	Rototill	Control
Oppo (lobes/m ²)	4.50	1.50	14.2	43.6
Arlo (plants/m ²)	2.00	12.33	5.87	3.05
n	24	24	20	7

The differences between the recovery pattern of these two species can be attributed to several properties of the species and of the plots. Probably the most important factor for Oppo was the action of the tilling which cut the lobes and left many of them partially buried and, therefore, in firm contact with the soil. Therefore, the recovery was really the result of vegetative propagation and not seed germination as would have had to occur on the burn or scrape plots. The burn treatment apparently resulted in a better seedbed for Oppo than the scrape plot or a better chance that a seed would be carried into the plot by an insect or small mammal and dropped. The data do not shed any information as to which method might have been responsible for the new plants that did appear. Of the 24 burn plots, 14 did not have any Oppo plants by 1978 and of the 10 that did, the lobe density ranged from 1.33 to 52/m². Of the 24 scrape plots, 22 did not have any Oppo and the density of the two that did was 16 and 20/m². Of the 20 rototill plots, 7 did not have any Oppo.

Arlo seed can move by wind as well as by animals. Therefore a more uniform seed distribution might be expected. Although the seed distribution was not known, the distribution of plants was more uniform over all treatments than for Oppo, except for the control plots. Twenty three out of 24 scrape plots had Arlo plants and the density ranged from 2.7 to 33/m². Nineteen out of 20 rototill plots had plants and the density ranged from 1.6 to 17/m². For the burn plots, 13 out of 24 plots did not have any Arlo plants. Of those plots that had plants, the density ranged

from 1.3 to 11/m². The control plots had 3 with plants (density of 2.7 to 11/m²) and 4 were without any Arlo plants.

Thus it seemed that a hard, bare surface favored the establishment of Arlo seedlings. Tilled soil, typically considered to be a favorable seedbed, did not seem to be as favorable as scraped soil. The burn and control plots had similar Arlo plant densities. It seemed that the small bare patches in these plots were less favorable for the establishment of Arlo than the open bare scraped plots. Whether competition from the existing vegetation had a role in this result is not known.

Another factor that was not investigated but that may be an important contributing factor, was the role of primary invaders in setting the stage for species in the secondary and tertiary seral stages of secondary succession (Mi79). This factor cannot be ruled out as being one of the more important factors in the distribution of the two species reported on above, especially Arlo.

SUMMARY

The radiosensitivity of native shortgrass plains vegetation was determined to be quit low as compared to other plant communities. Plant diversity was only slightly reduced at a chronic exposure rate of 6 R/h after 9 years of irradiation. The

dominant species, Bogr, had an LD50 of approximately 3 R/h after 9 years (as measured by basal cover) and appeared to have stabilized at that value.

The vegetation was most sensitive to ionizing radiation in the late fall, least sensitive when irradiated in the summer, and intermediate when irradiated in the spring. With diversity D50 values for short-term irradiation in the range of 50 to 150 kR, the question of relevance becomes important. It seems to me that that there are only two possible situations where exposures of that magnitude might be encountered.

One is the fallout after a nuclear war. Because of the changing exposure rate, fallout exposures to produce the same result as constant exposure rate, short-term irradiation would probably be about one fourth as much. Following a nuclear war, considerable areas might be contaminated to the levels necessary to produce the effects comparable to the D50 value for this study. However, because of other severe consequences, it is impossible to predict how important the effect would be.

The other possible situation which would result in exposures of that magnitude would be a serious nuclear accident at a power reactor or fuel processing facility. In this situation, a few 10's of square kilometres might receive exposures that would cause moderate to severe radiation damage to grasslands. However, this would be a relatively minor insult on a global scale and recovery would be rapid. Use of the land for food

production purposes would have to be evaluated on the basis of radionuclide cycling and not on the basis of direct exposure effects to the vegetation.

When the effects of disturbance by burning, scraping and rototilling are compared to the effects caused by ionizing radiation, those plots that were scraped and tilled responded similarly to the irradiated plots that received exposures resulting in complete lethality to the dominant species, *Bogr.* The effect of burning the plots was similar to radiation exposures resulting in damage to, but not elimination of, *Bogr.*

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