DIRECT AND INDIRECT EFFECTS OF SHORT TERM IONIZING RADIATION ON OLD-FIELD SUCCESSION

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TABLE OF CONTENTS

INTRODUCTION

In Dawson County, Georgia, in the upper Piedmont Province, an air shielded nuclear reactor has released intermittent radiation since the spring of 1959. The location of this research area and the broad program of study were described by Platt & Mohrbacher (1959).

An earlier paper (Daniel 1963) described the natural pattern of flood plain succession, the effects of ionizing irradiation on this pattern, the role of the plants in water runoff and erosion, and certain life history phases of the dominants.

Objectives of this study are: (1) to provide an account of the changes in species composition from season to season due to competition and irradiation, (2) to correlate the life cycle of certain species with their sensitivity to radiation, (3) to describe some indirect effects, such as stimulation, when a species is released from limiting competition as a result of irradiation, (4) to describe damage in relation to dose for certain dominants, and (5) to evaluate the partial shielding effect of the soil to underground plant organs.

The term *dominant*, as used in this study, refers to species which limit water, minerals, and light needed by lesser species (non-dominants) for optimum growth response. *Aspect dominance* means to have showy flowers or other characters which cause an appearance of dominance. Aspect dominants do not necessarily control lesser species of the community by competition. Dominants may control other species through the production of inhibitor substances (Keever 1950).

Historically, the study of succession in the Piedmont and related areas began with Crafton & Wells (1934). Their study, carried out near Raleigh, North Carolina, showed stages dominated in order by crabgrass, horseweed, aster, and broom-sedge. Shade from horseweed and aster limited crabgrass and bermuda grass. Aster, for example, might attain a height of 12 in. by May 1, and its shade then limit development of later-germinating annual grasses. Greenhouse studies showed that with drought conditions broomsedge survived while horseweed and aster died.

In an extensive study of successional communities near Durham, North Carolina, Oosting (1942) observed successional stages in sequence from year of abandonment through climax forest. The initial community had about 33 species, mostly annuals, which germinated from seed present in the abandoned field. In the second year after abandonment, 31 original species were present and 31 new species were added, including many perennials and biennials. Third year fields, dominated by broom-sedge and pine, had only 37 species. Oosting's study of flood plain fields began with a broom-sedge community, but he did indicate that the initial stages were not unlike those found on the upland fields.

Bonck & Penfound (1945) investigated successional differences related to season of abandonment. This study in Louisiana demonstrated autumn-abandoned plots to be dominated by *Lamium amplexincaule* and *Alsine media;* for winter, Medicago and Melilotus; and for spring, summer grasses. At the end of the first summer all plots closely resembled each other regardless of the season of abandonment.

Causes for the rapid changes of dominants in early stages of Piedmont old field succession were studied by Keever (1950). She agreed with Oosting (1942) that Digitaria is the initial invader after final summer cultivation because its seeds are present and able to germinate. The following spring, horseweed rosettes, *Erigeron canadensis,* having germinated in late fall and being already established, grew into weeds as much as 7 ft tall. Thus Digitaria was replaced by Erigeron, which in turn during the second summer after abandonment, was replaced by Aster. Keever found some evidence that horseweed roots release an inhibitor which stunts the growth of horseweed seedlings in second year fields and thus may give Aster an advantage. Seeds of broom-sedge, *Andropogon virginicus,* which replaces Aster in third year fields, enter the field after cultivation ceases and must overwinter on the ground for cold vernalization before the seed will germinate. Once established, broom-sedge clumps so reduce available soil moisture that growth of Aster is inhibited. Thereafter broom-sedge is dominant until pines take over.

In the Piedmont Plateau of New Jersey (Bard 1952) *Oenothera parviflora,* a primrose, is dominant the first summer after abandonment, and remains so for several years before being replaced by Aster which, in turn, is slowly replaced by *Andropogon scoparius.*

Keever (1955) extended her studies into the Piedmont Plateau of South Carolina and to eastern Georgia by describing a new first year dominant which apparently had migrated from Texas. This aggressive migrant, *Heterotheca latifolia,* may replace Erigeron. Plummer & Keever (1962) reported a widespread distribution of Heterotheca in Georgia and South Carolina as a result of wind blown seed.

Byrd (1956) reported the relationship of old-field succession to the abundance of farm game in Cumberland County of the Virginia Piedmont. The species lists of the described vegetation largely agree with those of Oosting (1942) and Keever (1950).

A vegetation survey of the Savannah River Project near Aiken, South Carolina, included density and frequency lists of early successional species found in both the highland and flood plain (Batson & Tulloch 1954, 1955; Kelly & Batson 1956). The upland species were similar to those of the Piedmont Plateau of North Carolina while the lowland species were like those in the North Georgia Piedmont (Daniel 1963).

Quarterman (1957) found much diversity of dominance in the first year after abandonment on fields in the Central Basin of Tennessee. Like Bard (1952), Quarterman reported a delayed dominance by Aster and Andropogon when her results were compared with those of Oosting (1942) and Keever (1950) for the Piedmont Plateau of North Carolina.

A 7-year study, listing dominants and other major species with their relationships to production, energy turnover, and mineral cycling in old-field succession was published by Odum (1960). On fields at the Savannah River Project three successive forbs developed for the first 3 yrs after abandonment. *Erigeron canadensis* dominated the first year producing 500 gm/ sq m in what Odum called a "residual fertilizer bloom." In the second year, *Haplopappus divaricatus* became dominant, followed the next summer by *Heterotheca subaxillaris.* On thin, sandy soils, Andropogon did not invade until the fifth year, more than 2 yrs later than upland fields of the Piedmont. Average productivity of the second and subsequent years did not exceed 300 gm/sq m. This lowered productivity was attributed to a lack of phosphorus availability, since slowly decaying vegetation produced by the first year bloom tied up mineral nutrients. Odum also noted an apparent relationship between the silt-clay content of the sandy soils and the available soil moisture, which could be used to predict the successional dominants of the fields observed.

Rice, Penfound & Rohrbaugh (1960) observed that dispersal of Andropogon seed by wind in Oklahoma was in general, limited to a distance of about 6 ft.

Succession over a 5-yr period has been described (Daniel 1963) for a flood plain of Air Force Plant 67 receiving gamma-neutron irradiation from an air shielded nuclear reactor. A control field on a nearby flood plain without irradiation was observed at the same time. The natural old-field following cultivation in the summer supported, between the corn stalks, low annual weeds and grass dominated by *Diodia teres, Digitaria sanguinalis,* and *Croton glandulosus.* The following spring and early summer *Oenothera laciniata* held dominance but in midsummer it was replaced by taller annuals, *Erigeron pusillus* and *Haplopappus divaricatus.* The dominants in the third summer were perennials (*Monarda punctata, Smilax glauca, Smilax bona-nox*) which remained through the fifth year when the study was terminated.

In the experimental field the pattern of dominants of the first three years was changed as a result of the ionizing radiation. The tall forbs dominant during the second year of succession were eliminated by an accumulated dose of 30,000 rads and were replaced with the low annuals *Diodia teres* and *Trichostema dichotomum* in the third year. Where the *Monarda-Smilax* community was already established before irradiation, it maintained itself while accumulating a total dose of 44,650 rads over a 3-yr period. This radiation resulted in sterile seed but vegetative propagation produced an observed increase in biomass for this established community.

Chappell (1963) observed that exposed aerial stems of species of *Smilax* on the same flood plain described by Daniel (1963) had accumulated a dose of 32,000 rads and were killed. Stolons and rhizomes buried deeper than 11 cm underground survived and allowed regeneration of the plants.

Woodwell (1962, 1963) reported on the effects of gamma radiation on an oak-pine forest and a first year succession field on Long Island, New York. He postulated that when irradiation eliminates sensitive species the biological interactions of the remaining species will be altered. He also noted that the surviving species have shortened life spans and reduced ability to withstand such physiological stresses as temperature extremes, drought, and intense light. Platt & McCormick (1962) also observed reduction of life span and resistance to physiological stress in rock outcrop vegetation in a gamma radiation field. Sparrow & Miksche (1961) showed that the relative sensitivity of plant species to radiation may be predicted on the basis of nuclear volume and rate of cell division. Polyploidy had an apparent protective effect. Mergen & Stairs (1962) observed that 95% of dormant pine seeds germinated after receiving a chronic gamma radiation dose which killed 90% of the parent trees. Radiation resistance of the seeds was attributed to dehydration, small chromosome size, and low oxygen content. Woodwell & Oosting (1965) found that the grass, *Digitaria*, increased strikingly when released from competition with radiation sensitive herbs and grasses.

MATERIALS AND METHODS

A *Monarda-Smilax* flood plain community 2 mi northwest of the reactor, well beyond any ionizing radiation penetration, was chosen as a control area for the irradiated field. Both fields were last planted in corn in 1956.

Vegetation, uniform in species present and in height and density, was selected for analysis in each field. Some 600 ft from the reactor an area 70 ft wide and 220 ft long, having the shape of an arc around the reactor, was chosen. In the control field, a larger area was necessary, to permit special soil moisture studies and tree counts. Here an area of 2.5 acres was set aside for sampling. In 1961, a third flood plain was observed briefly as to vegetation and soil for comparison with the reactor field and the control. This latter area, a few miles northwest of Hightower, Georgia, locally known as Sherrill's Bottom, contained several alluvial soil types which had been mapped by the Soil Conservation Service and the results published in *Soil Survey Forsyth County Georgia, Series 1956*. On all three flood plains, the fields were located on the inside river curves away from bluff margins on the opposite side of the river.

To observe initial stages of succession, the soil was turned in late summer, in winter, and in spring. In some cases, corn was planted in rows, cultivated until July and then abandoned. Square meter quadrats were staked subjectively on the plowed and unplowed parts of both fields. By this means, 5 yrs of succession were observed in 3 yrs. Quadrats were observed in detail in June and October and to a lesser extent in January and March. Species identification was simplified by the transplant of seedlings to the greenhouse for observation. Nomenclature follows Gray's Manual of Botany, eighth edition (Fernald 1950).

When harvest biomass was collected in the field, density and frequency for each species were determined. The separated specimens of a quadrat series were washed, dried at 75 C, and weighed to determine standing crop biomass by species, which divided by the number of quadrats in the series, gave the average biomass per square meter for each species. Combining these values gave an estimate of the total standing crop per square meter.

The dominance value for a given species was obtained by the following computations. Relative density for each species was converted to percent density by dividing the total number of stems of a given species by the total number of stems of all species and multiplying by 100. Percent biomass for each species was obtained by dividing the resultant standing crop biomass of each species for all quadrats by the total standing crop of all species multiplied by 100. The following equation is based on the area of a triangle in which percent density and percent frequency form the base and percent biomass forms the altitude.

$$\text{Dominance value of a given species} = \frac{\%\ density + \%\ frequency}{\text{two}} (\%\ \text{biomass})$$

Species dominance values were then ranked and those with the highest values were designated dominants. Percent density and percent biomass are not given in tables but may be calculated from the data. For complete dominance indices, see Daniel (1965).

The Student *t* test of significance and the Chi square test of goodness of fit were used to determine probability of given samples being of the same population. The expression "significant" is used to indicate 5% probability and "very significant" a probability of 1% or less.

The mean, standard deviation, and standard error were determined for field soil moisture values. Regression analysis was used to analyze soil temperature curves resulting from soil temperature increase in the spring.

A community coefficient for index of frequency similarity was used to compare two comunities as to frequency composition of species present for a given stage of succession or before and after irradiation treatment.

Certain observations were made at weekly intervals at each experimental area. These included life history stages, rainfall, maximum and minimum air temperature, soil temperature at the 1- and 6-in. levels, available soil moisture in the upper 6-in. layer as percent of dry weight of soil collected in triplicate samples, and sky conditions at the time of observation. At less frequent intervals plastic pipes, each 34 ft long, which had been placed vertically in the ground for other hydrological studies, were used to determine the water table level.

For comparative measurements, June light intensity was determined at noon on a cloudy, bright day with a Photovolt Model 200 light meter, just above the vegetation. Also on a June day with light conditions of 10,000 ft-c, a soil-air temperature profile was made beginning at 11:00 am and continuing until 3:30 pm taking readings each half hour from 6 in. below the soil surface to the surface at 1 in. intervals and in the air at the 1 in., 2 in., and 2 ft, intervals above the soil surface. A Yellow Springs Instrument Company, Inc. Tele-thermometer 12 channel unit was used. Calibration at each reading was made with 3 Weston dial-face thermometers previously tested in a water bath for the temperature range expected.

The Bouyoucos hydrometer method for gravimetric soil analysis was used for the top six inch soil samples taken in triplicate from 34 locations. Soil pits 4 ft deep were dug in both fields to observe the soil profile and the root distribution of the dominant species. A Beckman Zeromatic meter was used to determine the pH of the upper 6 in. of soil from duplicate samples at 15 locations in the sample areas. Following floods occuring in February and December, 1961, observations were made on erosion, debris effects, water depth over the vegetation, and plant survival.

Random surface soil samples from the irradiated and control areas, along with their contained seed, were carried in flats to the Emory campus gamma field for additional productivity studies. This soil was layered over a common subsoil, and that from the irradiated area placed parallel to that from the control in the same bin so as to provide comparable environments. The experiment was duplicated, in the gamma field and outside the field. The resulting communities were analyzed for species density, frequency, and dry weight harvest crop using ¼ sq m quadrats, and the relative dose of irradiation in roentgens was calculated. The gamma source contained 160 curies of Co^{60}.

Two strips, each 250 ft long, were plowed in the control field for soil moisture studies along a steep moisture gradient, extending from the xeric *Monarda-Smilax* community into the mesic pine-broomsedge community. The strips were planted with corn in rows and cultivated until July, when they were abandoned and weeds and grasses allowed to develop. Dominants were noted and available soil moisture recorded at intervals of 50 ft along the strips. *Erigeron pusillus* and *E. canadensis* were sampled by ¼ sq m quadrats at each soil moisture point. Relative abundance of other important species was observed.

In the control field two 20-ft squares were turned. One was fertilized with a 10-10-10 fertilizer liberally applied and then both were seeded with corn in rows which was thinned to give 100 plants per 20 ft square plot. At near maturity relative corn stalk size was compared.

Radiation dosimetry was carried out by Cowan (1961) using threshold detection methods to determine neutron dose, while film badges, activated phosphate glass, and Sigoloff chemical dosimeters were used for gamma-ray measurements. A combination of film badges and calculated dose rates were used to determine the radiation dose in roentgens for the Emory gamma field.

OBSERVATIONS AND RESULTS

Microenvironmental Studies of the Experimental Communities

COMMUNITY TYPE, LOCATION, AND TOPOGRAPHY

Initial observations concerned interrelationships between dominant species and soil characteristics of the reactor flood plain communities. The reactor flood plain contained, when first observed in July 1958, many successional communities, on hydric, mesic, and xeric areas of diverse size and uniformity of plant cover. The *Monarda-Smilax* community selected for study was not shielded from the reactor and had an area of 30,000 sq ft which was sufficient to permit frequent sampling. This flood plain (Fig. 1) had last been cropped in corn in 1956. In the sample area the soil was well drained with uniform texture.

FIG. 1. Reactor field flood plain and surrounding hills. The experimental area, 600 ft from the air-shielded reactor (center building) is indicated by the dotted line.

The control community consisted of approximately 4 acres of *Monarda-Smilax*, also abandoned from corn in 1956. The soil was sandy and well drained. The control field and reactor flood plains in addition to the *Monarda-Smilax* communities had large areas with tree vegetation and *Aster-Andropogon* communities. *Aster-Andropogon* dominated areas which had been disturbed by reactor construction. Portions of the flood plain had become swampy as a result of diverted streams and springs.

SOIL ORIGINS

The Forsyth County flood plain known as Sherrill's Bottom had been mapped by the Soil Conservation Service and this map made it possible to indentify the soils and their characteristics on the flood plains of the control and irradiated areas. The control field is Buncombe loamy fine sand; the irradiated field, Congaree fine sandy loam. These are alluvial soils, 9 to 15 ft deep over Gneiss and Schist rock. The flood plains have a 0 to 2% slope, are well drained, and have a medium runoff potential. Buncombe loamy fine sand has a permeability rate of 10 in./hr while the Congaree fine sandy loam has a 3 to 5 in./hr rate. These flood plains lie to the inside curve of the river and during floods the faster current deposits coarse sand which becomes Buncombe loamy fine sand. Slower currents deposit the silt and clay more abundant in the Congaree fine sandy loam.

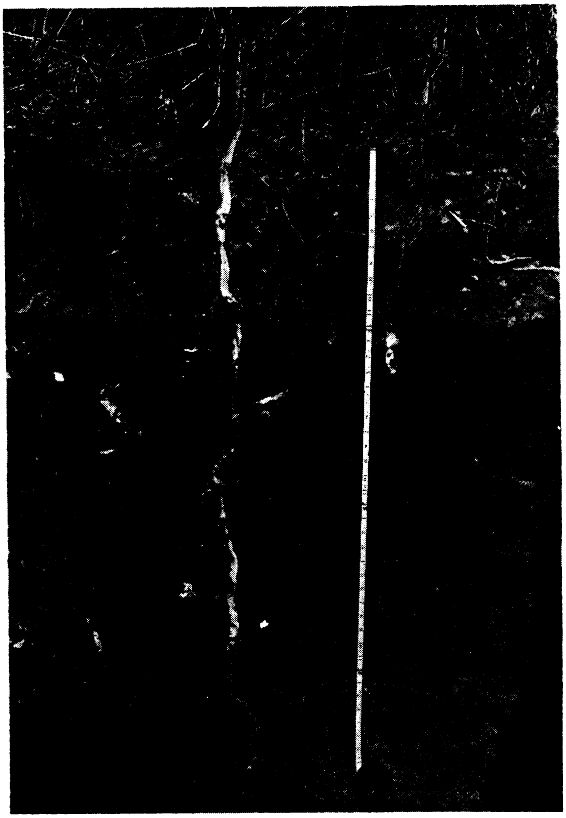

FIG. 2. Wall of soil pit in Congaree fine sandy loam of reactor field. A brown silt loam, 12 in. deep, lies over dark-brown silt loam. A tap root system of *Campsis radicans* extends down the pit wall.

SOIL PROFILES

Figure 2 shows the wall of a soil pit dug in the *Monarda-Smilax* community in the reactor field. The extensive network of plant roots in the A_p layer (0 to 8 in.) is *Monarda punctata*. The A_L layer of this Congaree fine sandy loam is ¼ in. thick and the A_h layer is 1/16 in. thick. The plow layer is a brown silt loam with a weak, medium-granular structure and friable consistancy. The composition of the upper 6 in. was sand 77.81 ± .76%, silt 13.88 ± .56%, and clay 8.42 ± .24% where N equals 15 and all averages are ± one standard error of the mean. The A_b layer of gray silt loam extended from the A_p boundary at 8 in. to 20 in. on the mark. The A_{cb} layer which is dark brown with dark mottles at its lower border ranged from the 20 in. mark to the 28 in. mark. The pH of the plow layer ranged from 5.6 to 5.8. This soil is listed in the *Soil Survey Forsyth County* as capable, with good management, of producing 90 bu. of corn to the acre.

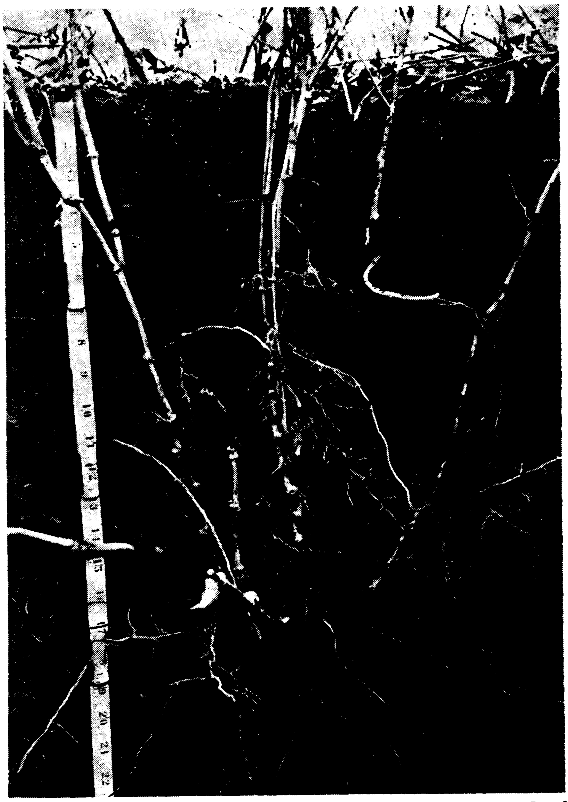

FIG. 3. Soil pit wall in Buncombe loamy fine sand of control field showing exposed rhizomes and stolons of *Smilax bona-nox* in and below plow layer. A light brown loamy fine sand 8 in. deep, lies over yellowish-gray sand with gravel increasing below 3 ft.

Figure 3 shows the deep network of rhizomes and stolons found under a *Smilax bona-nox* clump in a soil pit of the control field. The profile of this Buncombe loamy fine sand had a plow layer of loose loamy fine sand 9 in. deep, which gradually changed into an A_c layer of pale brown with yellowish gray sand and gravel of the deeper C layer at about 28 in. The upper 6 in. of this plow layer had a pH of 5.4 to 5.6 and a textural composition of sand of 88.05 ± .36%, silt 8.08 ± .36%, and clay 3.88 ± .19%, the N being 12. With best agricultural practice, the Buncombe soil is capable of producing 50 bu. of corn to the acre.

The textural compositions of the plow layers of the reactor field Congaree soil and the control field Buncombe soil are statistically so very significantly different that they can not be regarded as of the same soil population. The Buncombe loamy fine sand with a faster permeability rate and greater leaching than the Congaree fine sandy loam is a more xeric habitat, and has less productivity. However, of the 66 species observed in the quadrat studies, 37, including all of the major dominants, occurred in both fields.

WATER RELATIONS

The water table was observed to rise and fall in the hydrological plastic pipes with the level of the adjacent streams, but generally stood at a level of 14 to 16 ft under both fields. During flood conditions in December 1960 and in February 1962, it was possible to wade into the reactor field for direct observation. In both instances, water covered the ground surface from a depth of 4 to 20 in., but caused little erosion damage where the plant cover was intact. The water in the reactor field was relatively quiet, but some current effects could be detected in the control field. In one area with disturbed, bare soil, considerable erosion damage took place. On a bank area rosettes of first year succession were covered with sand.

TABLE 1. Precipitation at Air Force Plant 67 during the period of October 4, 1959 through October 16, 1960.

Time interval	Weather station recorded in inches/hour	Irradiated experimental field recorded wkly in inches	Nonirradiated control field recorded wkly in inches
October 4, 1959 to October 31	6.3	6.5	5.6
November 1, 1959 to January 24	7.5	8.3	7.6
January 25, 1960 to March 28	10.8	10.5	9.9
March 29, 1960 to June 4	6.8	4.4	No rainfall record kept
June 5, 1960 to October 16	24.4	21.3	19.9
Total for 54 weeks	55.8	51.0	
Total of 54 weeks less time interval of March 29 to June 4	49.0	46.6	43.0

Table 1 shows a comparison of precipitation recorded on an hourly basis at the weather station located 2 mi. southeast of the reactor field, as well as precipitation measured in the reactor field and the control field. For a 54 week period between October 4, 1959 and October 16, 1960, a total of 55.8 in. was recorded at the weather station and 51.0 in. in the reactor field.

SOIL AND AIR TEMPERATURES

Figure 4 shows the rise of soil temperature between February 6 and June 23 for a series of readings at the 1 and 6 in. depths in the irradiated field and the control field during 1960 and 1961. At the 6 in. depth, monthly averages in °F were, February

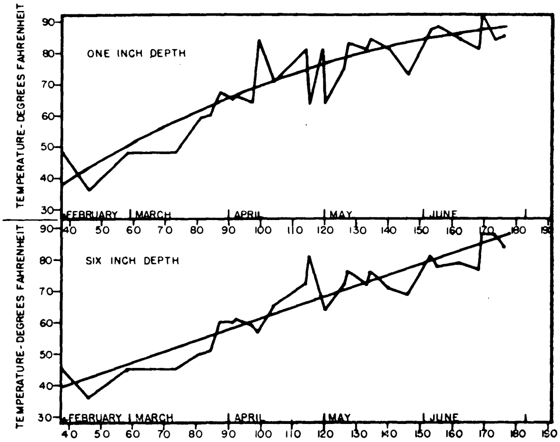

FIG. 4. Rise of soil temperature in the spring. Data for 1960 and 1961. Time accounts for most of the variation as seen in the curvilinear regression at the 1 in. depth and linear regression at the 6 in. depth.

TABLE 2. Air and soil temperature (°F) gradients on a cloudy bright day with 10,000 ft-c of light at 2:00 pm on June 16, 1961.

Thermister location	Summer of abandonment	First year succession	Third year succession
	*	**	***
2 ft above ground	95	—	—
2 in. above ground	110	108	108
1 in. above ground	113	111	99
0 -at ground surface	133	135	119
¼ in. below surface	131	132	114
1 in. below surface	110	108	101
2 in. below surface	105	96	93
4 in. below surface	99	92	87
6 in. below surface	94	87	81

*Determined in weedless corn row with corn 12 in. tall
**Determined in seedling *Erigeron-Haplopappus* community
***Determined in perennial *Monarda-Smilax* community

41.3; March, 51.5; April, 65.0; May, 72.7; and June, 82.1. The temperature ranged from 36 to 88 F at the 6 in. depth and from 36 to 92 F at the 1 in. depth.

For the 1 in. depth readings, a linear regression using time in days was fitted to the temperature data. In a highly significant regression, time accounted for 77% of the variation of soil temperature. This was calculated by a t test by which $t = 9.58$. However, when a curvilinear regression was fitted to the data, the second degree polynomial accounted for 81% of the variation in soil temperature at the 1 in. depth. When a linear regression was fitted to the 6 in. soil temperature data, this model accounted for 86% of the variation in soil temperature. See Daniel (1965) for additional statistical treatment of these data.

Table 2 shows the soil temperature gradient and air temperature in and just above the vegetation. This was determined for summer-of-abandonment, first year, and third year succession fields at 2:00 pm on a cloudy bright day in June, 1961 with 10,000 ft-c of light present. Readings were begun at 11:00 am and continued through 3:30 pm, but the tabled

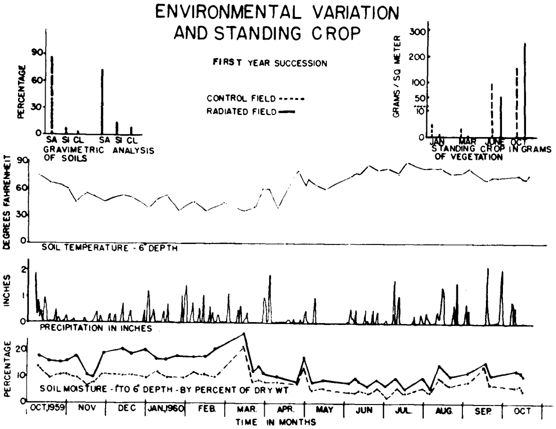

FIG. 5. Data for each of the 5 successional years are provided in Figs. 5-9. These 5 yrs were observed over a period of 3 yrs by manipulation of the experimental area. See text for full explanation. Note that for each year available soil moisture percent for the radiated field is higher than that of the control field, because of its higher silt-clay fraction. In late summer when soil temperature and moisture were critical, the irradiated area had a higher productivity.

readings are maximum. The highest temperature was recorded in first year areas at the ground surface. This first year area had a darker soil surface from deposited organic duff and relatively open vegetation. Temperatures were reduced at the surface where cover increased. In the year of abandoment area surface temperature reached 133 F., in first year area 135 F, but in the third year area with greater shade it reached 119 F. Temperatures above 104 F (40 C) occurred in all three succession areas from 11:00 am until 3:30 pm. For the years 1959 through 1962 in weekly soil temperature tests, the highest temperature occurred during June. Figure 5 shows the decline in soil temperature at the 6 in. depth between early July and late January. The soil temperature began to rise in February and continued to rise through the third week in June. (See also Fig. 4).

Minimum and maximum air temperatures at the vegetation top were recorded weekly in both the control field and reactor field. Highest temperatures of 104 F (40 C) were recorded on six different occasions in late July and August. Prolonged high temperatures occurred in August. Mean annual temperature for the area is approximately 60 F (Platt & Mohrbacher 1959). Most nights in December, January, and February are below freezing. A low temperature of −2 F was recorded in January, 1960. Normal frost occurs as late as April 10 and as early as October 16. An abnormal frost which simulated radiation damage to exposed leaves killed Smilax, Campsis, Sassafras, and Nyssa leaves in both the reactor and control fields on May 25, 1959.

FIVE-YEAR SUMMARY

The late summer high temperatures of July and August, combined with rain in scattered showers,

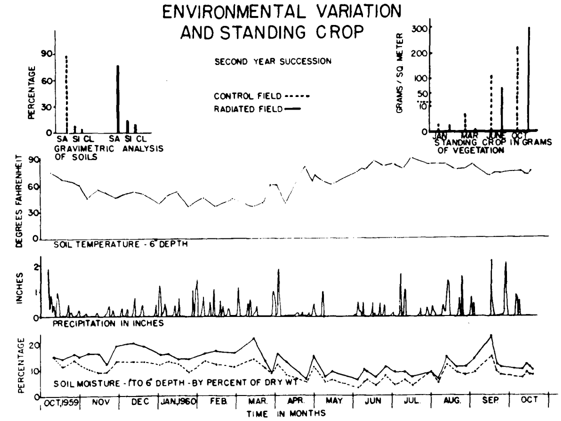

FIG. 6. Productivity increased the second year as tall annuals invaded.

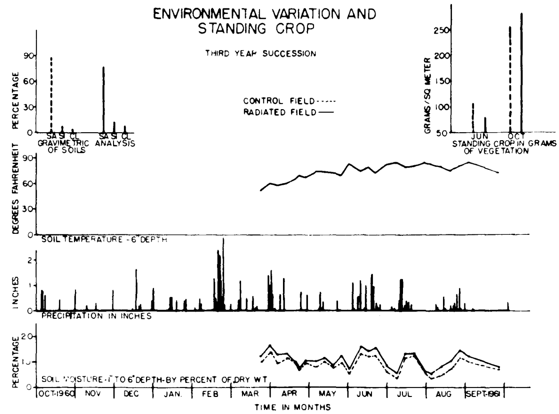

FIG. 7. For the third year, a late May frost depressed June productivity in both fields. Autumn perennial dominants of the control increased productivity. Low annual dominants re-invaded the irradiated field resulting in productivity decrease since 30,000 rads had eliminated tall annuals and blocked perennial invasion.

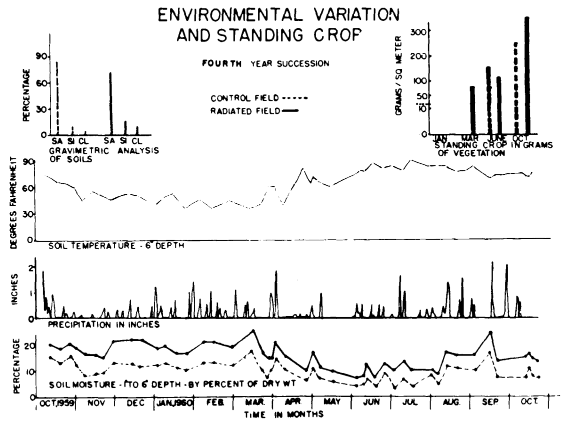

FIG. 8 In the fourth year, readily available soil moisture during autumn favored recovery from radiation injury and brought about a relatively high productivity, which continued to increase the fifth year.

TABLE 3. Mean soil moisture percent content of the reactor field and control field.

	Congaree series reactor field		Buncombe series control field		*t* test comparing each year of succession for first 5 yrs	
Year of succession	Soil moist. %	N	Soil moist. %	N	*t* value	Probability same population
First year 11/21/1959 to 10/16/1960	12.59 ± .63*	61	7.80 ± .55	34	29.05	less than .001
Second year 11/21/1959 to 10/16/1960	11.96 ± .52	68	8.26 ± .59**	34	32.61	less than .001
Third year 3/25/1961 to 9/30/1961	10.45 ± .53	44	8.89 ± .68	22	7.85	less than .001
Fourth year 11/21/1959 to 10/16/1960	15.06 ± .58	68	8.26 ± .59**	34	42.59	less than .001
Fifth year 3/25/1961 to 9/30/1961	12.04 ± .59	44	9.41 ± .70	22	12.26	less than .001

*all averages ± one standard error of the mean.
**same soil sample for second and fourth year taken in border between sample areas.

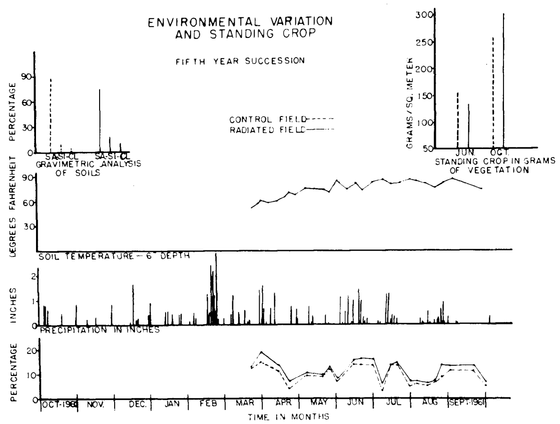

FIG. 9 Both fields were flooded in February, 1961.

relatively high soil temperatures, high rate of permeability to soil moisture, and high soil moisture evaporation rate resulted in limited productivity in the control field for all years of succession (Figs. 5 through 9).

Soil moisture is plotted for association with rainfall, soil temperature, and productivity in Figs. 5 through 9. Weekly mean soil moisture percentages for each of 5 yrs of succession for both the control and the reactor fields are listed in Table 3. Larger N numbers of the reactor field mean values are the result of combination of data from two weekly sample points throughout the year. Two points were sampled to provide better observation of the relatively long arcs of vegetation. Soil moisture was consistently higher in the reactor field than in the control field (Table 3).

Productivity per square meter of the control field exceeded that of the reactor field in June, but the condition was inverse in October. The wilting percentage of these soils is 2%. At no time during the 5-yr study was soil moisture less than 3% in the field or was permanent wilting observed in the field. These facts necessitated the soil moisture gradient studies which are reported, in part, under Standing Crop.

IONIZING RADIATION

Ionizing radiation was an important variable of the reactor field. In the control field, only background radiation was observed. General facts concerning the reactor and its operation, were reported by Platt & Mohrbacher (1959) and the radiation around the reactor and its surrounding fields and hills Cowan (1961). Data given here as dose in rads for the succession years represents the mixed gamma-neutron radiation emitted by the reactor. Because of the neutron pattern of particle collisions and resultant scattering in the *Monarda-Smilax* community in the reactor field, it was determined that the dose was the same, within the margin of error, for the entire sample area. The dose in rads is plotted in the upper half of Figures 10 and 11, which indicate the dominants of succession in the reactor field, their life history pattern and radiation exposure. The reactor was first activated in December, 1958, but no important radiation was released before March, 1959. Significant radiation was released on only two occasions. A dose of 8,500 rads occurred in June, 1959 and of 30,000 rads during August, 1960. Operation of the reactor continued through June of 1961. The original vegetation of the field, including the *Monarda-Smilax* invaders, and perennial species, accumulated a dose of 44,650 rads.

COMMUNITY COMPOSITION AND STRUCTURE

A combined list of the 66 species collected in quadrats in the reactor and control fields is given in Table 4. The table includes more than 90% of the species present in the sample areas. Species not included in the quadrats occurred rarely and survived only a short time in competition with the dominants.

The more mesic Congaree fine sandy loam of the

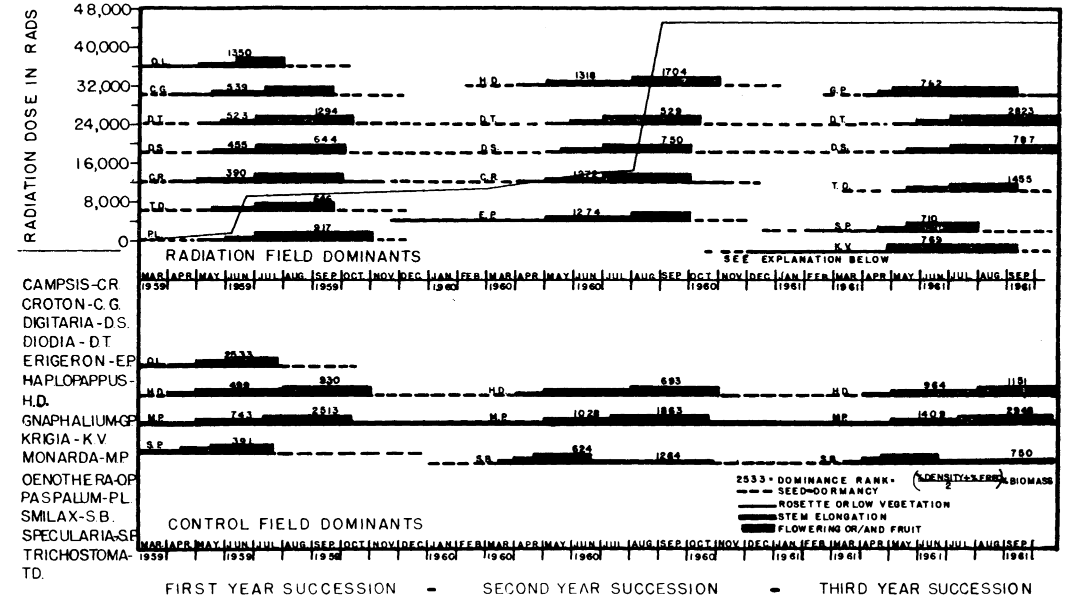

FIG. 10. Successional dominance changes of first 3 yrs. Numbers above the bars are dominance values. The accumulated radiation dose is superimposed on the upper half of the figure.

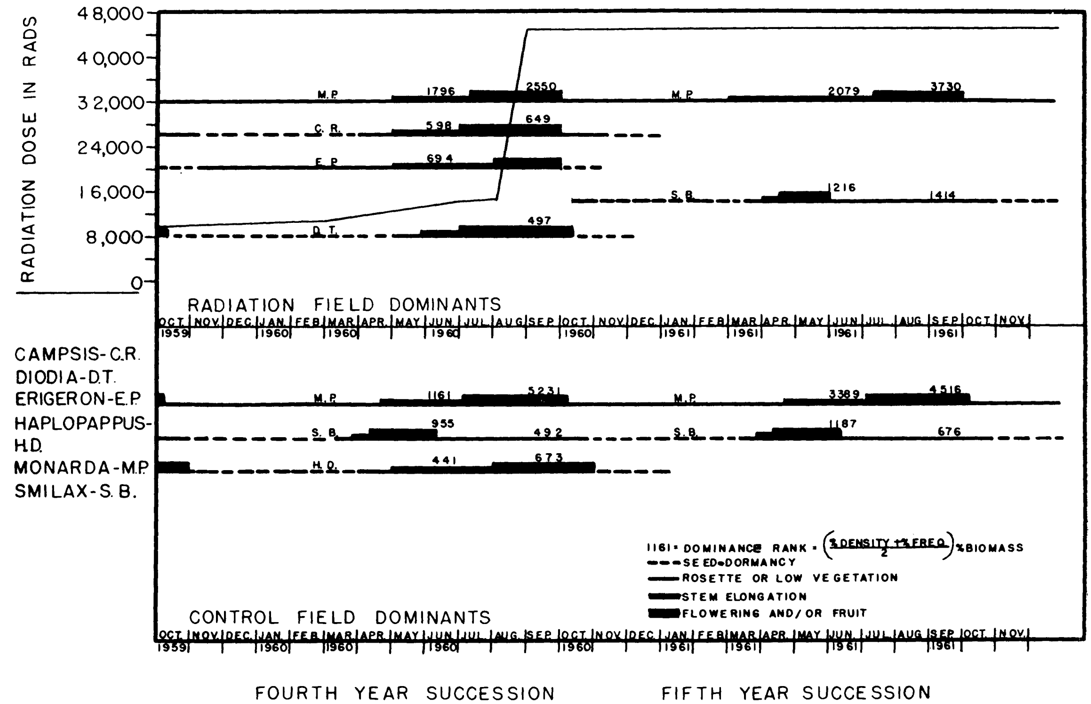

FIG. 11. Successional dominance changes of fourth and fifth years. Numbers above the bars are dominance values. The accumulated radiation dose is super imposed on the upper half of the figure.

reactor field supported 57 species but the drier Buncombe loamy fine sand of the control field, a more adverse habitat, had only 48 species in the plots. Thirty nine species occurred in both fields. All dominant species were found in both fields except the aspect dominant *Viola kitaibeliana,* which occurred only in the reactor field. Eighteen species occurred in the reactor field only; 9 species only in the control field.

Observations of the effect of radiation on life his-

TABLE 4. Life history stages of flood plain successional species. R= rosette or germinant stage, S= stem elongation, F= flower or fruit, D= dormant or seed only, r= occurs in irradiated field, c= occurs in control field.

Species name	Occur in	Form	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.
Allium vineale	r	Annual	RS	S	S	S	S	S	F	F	F	D	D	D
Ambrosia artemisiifolia	rc	Annual	D	D	D	D	R	R	RS	RS	SF	F	F	F
Amphicarpa bracteata	rc	Peren.	D	D	D	D	R	S	S	S	F	F	F	D
Andropogon virginicus	rc	Peren.	F	D	D	D	R	S	S	S	S	S	F	F
Aster pilosus	r	Peren.	F	R	R	R	RS	S	S	S	S	S	F	F
Betula nigra	r	Peren.	D	D	D	D	D	D	RS	S	S	S	S	S
Bulbostylis capillaris	rc	Annual	D	D	D	D	D	R	S	S	F	F	F	D
Campsis radicans	rc	Peren.	D	D	D	D	D	R	S	S	F	F	F	D
Cassia fasciculata	rc	Annual	D	D	D	D	D	D	R	S	F	F	F	D
Cerastium viscosum	r	Annual	D	D	D	D	D	D	D	RS	S	F	F	D
Convolvulus arvensis	rc	Peren.	D	D	D	D	D	D	RS	S	F	F	S	D
Croton glandulosus	rc	Annual	D	D	D	D	D	R	RS	S	SF	F	F	D
Cyperus strigosus	rc	Annual	D	D	D	D	D	R	S	S	F	F	FD	D
Desmodium canescens	r	Peren.	D	D	D	D	D	D	R	S	S	F	F	F
Digitaria sanguinalis	rc	Annual	D	D	D	D	D	D	RS	RS	F	F	F	D
Diodia teres	rc	Annual	D	D	D	D	D	D	RS	S	F	F	F	D
Diospyros virginiana	c	Peren.	D	D	D	D	D	S	S	S	S	S	S	S
Erigeron canadensis	rc	Annual	R	R	R	R	R	RS	S	S	F	F	F	F
Erigeron pusillus	rc	Annual	R	R	R	R	R	R	S	S	S	F	F	D
Fragaria virginiana	rc	Peren.	R	R	R	R	R	F	F	F	R	R	R	R
Galax aphylla	r	Peren.	R	R	R	R	R	R	F	F	F	R	R	R
Geranium carolinianum	r	Annual	D	R	R	R	R	S	SF	F	S	S	D	D
Gnaphalium obtusifolium	r	Bienn.	R	R	R	R	R	R	S	S	S	F	F	F
Gnaphalium purpureum	rc	Annual	R	D	D	D	D	RS	SF	F	F	F	FR	R
Haplopappus divaricatus	rc	Annual	R	D	D	D	D	R	S	S	S	F	F	F
Hieracium scabrum	c	Bienn.	R	R	R	R	R	R	S	S	S	F	F	D
Hypericum gentianoides	rc	Annual	D	D	R	R	R	S	S	SF	F	F	F	D
Krigia virginica	rc	Annual	D	R	R	R	R	R	F	F	F	FD	D	D
Lactuca canadensis	r	Bienn.												
Lepidium virginicum	rc	Annual	R	R	R	R	R	R	SF	F	F	F	F	D
Lespedeza cuneata	r	Peren.	R	R	R	R	R	R	S	S	S	SF	F	F
Lespedeza procumbens	rc	Peren.	R	R	R	R	R	R	S	S	S	F	F	S
Lespedeza repens	r	Peren.	R	R	R	R	R	R	S	SF	F	F	F	S
Lespedeza striata	rc	Annual	D	D	D	D	D	R	S	S	S	F	F	F
Linaria canadensis	rc	Annual	D	D	D	D	D	RS	F	F	D	D	D	D
Mollugo verticillata	rc	Annual	D	D	D	D	D	D	D	R	F	F	F	D
Monarda punctata	rc	Peren.	R	R	R	R	R	R	S	S	F	F	F	R
Oenothera biennis	rc	Bienn.	R	R	R	R	R	R	S	S	S	F	F	R
Oenothera laciniata	rc	Annual	R	R	R	R	R	R	RS	SF	F	D	D	D
Oxalis stricta	r	Annual	D	D	D	D	D	R	SF	F	F	F	S	D
Panicum spp.	r	Peren.	R	R	R	R	R	R	S	SF	F	F	S	R
Panicum capillare	r	Peren.	R	R	R	R	R	RS	S	SF	F	F	S	R
Paspalum laeve	rc	Annual	D	D	D	D	D	D	R	S	F	F	F	D
Pinus taeda	rc	Peren.	S	S	S	S	S	S	S	S	S	S	S	S
Plantago aristata	c	Annual	D	D	D	D	R	R	F	F	F	F	D	D
Plantago virginica	rc	Annual	D	D	D	R	R	R	F	F	D	D	D	D
Polygonum pensylvanicum	c	Annual	D	D	D	D	D	R	S	S	F	F	F	D
Prunella vulgaris	r	Peren.	R	R	R	R	R	R	S	SF	F	F	F	F
Prunus serotina	c	Peren.	D	D	D	D	D	S	S	S	S	S	S	S
Rumex acetosella	r	Peren.	R	R	R	R	R	R	SF	F	F	R	R	R
Sassafras albidum	c	Peren.	D	D	D	D	D	S	S	S	S	S	S	S
Senecio smallii	rc	Bienn.	R	R	R	R	R	R	SF	F	R	R	R	R
Silene antirrhina	rc	Annual	D	D	D	D	D	R	SF	F	FD	D	D	D
Smilax bona-nox	rc	Peren.	D	D	D	D	D	DR	SF	F	S	S	S	S
Smilax glauca	rc	Peren.	D	D	D	D	D	D	RSF	F	S	S	S	S
Solanum carolinense	rc	Peren.	D	D	D	D	D	R	S	S	F	F	S	S
Solanum nigrum	rc	Annual	D	D	D	D	D	D	R	S	SF	F	F	D
Solidago altissima	rc	Peren.	R	R	R	R	R	R	S	S	S	S	F	F
Sorghum halepense	r	Peren.	D	D	D	D	D	R	S	S	SF	F	F	D
Specularia perfoliata	rc	Annual	D	D	D	R	R	RS	SF	F	F	D	D	D
Strophostyles umbellata	c	Peren.	D	D	D	D	D	D	R	S	S	F	F	D
Tephrosia virginiana	c	Peren.	D	D	D	D	D	S	RS	SF	F	FD	D	D
Trichostema dichotomum	rc	Annual	D	D	D	D	D	D	RS	S	F	F	D	D
Valerianella olitoria	c	Annual	D	D	D	D	R	SF	F	FD	D	D	D	D
Viola kitaibeliana	r	Annual	D	D	R	R	RS	F	F	F	D	D	D	D
Yucca smalliana	rc	Peren.	R	R	R	R	R	R	S	F	F	R	R	R

tory stages of individual species were made in 1960 and 1961. Since no major burst of reactor power occurred during seed germination time for most species, the flower and fruit stage of development was most sensitive of those exposed to radiation. For sensitive species, relatively high doses resulted in abortion when the plant was in flower or fruit. On the vegetative stage, these resulted in fasciation and shortening of stem internodes, usually with thickening of leaves and distortion of leaves and stem.

The species observed and listed in Table 4 include 32 annuals, 5 biennials, and 29 perennials. The most frequently observed tree seedlings (*Pinus taeda, Nyssa sylvatica*) were all killed. Several *Pinus taeda* seedlings present in the reactor field in 1958 died after the June, 1959 high level dose of irradiation. *Betula nigra*, observed at several places in the reactor field as small seedlings of 3- or 4-leaf size, also died.

Photographs of the control field, made in September, 1960, show few trees above the herb vegetation. Small pine and black gum seedlings, present in the fall of 1958, by 1962 had become pines 7 to 8 ft tall and black gums over 10 ft tall. In 1962 the tree stem count was still very low (1 random tree stem per 20 quardrats). Of the 66 species observed, most had tap roots except the grasses, sedges, and the perennial dominant *Monarda Punctata.* Tap roots aid in survival when these sandy soils become dry during late summer.

RADIATION EFFECTS

A general effect of irradiation was the shortening of life span of about half the species, as evidenced by earlier blooming and seed production of reactor field species compared with control field species.

High irradiation, such as the 30,000 rad dose in a 3-week period, August, 1960, resulted in stem and flower blackening that progressively moved down the stems of *Haplopappus divaricatus.* Abortion of the necrotic stem followed. Terrain-shielded Haplopappus showed little damage 100 yds away where the dose was only 8,500 rads. After irradiation ended, Haplopappus put forth new stem branches and flowers. The aerial stems of *Smilax glauca* and *Smilax bona-nox* were killed by the August, 1960, irradiation but recovered in the spring, when new aerial stems arose from underground rhizomes and from stolons partially shielded by soil. *Yucca smalliana,* another perennial, which had bloomed and produced seed in July, 1960, was killed by the August burst of radiation and did not recover in 1961, despite its long root and underground storage of food. *Campsis radicans,* a perennial vine-shrub, was killed back to the ground surface but put out new stems from dormant buds at or just below the ground surface in 1961. *Monarda punctata,* like Haplopappus, aborted some terminal flowers and produced sterile seed. Where established, Monarda increased its dominance through the production of new shoots from buds at the ground surface in 1961.

The annual, *Oenothera laciniata,* an early summer dominant, was exposed to an 8,500 rad dose during its seed formation stage in June, 1959. The following winter and spring, Oenothera germinated but was killed by water deprivation when the ground was frozen. *Trichostema dichotomum,* known to tolerate high radiation intensity in gamma field expreiments, produced flowers and seed during the August, 1960, dose of 30,000 rads and greatly increased its stem count in 1961 in open spaces.

Certain color changes occurred as a result of the August radiation burst. Leaves of *Campsis radicans, Diodia teres,* and *Cyperus strigosus* turned yellow. *Ambrosia artemisiifolia, Croton glandulosus, Geranium carolinianum,* and the grasses *Paspalum laeve* and *Digitaria sanguinalis* showed increased red pigmentation, the former at stem tips and upper leaves, and the latter at the stem base.

Erigeron pusillus, Diodia teres, and *Ambrosia artemisiifolia* continued to grow during the irradiation, but developed shortened internodes and thickened leaves.

Certain survival factors such as dormant seed, dormant buds, and soil-shielded organs were observed. The seeds of *Viola kitaibeliana, Krigia virginica, Gnaphalium purpureum,* and *Specularia perfoliata* were produced before the irradiation and lay dormant on the ground throughout the 30,000 rad burst. Dense stands of these species resulted the following spring. *Diodia teres* produced seed before and during the 30,000 rad burst. The following summer these seed produced a dense summer stand were not in competition with *Monarda punctata* and the radiation-eliminated Haplopappus. The established perennials, Monarda, Smilax, and Campsis, whose roots, stolons, and rhizomes were partially protected from radiation regenerated from these roots and from dormant buds on buried stems.

NATURAL SUCCESSION

The species which invade and characterize a field in natural succession enter the field through a natural pattern of events as a crop is planted, cultivated, and harvested. Between the time of final cultivation and harvest, natural succession begins. The invading species have seed which are able to germinate and grow at the soil temperature and with the moisture present at the time of final cultivation.

In this study, certain contrary results occurred when attempts were made to bring about natural succession in the control field by turning the soil but not cultivating a crop. This was not a problem in the reactor field. Natural succession took place with normal dominants in the control field's 250-ft-long soil moisture strip. Here corn was planted in early spring and cultivated until the first week of July, after which the land was abandoned. This procedure destroyed the early spring dominants before seed were produced. This is the normal use of such land on the farm in this region and was a parallel to that which occurred in 1956 when the last commercial crop of corn was planted throughout the field and

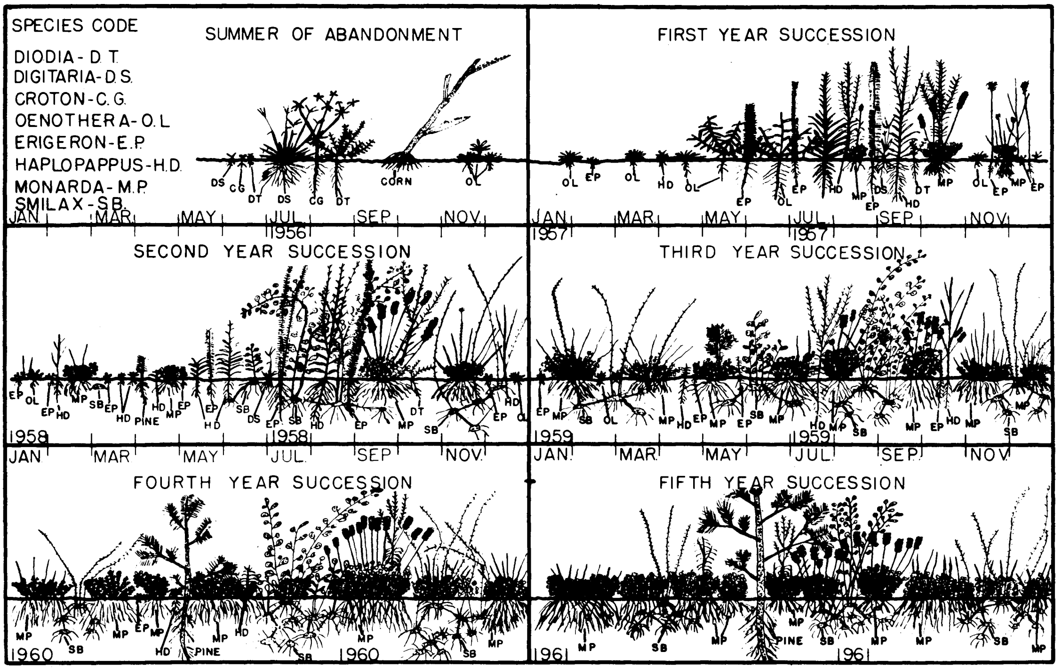

FIG. 12. The natural pattern of dominancy in floodplain succession.

the land abandoned at final July cultivation. Without spring cultivation, first year succession was dominated by *Monarda punctata,* a perennial, whose seed normally must lie on the ground through the winter for vernalization. Dominants for the summer-of-abandonment are shown in Figure 12. These appear between the corn rows when summer thunderstorms and temperatures ranging from 84 to 98 F at the soil surface prevail. *Diodia teres* and *Digitaria sanguinalis,* both early summer germinants with copious seeds, form dense stands. Diodia sends down a tap root and Digitaria spreads fibrous roots in the surface soil. Diodia grows tall with many branches to become dominant and *Digitaria* and *Croton glandulosus* are subdominants. The number of Croton stems is limited by a low natural seed productivity. There were 29 other species observed in a 110 ft row of corn in the Buncombe loamy fine sand, including *Convolvulus arvensis, Cyperus strigosus, Erigeron pusillus, Trichostema dichotomum* and *Lepidium virginicum.* Common successional species not present because they complete their life cycles in the spring and early summer were *Oenothera laciniata, Linaria canadensis, Specularia perfoliata, Plantago virginica,* and *Krigia virginica.* The perennials *Yucca smalliana, Smilax glauca, Smilax bona-nox,* and *Monarda punctata* were present, but had few stems. These perennials had regenerated new shoots from deep roots and rhizomes and stolons that were not destroyed by cultivation. By mid-October, the community was brown and by mid-November, only a few scattered stalks remained.

The winter annuals germinated with the first heavy, fall rains following frost. While most nights of late fall and winter have temperatures below freezing or just above, the days often are warm and the exposed soil warms up rapidly at the surface. *Erigeron pusillus* seed, produced in large quantity and wind-spread in late summer and fall, germinated to form numerous rosettes. *Oenothera laciniata* germinated after fall frost, and became the dominant of winter and spring, but in early summer terminated its dominancy after flowers and seeds were produced. Oenothera rossette-stems broke winter dormancy ahead of *Erigeron pusillus* which was held in stem dormancy until May 1, when day length was 14 hr. Oenothera, restricted only by temperature, began stem elongation in late March and early April. Haplopappus, another dominant (upper right, Fig. 12) of first year succession, did not germinate until spring and, therefore, grew under the already established Oenothera which spread out with many stems from a central tap root. Oenothera plants were able to reach maturity in June (Fig. 12) and hold Erigeron and Haplopappus in check, by competition for light, space, and soil nutrients. With the death of Oenothera, Erigeron and Haplopappus were inhibited no longer by this strong competition and became the tall dominants of late summer. Other spring annuals such as *Krigia virginica, Silene antirrhina, Plantago virginica, Gnaphalium purpureum, Linaria canadensis,* and *Lepidium virginicum* had also produced seeds and died, further eliminating competition for nutrients and water.

In late summer of first-year succession two distinct strata evolved. Above were Erigeron and Haplopappus, some Monarda and Smilax. Below were the vines, *Convolvulus arvensis* and *Amphicarpa* *bracteata,* the grasses Digitaria, *Paspalum laeve,* and the hair-like *Bulbostylis capillaris.* Other annuals such as *Hypericum gentianoides, Diodia teres,* and *Croton glandulosus* pushed up in this lower stratum, but were single-stemmed or much reduced in branching. Monarda formed clumps, well spread apart, which became a major factor in later years of succession. These clumps enlarged at the base by vegetatively-produced stems and developed a network root system which choked out lesser species, especially the annuals.

Two species well adapted to the Congaree fine sandy loam of the reactor field occupied important niches in first year fields. *Trichostema dichotomum,* a late summer annual, grew well in areas with open vegetation. *Campsis radicans,* a perennial with long surface runners, ran through and over other plants as a major species in shade.

In the winter beginning with the second year of succession, Monarda, by holding its leaves and spreading, reduced the number of Oenothera rosettes. Later in the spring, Haplopappus, developing from a much greater seed source dropped from the first year dominants, was able to hold Oenothera as a non-branching plant with, at most, 1 or 2 stems per individual. Thus in April of the second year of succession, the Haplopappus seedlings elongated between the Monarda clumps, and in May the Erigeron rosettes broke dominance to compete for light. The Monarda clumps quickly increased in size and number and an open type vegetation no longer existed. The non-dominant annuals were still present, but widely scattered and obscured by their taller competitors. *Smilax bona-nox* formed clumps, often 25 to 50 aerial stems, above its stolons and rhizomes, but too widely scattered at first to be considered a dominant. Thus Haplopappus dominated the early and mid-summer months, but Monarda became a strong co-dominant of late summer and fall.

In the third year of succession, the perennial shrub-vine community of Monarda-Smilax became a reality. Haplopappus was the only annual of importance, but now limited in its stem elongation, particularly in the multi-stemmed inflorescences. Monarda multiplied by clumps which met one another, and so increased in diameter that they might cover 70% of a square meter. Smilax, with its rapidly developing stems, was an aspect dominant of June and early July. In late July, as Monarda sent up floral spikes, Smilax could hardly be seen. The non-dominant species were still present, but greatly reduced in stem number.

In the fourth and fifth years of normal succession, Monarda began to eliminate Smilax by closing the remaining open spaces between the Monarda clumps and shading the new aerial stems produced by the spring buds of Smilax stolons and rhizomes. Even older Smilax stems were restricted in lower-stem leaf production by the shade. Monarda produced a root network in the top 8 in. of soil which effectively blocked other species. The stem count of Monarda ranged as high as 300/sq m.

Beginning in the second year of succession, trees began to invade these fields, when seeds were brought in by the winter floods. From their observed rate of increased stem density, it was calculated that the trees would become limiting to Monarda in the seventh or eighth year of succession. *Pinus taeda* was most frequent, but *Pinus echinata* and *Pinus virginiana* were present. Climax at Sherrill's Bottom with its well-drained soils is willow oak and hickory.

SUCCESSION IN THE IRRADIATED FIELD

The reactor field had been in corn in 1956 when the original summer of abandoment took place. In 1957 it had developed as a first year field and in 1958 it was in Erigeron-Haplopappus dominancy when the field study was begun. In 1959 when effective irradiation began, the Monarda-Smilax community was already established. A second successional series was begun in 1958 by turning an arc 220 ft long in the reactor field and a larger area in the control field. The long arc in 1959 was in first year succession when the initial burst of 8,500 rads irradiation took place during the first 2 weeks of June.

Community productivity was assessed by stem-counts of individual species and dried harvest biomass. These values were transformed into a dominance index, based on biomass, density, and frequency expressed as percentage values.

SUCCESSION DOMINATED BY ANNUALS AND PERENNIALS

Table 5 is a summary of important species observed in quadrats during the winter and spring. Quadrats of first year succession were located on an arc 600 ft from the reactor where *Oenothera laciniata* was dominant in December, 1958 (Table 5, Section A). On 3 of 10 quadrats there were dense stands of *Allium vineale* 2 to 6 in. tall. Low density Smilax shoots developed from stolons which were buried when the soil was turned. Oenothera which germinated after frost and first rains in November had a dominance equal to that in the control field.

Count data of important species obtained in late March for the reactor and control field are shown in Table 5 (Section C and D). No effective irradiation had occurred, although the reactor was first made critical in December, 1958 and made short operational bursts during March, 1959. Eleven species were present in the reactor field quadrats with *Oenothera lacinata* the dominant and *Allium vineale* subdominant. *Krigia virginica* and *Lepidium virginicum* were the most important non-dominants. In the control field there were 7 species with Oenothera as dominant. *Monarda punctata* was subdominant but this was abnormal because the soil had been turned in September after Monarda seed drop. The reactor field had been turned in August and no Monarda seed were cold vernalized as in the control field.

The results for important species of a similar reactor field sample surveyed in March, 1960 after an acute dost of 8,500 rads are given in Table 5 (Section E). The control for this experiment was sampled 1

TABLE 5. Summary of important winter and spring species listed in tables of Daniel (1965).

Section	Species name & number of species in table	Area & yr. of succes.	Table no. of Dan.	Season & yr. sample	Rel. Dens.	Total stems sq. m.	Freq. %	Biom. in g.	Total biom. sq. m.	Dom. ind.	Cumul. rad dose	Acute dose in rads
A........	*Oenothera laciniata* 4	Rad-1st	6	W-1958	72.8	84.8	100	64.0	69.3	8579	bk.grd.	
	Allium vineale 4	Rad-1st	6	W-1958	10.2	84.8	90	3.6	69.3	265	bk.grd.	
B........	*Erigeron pusillus* 5	Con-1st	7	W-1958	0.3	65.0	20	0.1	53.5	3	bk.grd.	
	Krigia virginica 5	Con-1st	7	W-1958	9.2	65.0	80	2.8	53.5	245	bk.frd.	
	Lepidium virginicum 5	Con-1st	7	W-1958	0.3	65.0	20	0.9	53.5	17	bk.grd.	
	O. laciniata 5	Con-1st	7	W-1958	54.0	65.0	100	47.5	53.5	8144	bk.grd	
C........	*Allium vineale* 11	Rad-1st	8	S-1959	26.0	126.5	90	23.3	143.7	902	100	
	E. pusillus 11	Rad-1st	8	S-1959	0.6	126.5	20	0.1	143.7	1	100	
	K. virginica 11	Rad-1st	8	S-1959	5.6	126.5	90	4.2	143.7	137	100	
	L. virginicum 11	Rad-1st	8	S-1959	4.6	126.5	80	4.8	143.7	138	100	
	O. laciniata 11	Rad-1st	8	S-1959	85.0	126.5	100	109.7	143.7	6400	100	
D........	*E. pusillus* 7	Con-1st	9	S-1960	4.0	128.1	100	0.9	32.9	139	bk.grd.	
	K. virginica 7	Con-1st	9	S 1960	4.0	128.1	70	0.7	32.9	73	bk.grd.	
	L. virginicum 7	Con-1st	9	S-1960	2.0	128.1	40	0.3	32.9	17	bk.grd.	
	Monarda punctata 7	Con 1st	9	S-1960	36.0	128.1	90	9.7	32.9	1730	bk.grd.	
	O. laciniata 7	Con-1st	9	S-1960	78.0	128.1	100	19.8	32.9	4800	bk.grd.	
E........	*K. virginica* 4	Rad-1st	10	S-1960	0.8	8.8	66	0.14	1.3	329	10,960	8,500
	L. virginicum 4	Rad-1st	10	S-1960	0.4	8.8	33	0.05	1.3	411	10,960	8,500
	O. laciniata 4	Rad-1st	10	S-1960	6.6	8.8	100	0.90	1.3	6125	10,960	8,500
F........	*E. pusillus* 5	Rad-2nd	15	W-1959	0.2	20.0	10	0.1	38.1	2	9,000	8,500
	K. virginica 5	Rad-2nd	15	W-1959	2.2	20.0	70	2.8	38.1	305	9,000	8.500
	O. laciniata 5	Rad-2nd	15	W-1959	9.9	20.0	100	27.9	38.1	5457	9,000	8,500
G........	*K. virginica* 6	Con-2nd	16	W-1959	0.7	8.7	35	0.7	29.0	52	bk.grd.	
	M. punctata 6	Con-2nd	16	W-1959	2.2	8.7	20	14.1	29.0	1103	bk.grd.	
	O. laciniata 6	Con-2nd	16	W-1959	5.2	8.7	95	11.4	29.0	3050	bl.grd.	
H........	*K. virginica* 9	Rad-2nd	17	S-1960	4.6	212.3	88	0.4	6.3	364	10,960	8,500
	O. laciniata 9	Rad-2nd	17	S-1960	76.0	212.3	100	2.9	6.3	3110	10,960	8,500
	Viola kitaibeliana 9	Rad-2nd	17	S-1960	125.1	212.3	63	1.8	6.3	1743	10,960	8,500
I........	*E. pusillus* 8	Con-2nd	18	S-1960	39.3	100.1	100	2.2	44.9	341	bk.grd.	
	K. virginica 8	Con-2nd	18	S-1960	4.4	100.1	43	0.4	44.9	24	blkgrd.	
	L. virginicum 8	Con-2nd	18	S-1960	10.3	100.1	86	1.3	44.9	135	bk.grd.	
	M. punctata 8	Con-2nd	18	S-1960	25.6	100.1	86	33.4	44.9	4137	bk.grd.	
	O. laciniata 8	Con-2nd	18	S-1960	11.4	100.1	100	1.1	44.9	122	bk.grd.	

yr earlier in the same area before effective irradiation began (Table 5, Section C). In 1959, dry weight biomass of 144.0 g/m^2 was collected but in 1960, only 1.3 g/m^2 was sampled. *Allium vineale,* present in 1959, was absent in 1960, and *Oenothera laciniata* had only 1% of the productivity of the previous year. Krigia, a non-dominant, also showed a significant decrease in productivity. Three factors are probably responsible for this change: irradiation of Oenothera during its flowering and seed production stage; low temperatures which froze the ground for 2- to 3-day periods in February and March; and the dehydration of these seedlings which had poor root and leaf development. In 1959 these rosettes observed weekly were 2 to 5 in. in diameter but in 1960, only 1 to 2 in. in diameter. Similar rosettes in the control field were not damaged by the cold.

Figure 10 shows summer and autumn dominants of first year succession for both the reactor and control fields. In reactor field sampling, counts were made on the weekend prior to the June, 1959, 8,500 rad dose. In the control field, counts were made during the reactor period of operation. Both fields were dominated by *Oenothera laciniata,* which had 10 to 12 divergent branches from a central stem and tap root. In the more mesic reactor field 4 subdominants occurred which, ranked in importance, were *Croton glandulosus, Diodia teres, Digitaria sanguinalis,* and *Campsis radicans.* In the control field, the subdominant species were *Monarda punctata, Haplopappus divaricatus,* and *Specularia perfoliata.* This experiment, repeated in 1960, showed similar dominants (Tables 6, 7).

Oenothera laciniata completed its life cycle in July, and Monarda became the dominant in the control. Haplopappus, having germinated in March and elongated its stem since mid-April, matured as a tall subdominant in autumn. In the reactor field *Diodia teres* dominated 7 quadrats while *Paspalum laeve,* with heavy seed production, dominated 3 quadrats with a high density. Both species produced more than 50 g/m^2 of dry weight biomass. *Digitaria sanguinalis* and *Trichostema dichotomum* were subdominants. Table 8 and Table 9, respecively, list autumn counts

TABLE 6. First, second, and third year reactor field summer succession.

Data in % values Radiated species	First year -60			Second year -60			Third year -61		
	Biom	Dens	Freq	Biom	Dens	Freq	Biom	Dens	Freq
Ambrosia artemisiifolia	18.4	0.8	33	2.6	2.5	80	0.2	0.4	71
Amphicarpa bracteata	6.5	3.8	78	0.4	0.5	80	0.1	0.1	43
Andropogon virginicus	—	—	—	1.4	0.5	50	0.1	0.1	29
Aster pilosus	—	—	—	2.4	0.1	20	14.0	1.0	86
Betula nigra	—	—	—	0.1	0.1	20	—	—	—
Bulbostylis capillaris	—	—	—	0.1	0.6	60	0.2	1.6	100
Campsis radicans	7.5	4.1	100	27.8	1.5	90	5.4	0.9	100
Cassia fasciculata	1.0	5.5	100	0.5	2.0	100	0.3	1.6	100
Cerastium viscosum	—	—	—	0.3	0.2	30	—	—	—
Convolvulus arvensis	0.1	0.2	22	0.1	0.1	10	—	—	—
Croton glandulosus	9.8	9.9	100	0.4	0.8	90	0.1	0.2	86
Cyperus strigosus	5.0	4.6	56	0.3	1.4	90	1.2	1.5	57
Desmodium canescens	—	—	—	0.1	0.1	20	—	—	—
Digitaria sanguinalis	7.1	28.3	100	2.6	35.6	100	1.2	16.5	100
Diodia teres	8.7	20.3	100	1.9	21.0	100	3.5	28.0	100
Erigeron pusillus	2.1	2.7	78	22.1	15.3	100	0.7	0.9	100
Gnaphalium purpureum	0.1	0.1	11	0.5	0.6	50	14.1	8.1	100
Haplopappus divaricatus	1.8	0.7	11	25.2	4.6	100	0.3	0.3	57
Hypericum gentianoides	0.1	0.2	22	0.1	0.1	20	1.1	4.2	100
Krigia virginica	0.6	0.2	22	2.8	1.8	100	14.3	7.6	100
Lepidium virginicum	0.5	0.4	33	0.4	0.4	60	1.1	1.2	43
Lespedeza repens	0.1	0.9	11	0.2	0.1	10	—	—	—
Linaria canadensis	0.1	0.4	33	0.2	0.3	60	0.8	0.6	71
Mollugo verticillata	—	—	—	—	—	—	0.1	0.1	14
Monarda punctata	0.1	0.1	11	—	—	—	—	—	—
Oenothera biennis	1.6	1.4	78	0.2	0.2	40	0.5	0.1	29
Oenothera laciniata	24.3	11.1	100	1.4	1.8	90	5.9	1.3	100
Oxalis stricta	0.3	0.1	11	0.2	0.2	30	0.1	0.2	57
Panicum spp	—	—	—	0.5	0.4	60	0.1	0.4	43
Plantago virginica	0.1	0.2	22	0.2	0.3	40	6.4	5.3	100
Senecio smallii	—	—	—	0.1	0.1	20	4.5	0.5	71
Silene antirrhina	0.9	0.1	11	—	—	—	0.1	0.1	29
Smilax bona-nox	—	—	—	0.2	0.1	10	0.9	0.1	43
Smilax glauca	0.6	0.5	56	0.4	0.2	60	4.6	0.8	71
Solanum carolinense	0.1	0.2	22	0.1	0.1	10	—	—	—
Specularia perfoliata	0.1	0.2	11	3.4	3.9	90	12.7	11.8	100
Trichostema dichotomum	3.0	3.0	100	0.9	2.8	90	1.7	3.1	100
Viloa kitaibeliana	—	—	—	—	—	—	3.6	1.4	43
Grams biomass per sq m	44.7	—	—	68.6	—	—	78.0	—	—
Stem count per sq m	—	126.6	—	—	411.6	—	—	403.3	—
Cumulative Radiation dose in rads		(14,500)			(14,500)			(44,650)	

for species in the reactor and control fields. Tables 6 through 9 give biomass productivity totals for 1960. These first year communities developed from seed of irradiated parents. For June the control produced 98.1 g/m^2 while the reactor field had 44.7 g/m^2. In October the control field had 151.2 g/m^2 and the reactor field produced 252.9 g/m^2 (aver. productivity for 10 sq m). This reversal of the principle that the reactor field would produce less than the control established in June is true for all 5 yrs of sampling (Figs. 5-9). The reversal is attributed to soil moisture limitations discussed elsewhere.

Second year succession, sampled in December, began with late fall germination of annuals, (Table 5, Sections F, G). In December, 1959, the biomass of *Oenothera laciniata* in the reactor field was 27.9 g/m^2. The seed from which these plants germinated were irradiated in development the previous June. Seven times as many Oenothera rosettes were present and biomass was twice as high in this same field in 1958 (Table 5, Section A). Oenothera dominated the control, but had only half the density as in the reactor field. *Monarda punctata,* clumped with overwintering leaves, was a strong subdominant of the control field.

March counts for the irradiated and control fields appear in (Table 5, Section H, I). In the reactor field, the dominant Oenothera had less than one-ninth of the biomass found in December. Weekly observations indicated that these rosettes were dying during the extreme cold of February and March. In the control field Monarda was dominant, having by competition reduced Oenothera to a non-dominant role. However, Oenothera surviving in the control field had the same biomass per plant present in the earlier December counts. This suggested, as did the first year field, that irradiation of seeds in development lowers the ability to resist frozen soil conditions. As a community, the control produced 7 times more biomass per unit area than the irradiated community. Productivity per unit area for first year succession was 25 times higher in the control than in the reactor field (Table 5, Sections D, E).

TABLE 7. First, second, and third year control summer succession.

Data in % values Control species	First year–60			Second year–60			Third year–61		
	Biom	Dens	Freq	Biom	Dens	Freq	Biom	Dens	Freq
Ambrosia artemisiifolia	0.7	1.5	100	1.6	10.8	80	1.0	0.7	100
Amphicarpa bracteata	—	—	—	0.1	0.1	10	—	—	—
Andropogon virginicus	—	—	—	—	—	—	0.5	0.3	25
Bulbostylis capillaris	—	—	—	0.1	0.2	10	0.1	0.1	25
Campsis radicans	0.1	0.1	13	—	—	—	—	—	—
Cassia fasciculata	0.1	0.4	50	0.1	2.9	100	0.1	0.7	100
Convolvulus arvensis	0.5	0.3	50	13.1	1.2	70	1.2	1.0	88
Croton glandulosus	0.1	2.6	100	0.1	1.6	90	0.1	0.1	13
Cyperus strigosus	—	—	—	—	—	—	0.3	0.1	25
Digitaria sanguinalis	1.1	9.0	50	0.1	0.6	60	0.1	0.7	75
Diodia teres	0.2	6.5	100	0.8	29.1	80	1.1	27.8	100
Erigeron pusillus	2.7	8.2	100	6.6	7.3	90	1.1	8.5	100
Haplopappus divaricatus	10.6	6.2	88	5.8	1.4	80	14.4	34.9	100
Hypericum gentianoides	—	—	—	0.1	0.1	10	0.1	0.1	38
Krigia virginica	2.5	1.4	75	0.4	0.3	40	1.3	3.4	100
Lepidium virginicum	2.3	1.7	75	4.3	6.4	100	0.5	2.0	100
Lespedeza procumbens	—	—	—	—	—	—	0.8	0.3	63
Linaria canadensis	0.1	0.3	13	0.1	0.1	10	—	—	—
Monarda punctata	12.9	27.2	88	18.2	13.1	100	25.2	11.8	100
Oenothera biennis	0.1	0.2	13	0.2	0.7	40	—	—	—
Oenothera laciniata	47.0	7.8	100	1.4	1.0	80	0.5	2.0	100
Plantago aristata	—	—	—	0.1	0.2	20	—	—	—
Plantago virginica	—	—	—	0.1	0.1	10	0.1	0.3	38
Prunus serotina	0.1	0.2	25	—	—	—	—	—	—
Sassafras albidum	—	—	—	—	—	—	7.9	0.2	13
Senecio smallii	—	—	—	—	—	—	0.1	0.3	13
Silene antirrhina	6.0	3.8	75	1.9	2.9	80	0.5	0.8	88
Smilax bona-nox	0.9	0.3	13	17.3	2.1	70	20.5	0.6	38
Smilax glauca	4.4	2.2	75	3.8	0.8	30	3.5	0.7	50
Solanum carolinense	0.1	0.1	13	0.3	2.5	90	0.1	0.1	13
Specularia perfoliata	7.1	19.5	88	4.6	13.8	100	0.7	2.0	88
Trichostema dichotomum	—	—	—	—	—	—	0.1	0.5	75
Yucca smalliana	—	—	—	18.9	0.8	40	19.6	0.5	63
Grams biomass per sq m	98.1	—	—	114.6	—	—	104.9	—	—
Stem count per sq m	—	221.9	—	—	191.0	—	—	518.6	—
Radiation dose in rads		background			background			background	

Second year succession data for summer and autumn, 1960, appear in Tables 6 through 9 and life history diagrams of the dominants in Figure 10. In June, 1960, (Table 6) three species shared reactor field dominance. In early April *Haplopappus divaricatus* germinated from a heavy seed crop developed after recovery from the June, 1959 irradiation burst. Stem elongation of *Campsis radicans,* and *Erigeron pusillus* began in May. These three species were co-dominants in June. *Haplopappus divaricatus* grew rapidly into a tall forb. In August, as Haplopappus flowered, the reactor began its longest burst of irradiation, releasing 30,000 rads in a 3-week period. A resultant wilt destroyed 50% of the stem of Haplopappus with its flowers. In September Haplopappus regenerated new stems and flowers, to become dominant in October. While the community was open as a result of the Haplopappus wilt, *Diodia teres* and *Digitaria sanguinalis,* with greatly increased light, developed into co-dominants, having stem branching and subsequent higher stem density than normally would occur in a shaded habitat.

Control experiments in the Emory University field have shown that an equivalent dose from Co^{60} was sufficient to inhibit *Erigeron pusillus* but not to damage it extensively. As stated before, 100 yds away, behind terrain shielding, a dose of 8,500 rads did not cause Haplopappus to wilt. In the control field *Monarda punctata,* continuing to enlarge by new stem production, was top dominant in June and October. *Smilax bona-nox,* growing from newly developing rhizomes and stolons, formed large stem clusters and became a subdominant of June and October. Haplopappus was also subdominant despite the shade of Monarda and Smilax. June productivity was 68.6 g/m^2 and 114.6 g/m^2 respectively in the reactor field and in the control. Greater productivity per unit area of the control was reversed in the fall when 290.9 g/m^2 and 220.7 g/m^2 were harvested in the reactor and control fields respectively. Thus second year succession followed first year succession when, apparently, soil moisture was the limiting factor in the control field. Stem count in the fall was 462.6 stems/m^2 in the reactor field compared with 245.9 stems/m^2 in the control. This stem increase was produced by Diodia and Digitaria when the canopy opened as Haplopappus wilted.

No further appreciable irradiation took place, although the reactor was used for short-time low level radiation tests until mid-summer, 1961. Because these

TABLE 8. First, second, and third year reactor field autumn succession.

Data in % values Radiated species	First year–60			Second year–60			Third year–61		
	Biom	Dens	Freq	Biom	Dens	Freq	Biom	Dens	Freq
Ambrosia artemisiifolia	9.2	0.4	50	3.9	1.2	100	1.1	0.7	86
Amphicarpa bracteata	6.4	2.3	50	0.1	0.1	40	0.1	0.1	28
Andropogon virginicus	—	—	—	1.8	3.3	90	0.4	0.4	86
Aster pilosus	—	—	—	0.8	0.4	70	1.2	0.3	57
Betula nigra	—	—	—	0.1	1.0	10	0.1	0.1	14
Bulbostylis capillaris	0.1	0.1	10	1.2	0.9	80	1.3	1.7	100
Campsis radicans	2.5	1.3	90	1.9	0.5	70	0.1	0.9	71
Cassia fasciculata	2.2	2.9	100	2.0	2.6	100	4.6	2.1	100
Cerastium viscosum	—	—	—	—	—	—	1.8	0.1	14
Convolvulus arvensis	—	—	—	0.1	0.2	10	0.1	0.1	14
Croton glandulosus	5.4	5.0	100	0.5	1.4	90	0.1	0.3	71
Cyperus strigosus	1.6	3.5	70	0.6	0.9	70	0.3	0.8	71
Desmodium canescens	—	—	—	0.2	0.1	20	0.1	0.1	14
Digitaria sanguinalis	9.7	32.8	100	11.1	35.2	100	11.8	35.2	100
Diodia teres	23.0	12.5	100	8.4	25.9	100	38.7	45.9	100
Erigeron pusillus	0.2	0.3	40	17.6	12.6	100	1.4	0.7	100
Fragaria virginiana	0.1	0.1	10	—	—	—	—	—	—
Geranium carolinianum	0.1	0.3	20	—	—	—	—	—	—
Gnaphalium obtusifolium	—	—	—	0.2	0.1	10	—	—	—
Gnaphalium purpureum	—	—	—	0.1	0.3	70	0.2	0.4	57
Haplopappus divaricatus	—	—	—	32.4	5.2	100	0.8	0.2	28
Hypericum gentianoides	0.1	0.1	10	1.0	0.5	86	0.1	0.1	30
Krigia virginica	0.1	0.1	10	0.1	0.2	30	—	—	—
Lepidium virginicum	0.3	0.2	40	—	—	—	0.1	0.1	14
Lespedeza procumbens	0.2	0.6	20	0.1	0.1	10	—	—	—
Lespedeza striata	0.1	0.1	10	0.1	0.1	20	—	—	—
Linaria canadensis	—	—	—	0.3	0.1	20	0.1	0.1	14
Oenothera biennis	1.6	0.2	40	—	—	—	0.6	1.0	28
Oenothera laciniata	—	—	—	0.1	0.1	10	—	—	—
Oxalis stricta	—	—	—	0.1	0.2	40	0.1	0.2	28
Panicum spp	—	—	—	1.3	1.4	40	0.1	0.1	28
Paspalum laeve	20.1	31.2	60	2.0	2.2	90	1.8	0.7	71
Sassafras albidum	0.1	0.1	10	—	—	—	—	—	—
Senecio smallii	—	—	—	0.1	0.1	10	0.3	0.1	57
Smilax bona-nox	0.4	0.1	20	5.2	1.2	80	2.5	0.8	28
Smilax glauca	2.7	3.1	100	0.7	0.4	80	2.0	1.4	100
Solanum carolinense	0.1	0.1	10	—	—	—	—	—	—
Solanum nigrum	—	—	—	0.1	0.1	10	—	—	—
Solidago altissima	—	—	—	—	—	—	0.4	0.1	14
Sorghum halepense	—	—	—	0.2	0.3	20	—	—	—
Trichostema dichotomum	14.0	2.3	90	8.2	2.9	100	27.2	7.0	100
Grams biomass per sq m	252.9	—	—	290.9	—	—	281.3	—	—
Stem count per sq m	—	208.6	—	—	462.6	—	—	369.0	—
Cumulative Radiation dose in rads		(44,500)			(44,500)			(44,650)	

reactor tests were low level, i. e., producing a dose of less than 10 rads, communities of summer, 1961, are referred to as recovery communities.

Tables 6 through 9 give third year summer and autumn counts and life histories are given in Figure 10. In June, when Monarda normally would be the dominant, three spring annuals were co-dominants. *Gnaphalium purpureum, Krigia virginica,* and *Specularia perfoliata,* not having to compete with Oenothera, Erigeron, Haplopappus, and Monarda, had become dominants. In June, with the soil at its warmest, Diodia and Digitaria germinated from the plentiful seed produced when they were sub-dominants the previous fall and un-inhibited by shade of taller forbs, became dominant in July. In August Diodia and Digitaria were joined by *Trichostema dichotomum,* another radiation-resistant annual. In September, *Diodia teres* was dominant while *Digitaria sanguinalis* and Trichostema were subdominants. Thus radiation was indirectly responsible for the greater than usual growth of these annuals, by releasing them from competition.

For third year succession in the control field (Table 7, 9), Monarda dominated in summer and autumn as it increased from seed and vegetatively. Haplopappus was subdominant in June, and in September both Haplopappus and *Smilax bona-nox* were subdominants. The control community was one of perennials, increasing their dominance, while the irradiated community had little perennial development. This is of interest, since, on an adjacent area of the reactor field Monarda was the established dominant in 1959, before irradiation became effective, and held its dominancy and increased in stem density and biomass. Monarda's failure to spread into the adjacent area was attributed to sterile seed production.

Third year productivity was higher in the control

TABLE 9. First, second, and third year control autumn succession.

Data in % values Control species	First year–60			Second year–60			Third year–61		
	Biom	Dens	Freq	Biom	Dens	Freq	Biom	Dens	Freq
Ambrosia artemisiifolia	5.8	0.5	43	0.4	1.1	80	3.2	0.3	57
Amphicarpa bracteata	0.7	1.0	28	0.1	0.2	20	0.1	0.1	29
Andropogon virginicus	—	—	—	0.1	1.5	10	0.1	0.4	29
Bulbostylis capillaris	0.1	0.4	43	1.3	8.4	90	0.1	0.9	57
Cassia fasciculata	2.0	3.5	100	0.4	1.0	70	3.0	1.7	100
Convolvulus arvensis	1.3	0.4	28	0.4	0.4	50	0.6	0.2	57
Croton glandulosus	0.2	1.5	71	0.3	1.9	90	0.1	0.2	43
Cyperus strigosus	—	—	—	0.5	0.2	30	0.1	0.2	29
Digitaria sanguinalis	5.2	11.7	43	0.5	2.7	50	0.1	0.2	29
Diodia teres	4.8	14.8	100	6.7	32.5	80	1.0	8.4	71
Erigeron pusillus	3.3	2.7	100	9.9	5.2	100	0.9	10.9	100
Haplopappus divaricatus	25.0	3.4	71	13.7	1.1	100	16.7	37.9	100
Hypericum gentianoides	—	—	—	—	—	—	0.1	0.3	43
Lepidium virginicum	0.7	0.8	86	0.2	1.5	50	0.1	0.1	14
Lespedeza procumbens	—	—	—	—	—	—	0.9	0.4	43
Mollugo verticillata	—	—	—	0.1	0.1	30	—	—	—
Monarda punctata	34.4	46.2	100	27.6	35.0	100	43.8	34.6	100
Oenothera biennis	—	—	—	0.1	0.1	10	—	—	—
Oenothera laciniata	9.1	6.3	100	—	—	—	—	—	—
Paspalum laeve	2.4	4.2	57	0.1	0.2	10	—	—	—
Pinus taeda	—	—	—	0.2	0.1	10	—	—	—
Polygonum pensylvanicum	0.7	0.1	14	—	—	—	—	—	—
Silene antirrhina	0.1	0.1	14	2.2	0.1	10	—	—	—
Smilax bona-nox	0.4	0.1	14	24.0	5.3	100	25.2	2.5	57
Smilax glauca	2.0	1.4	86	1.2	0.3	30	1.9	0.2	14
Solanum carolinense	0.1	0.1	14	0.2	0.9	90	0.1	0.2	43
Trichostema dichotomum	—	—	—	0.2	0.1	20	—	—	—
Yucca smalliana	1.3	0.7	43	9.5	0.3	30	2.0	0.2	43
Grams biomass per sq m	151.2	—	—	220.7	—	—	254.8	—	—
Stem count per sq m	—	202.9	—	—	245.9	—	—	358.7	—
Radiation dose in rads		background			background			background	

field than in the reactor field with an inverse relationship being observed in September as a result of the decline of soil moisture in July and August in the control field (Fig. 7).

IRRADIATED SUCCESSION DOMINATED BY PERENNIALS

The second series of irradiated quadrats included a community in third-year succession and the changes which occurred in that community were followed through the fourth and fifth years of succession. These plots, located in a parallel position to the series just discussed, were first counted on July 3, 1959 (Table 10). No biomass was collected in this survey. Twenty five species were listed from 10 meter-square samples. *Monarda punctata* dominated again in typical scattered clumps. *Smilax bona-nox,* the subdominant, was well established between the larger *Monarda* clumps before the 8,500 rad June dose 2 weeks earlier. The only visible damage was the browning of *Pinus taeda* needles.

During 1959, no acceptable control was available. In 1961, another third-year field was sampled (Fig. 10). Monarda was summer-dominant, with Haplopappus sub-dominant.

In the reactor field (Table 11, autumn 1959), it was found that Digitaria, in the abundant light between Monarda clumps, increased its stem number to become co-dominant with Monarda. *Smilax bona-nox* and *Smilax galuca* were subdominants.

The control for this autumn succession was sampled in September, 1961 (Fig. 10, Table 9). The Monarda clumps were increasing in size and rapidly closing the space between clumps. Monarda was dominant, with Haplopappus and *Smilax bona-nox* as subdominants. No other species had any substantial biomass.

Andropogon virginicus, the normal dominant of upland third-year fields, did not develop any importance in the reactor or control fields. Its density of 18.3% (Table 10) is misleading, since 90% of these stems were within one clump. With irradiation no other large clumps developed in the reactor field. Only a few widely scattered clumps developed in the control field which had the more limiting soil mositure.

A 5 sq m sample of fourth-year reactor field succession was harvested in late April, 1960. Among the 15 species listed, *Viola kitaibeliana,* was dominant with a density of 1045.2 stems/m^2 and 32.4 g/m^2 of biomass. Co-dominant Monarda, with much lower stem density, produced 31.6 g/m^2. *Senecio smallii,* flowering in May, was an aspect dominant. Viola did not invade the Buncombe sands of the control field.

In the control field Monarda was the top-ranking dominant throughout this fourth year of succession.

Figure 11 shows the radiation pattern and life history stages of the dominants of the fourth and fifth year. There were 39 species in the June, 1960, fourth-year sample of the reactor field. Monarda was

TABLE 10. Third, fourth, and fifth year reactor field summer succession.

	Third year–59			Fourth year–60			Fifth year–61		
Data in % values Radiated species	Biom	Dens	Freq	Biom	Dens	Freq	Biom	Dens	Freq
Allium vineale	—	0.4	30	0.1	0.1	10	—	—	—
Ambrosia artemisiifolia	—	0.5	40	1.2	1.8	90	0.1	0.8	80
Amphicarpa bracteata	—	0.3	20	0.2	0.6	50	0.1	0.5	50
Andropogon virginicus	—	18.3	80	0.6	2.5	30	1.0	0.5	30
Aster pilosus	—	—	—	4.9	0.2	20	0.1	0.1	10
Bulbostylis capillaris	—	—	—	—	—	—	0.1	0.1	10
Campsis radicans	—	8.0	100	11.6	3.1	100	9.2	2.6	90
Cassia fasciculata	—	1.3	50	0.2	0.3	100	0.2	0.4	100
Cerastium viscosum	—	0.1	10	—	—	—	—	—	—
Convolvulus arvensis	—	—	—	0.1	0.2	20	—	—	—
Croton glandulosus	—	1.3	40	0.1	1.1	80	0.1	1.2	70
Cyperus strigosus	—	0.9	60	7.3	5.9	90	0.3	1.5	60
Desmodium canescens	—	—	—	2.0	0.6	30	0.2	0.1	10
Digitaria sanguinalis	—	0.9	10	2.5	10.5	100	0.1	5.2	90
Diodia teres	—	12.5	90	0.6	11.8	100	0.3	7.7	90
Erigeron pusillus	—	1.1	40	11.2	24.0	100	0.1	0.6	60
Fragaria virginiana	—	—	—	—	—	—	0.1	0.1	10
Galax aphylla	—	—	—	—	—	—	0.1	0.1	10
Geranium carolinianum	—	—	—	0.1	0.1	20	0.1	0.1	30
Gnaphalium obtusifolium	—	—	—	0.1	0.1	10	—	—	—
Gnaphalium purpureum	—	0.3	10	0.3	1.1	40	0.1	0.4	40
Haplopappus divaricatus	—	2.1	40	0.7	1.5	80	0.1	0.3	30
Hypericum gentianoides	—	—	—	0.1	0.2	10	—	—	—
Krigia virginica	—	—	—	0.1	0.9	70	0.4	2.0	80
Lepidium virginicum	—	—	—	0.6	0.8	50	0.2	1.2	50
Lespedeza procumbens	—	—	—	0.6	0.3	10	—	—	—
Lespedeza repens	—	—	—	—	—	—	0.3	0.8	10
Lespedeza striata	—	—	—	—	—	—	0.1	0.2	20
Linaria canadensis	—	—	—	0.1	0.3	30	0.3	1.8	70
Monarda punctata	—	30.6	30	43.8	12.0	70	39.6	25.0	80
Oenothera biennis	—	—	—	0.3	0.2	20	—	—	—
Oenothera laciniata	—	0.8	30	1.0	1.4	90	0.1	0.5	40
Oxalis stricta	—	—	—	0.3	0.8	40	0.2	0.5	50
Panicum spp.	—	0.5	30	0.8	2.0	40	0.1	0.1	20
Plantago virginica	—	—	—	0.1	0.1	10	0.1	0.2	20
Pinus taeda	—	0.3	10	—	—	—	—	—	—
Prunella vulgaris	—	—	—	—	—	—	0.1	0.1	10
Rumex acetosella	—	8.0	10	1.9	5.0	10	0.3	1.7	10
Senecio smallii	—	0.5	30	1.2	0.2	20	7.8	2.3	20
Silene antirrhina	—	—	—	0.6	2.4	80	0.2	0.7	70
Smilax bona-nox	—	7.5	60	0.2	0.2	30	26.0	3.5	90
Smilax glauca	—	9.5	80	0.1	0.3	40	10.2	2.1	80
Solanum carolinense	—	0.1	10	—	—	—	—	—	—
Solanum nigrum	—	—	—	0.1	0.1	10	—	—	—
Solidago altissima	—	—	—	3.6	0.2	20	—	—	—
Specularia perfoliata	—	—	—	0.1	0.5	60	0.1	2.3	90
Trichostema dichotomum	—	1.1	40	0.4	3.2	90	2.0	29.1	100
Viola kitaibeliana	—	—	—	0.1	0.2	10	0.1	0.8	90
Yucca smalliana	—	0.4	20	—	—	—	—	—	—
Grams biomass per sq m	—	—	—	113.4	—	—	136.4	—	—
Stem count per sq m	—	69.3	—	—	264.2	—	—	265.0	—
Cumulative Radiation dose in rads		(9,000)			(14,500)			(44,500)	

dominant, *Campsis radicans* and *Erigeron pusillus* subdominants. In October there were only 29 species. During August a 30,000 rad dose of radiation had been released by the reactor. The decline in species from 39 to 29 was not the direct result of radiation, since 7 species were spring annuals which completed their life cycles during the summer. The dominant of this autumn count was Monarda, with *Campsis radicans* and *Erigeron pusillus* as subdominants. The success of Erigeron as a dominant depended on the openess of the vegetation. Monarda did not produce viable seed. Yucca was killed.

Table 12 has a summary of the fourth-year autumn control counts. Monarda was dominant, with *Smilax bona-nox* and Haplopappus as subdominants.

Summer harvest biomass of the control and reactor fields, respectively, was 141.7 and 113.4 g/m^2 (Tables 10, 12). Reactor field seed had been irradiated during their development in 1959 and seedling growth in 1960. In autumn, soil moisture of the control field was more limiting than the irradiation of the reactor field. The reactor field (in the pattern of all fall counts) produced 356.6 g/m^2 of biomass (Table 11) while the control field, limited by soil moisture, pro-

TABLE 11. Third, fourth, and fifth year reactor field autumn succession.

Data in % values Radiated species	Third year -59			Fourth year -60			Fifth year -61		
	Biom	Dens	Freq	Biom	Dens	Freq	Biom	Dens	Freq
Ambrosia artimisiifolia	—	0.5	50	2.0	0.4	50	3.0	2.5	90
Amphicarpa bracteata	—	0.1	20	0.2	0.2	40	—	—	—
Andropogon virginicus	—	12.0	80	11.7	2.1	20	—	—	—
Bulbostylis capillaris	—	0.1	20	0.2	2.1	100	—	—	—
Campsis radicans	—	0.8	90	12.6	3.0	100	6.0	4.6	100
Cassia fasciculata	—	2.0	90	0.8	2.8	100	1.4	7.5	100
Cerastium viscosum	—	0.1	10	—	—	—	—	—	—
Convolvulus arvensis	—	0.1	10	—	—	—	—	—	—
Croton glandulosus	—	0.7	50	0.2	1.3	90	0.4	2.9	100
Cyperus strigosus	—	3.8	50	0.5	1.8	50	0.2	2.8	50
Desmodium canescens	—	—	—	0.3	0.1	10	—	—	—
Digitaria sanguinalis	—	34.1	90	0.6	4.0	80	0.2	2.3	70
Diodia teres	—	5.6	100	2.4	12.5	100	2.7	11.2	90
Erigeron pusillus	—	0.9	50	9.0	10.5	100	0.7	0.3	40
Geranium carolinianum	—	—	—	0.1	0.1	20	—	—	—
Gnaphalium purpureum	—	0.2	30	0.1	0.1	10	0.1	0.3	30
Haplopappus divaricatus	—	0.6	50	2.4	0.9	60	0.1	0.1	10
Hypericum gentianoides	—	—	—	0.1	0.1	10	0.1	0.2	10
Krigia virginica	—	—	—	0.1	0.1	10	—	—	—
Lepidium virginicum	—	—	—	0.1	0.1	20	0.1	0.3	40
Lespedeza procumbens	—	0.1	10	—	—	—	—	—	—
Linaria canadensis	—	—	—	0.1	0.1	10	—	—	—
Mollugo verticillata	—	—	—	0.1	0.1	10	—	—	—
Monarda punctata	—	26.0	30	43.3	47.8	70	56.0	33.2	100
Oenothera biennis	—	—	—	—	—	—	0.1	0.2	10
Oenothera laciniata	—	0.1	10	0.1	0.1	30	—	—	—
Oxalis stricta	—	0.1	10	0.1	0.1	10	0.1	0.3	20
Panicum spp	—	3.2	50	0.1	0.1	10	—	—	—
Paspalum laeve	—	—	—	1.3	2.6	70	0.4	0.9	20
Pinus taeda	—	0.1	10	—	—	—	—	—	—
Rumex acetosella	—	0.5	20	—	—	—	—	—	—
Senecio smallii	—	0.2	30	0.2	0.3	30	0.2	0.1	20
Smilax bona-nox	—	6.9	50	3.8	0.8	50	6.0	1.5	70
Smilax glauca	—	12.7	80	3.2	1.7	80	1.0	0.6	60
Solidago altissima	—	0.1	10	—	—	—	—	—	—
Trichostema dichotomum	—	0.2	70	3.9	3.4	90	22.1	28.0	100
Yucca smalliana	—	0.2	20	—	—	—	—	—	—
Grams biomass per sq m	—	—	—	356.6	—	—	301.3	—	—
Stem count per sq m	—	181.4	—	—	336.2	—	—	151.1	—
Cumulative Radiation dose in rads		(9,000)			(44,500)			(44,650)	

duced 241.2 g/m^2 (Table 12). It was very difficult to determine whether Smilax was alive. All stems with any green color were counted, whether leaves were present or not. Since only living plants were harvested, some excess Smilax probably was harvested.

The year 1961, in which fifth-year counts were made, is considered a year of recovery since no significant irradiation occurred. (See graph of radiation, Fig. 11). Table 10 lists the species observed in the reactor field in June. Monarda with increasing size, was the major dominant, with 80% frequency, 25% density, and 39.6% of the biomass. *Smilax bona-nox,* sub-dominant, had 90% frequency and 26% of the biomass. Its stems came from shielded, underground rhizomes and stolons. Many dead aerial stems of Smilax from the previous year were now brown and decaying. *Smilax glauca* and *Campsis radicans* were important. In September, 1961, Monarda was dominant and had increased its frequency to 100% and biomass to 56%. Radiation-tolerant *Trichostema dichotomum,* an important minor species the previous year, became a strong subdominant, growing in open spaces between the Monarda clumps.

The control species for fifth-year succession are listed in Table 12. Monarda dominated both June and September counts with *Smilax bona-nox* as subdominant. June biomass productivity was 152.1 and 136.4 g/m^2, respectively, for the control and reactor fields and in September it was 256.7 and 301.3 g/m^2, respectively. This also indicated that soil moisture limited the control field productivity in late summer.

In the summer of 1962 although no sampling was carried out at Air Force Plant 67 it was observed that *Smilax bona-nox* and Monarda had invaded the arc of vegetation from which they had been kept out by sterile seed production in the previous year. Between the late summer of 1960 and 1962 no significant irradiation had occurred.

STANDING CROP

Terms such as standing crop, dry weight biomass, harvest crop, and productivity have been used inter-

TABLE 12. Summary of fourth and fifth year summer and autumn control succession.

Data in % values Species of years 4+5	4th yr. summer			5th yr. summer			4th yr. autumn			5th yr. autumn		
	Biom	Dens	Freq	Biom	Dens	Freq	Biom	Dens	Freq	Biom	Dens	Freq
Ambrosia artemisiifolia	0.3	1.4	60	0.1	0.4	50	0.2	0.2	30	0.1	0.4	40
Amphicarpa bracteata	—	—	—	0.1	0.5	60	0.1	0.1	20	—	—	—
Andropogon virginicus	—	—	—	0.1	0.1	25	—	—	—	0.1	0.7	60
Bulbostylis capillaris	0.1	0.2	10	—	—	—	0.5	3.2	80	0.1	0.9	40
Cassia fasciculata	0.1	0.4	90	0.1	0.6	88	0.1	0.3	50	1.0	1.7	100
Convolvulus arvensis	0.7	3.4	90	0.6	2.1	75	1.0	0.5	80	0.3	0.8	90
Croton glandulosus	0.1	0.2	30	0.1	0.1	38	0.1	0.8	70	0.1	0.2	40
Cyperus strigosus	—	—	—	0.3	0.6	63	0.3	0.1	10	0.1	0.2	40
Digitaria sanguinalis	0.1	2.3	70	0.1	0.2	38	0.2	1.8	80	0.1	1.1	40
Diodia teres	0.5	25.9	100	0.1	6.4	88	0.5	9.8	100	0.2	3.0	80
Erigeron pusillus	4.2	10.2	100	0.1	0.8	88	2.1	3.3	100	0.1	1.3	80
Gnaphalium purpureum	—	—	—	0.1	0.1	13	—	—	—	—	—	—
Haplopappus divaricatus	8.2	7.5	100	0.1	0.6	63	12.7	6.0	100	1.6	11.7	90
Hieracium scabrum	—	—	—	—	—	—	—	—	—	0.1	0.1	10
Hypericum gentianoides	0.1	0.1	20	0.1	0.6	38	0.1	0.1	10	0.1	2.6	30
Krigia virginica	0.2	0.6	70	0.1	0.5	63	—	—	—	—	—	—
Lepidium virginicum	0.2	0.6	70	0.1	0.5	63	0.1	0.3	50	—	—	—
Lespedeza procumbens	—	—	—	0.9	1.2	50	—	—	—	1.2	0.5	40
Lespedeza striata	—	—	—	0.1	0.1	13	—	—	—	0.1	0.1	10
Linaria canadensis	0.1	0.2	20	—	—	—	—	—	—	—	—	—
Mollugo verticillata	0.1	0.2	10	—	—	—	—	—	—	—	—	—
Monarda punctata	18.6	24.8	100	38.4	76.5	100	61.8	69.3	100	53.6	68.5	100
Oenothera biennis	0.1	0.3	30	—	—	—	—	—	—	—	—	—
Oenothera laciniata	0.2	1.5	90	0.1	0.4	75	—	—	—	—	—	—
Pinus taeda	0.1	0.1	10	2.1	0.1	13	—	—	—	—	—	—
Plantago aristata	0.1	0.1	10	—	—	—	—	—	—	—	—	—
Sassafras albidum	—	—	—	10.1	0.6	25	—	—	—	0.1	0.1	10
Silene antirrhina	2.2	7.6	100	0.1	0.4	63	—	—	—	0.1	0.1	10
Smilax bona-nox	26.2	2.9	70	35.6	3.7	63	18.5	3.2	50	21.2	3.8	60
Smilax glauca	4.2	1.7	50	4.1	0.3	13	1.7	0.4	60	1.0	0.9	50
Solanum carolinense	0.1	0.4	50	0.1	0.1	25	0.1	0.1	10	0.1	0.1	30
Solidago altissima	—	—	—	—	—	—	—	—	—	0.1	0.1	10
Specularia perfoliata	0.8	3.9	80	0.1	0.9	100	—	—	—	—	—	—
Strophostyles umbellata	—	—	—	—	—	—	—	—	—	0.4	0.5	60
Tephrosia virginiana	—	—	—	—	—	—	—	—	—	0.1	0.1	10
Trichostema dichotomum	—	—	—	0.1	1.5	75	—	—	—	0.1	0.2	30
Yucca smalliana	26.6	0.1	20	7.1	0.2	38	0.1	0.1	10	18.3	0.5	60
Grams biomass per sq m	141.7	—	—	152.1	—	—	241.2	—	—	256.7	—	—
Stem count per sq m	—	196.0	—	—	272.1	—	—	289.2	—	—	245.8	—
Radiation dose in rads	background			background			background			background		

changeably to indicate dry mass of the entire plant (maximum which can be pulled readily from the sandy soil). Previously, productivity per unit area of the control and reactor field were compared. Figures 13 and 14 compare this productivity per unit area for summer and autumn for all 5 yrs sampled in the control and reactor fields. In the control, productivity was higher than the reactor field in summer with an inverse relationship in autumn. As suggested earlier and explained in the section on environment, this inversion is explainable in terms of differential moisture stress at the two sites.

There is a second trend (Figs. 13, 14) in which the amount of biomass per unit area increases each year for the control and reactor fields. This increase was due to change from short annual to tall annual to perennial dominants and increase in stem density for the communities as a whole. Biomass was also accumulating in the perennating organs of *Monarda punctata, Yucca smalliana, Smilax spp.,* and *Campsis radicans.*

EFFECTS OF SOIL MOISTURE ON STANDING CROP

A soil moisture experiment was carried out in the control field in which a strip was plowed and planted with corn along a steep soil moisture gradient. This gradient resulted from progressively slower river currents depositing higher percentages of silt and clay particles instead of sand particles. Four times a month, from April through August, soil moisture samples were collected at five points. Highest average soil moisture determined was 36.4 ± 1.4% for *Erigeron canadensis,* an early dominant of an Aster-Andropogon community. When soil moisture averaged 9.4 ± 0.9%, *Diodia teres* and *Haplopappus divaricatus* were dominants of the summer-of-abandonment and in first year succession, respectively. Where the soil moisture averaged 16.1 ± 1.7% in first-year fields, *Erigeron pusillus* was dominant instead of Haplopappus. The lowest average mean measured was 7.8 ± 0.7%, where Diodia dominated in the summer of abandoment and Haplopappus in first-year succession. Calculations are based on N = 19 with all

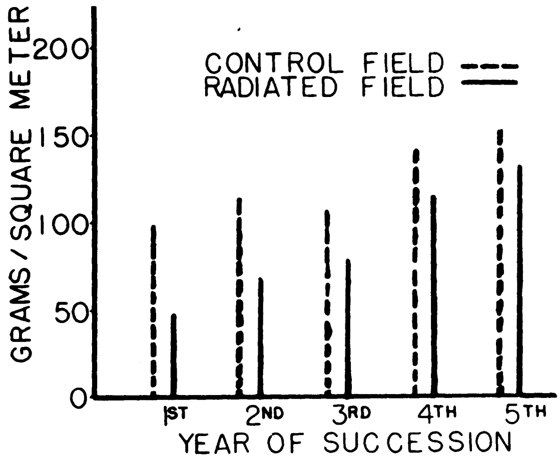

FIG. 13 The June standing crop for 5 yrs of succession. The slight decrease of the third year is related to a late May frost.

averages ± one standard error of the mean. Along the gradient, increasing soil moisture resulted in higher density of stems and greater biomass harvest.

The soil moisture strip began in Buncombe loamy fine sand and with increasing silt-clay fraction, became Congaree fine sandy loam which in turn passed into upland clay loam characteristic of this area. Soil moisture ranged as low as 3% in the dry Buncombe sand where productivity was limited when compared with that of the Conagree fine sandy loam. Mineral nutrient availability showed no variation in the Buncombe and Congaree soils as evidenced by tissue characteristics of the corn planted before abandonment. Aeration was excellent in these soils.

EFFECTS OF FERTILIZER ON STANDING CROP

Two 20-ft-square plots were turned in the control field in May, 1962. One was heavily fertilized with 10-10-10 fertilizer and then both were seeded with 2 corn seeds in each of 100 hills. After germination the corn was thinned to one plant per hill. On August 18, the unfertilized corn had a height of 3 to 4 ft, while the fertilized corn was 7 to 9 ft tall. This confirmed the rapid leaching away of mineral nutrients in these soils since natives of the area stated that both the reactor and control field had produced corn equal to the maximum to be expected when compared with the Sherrill's Bottom area where similar tall corn was observed.

Unfertilized corn throughout the control field showed nitrogen and phosphorus deficiency. This indicated a minimum nutritional mineral supply. Since the control out-produced the reactor field in June, it would appear that the reactor field, with higher available soil moisture, was also lacking in nutritional minerals.

No fertilizer was applied to either field which was sampled subsequent to abandonment in 1956. In all first-year fields sampled in 1960 and 1961, productivity was lower in succeeding years. Thus no residual fertilizer stimulus of productivity was observed.

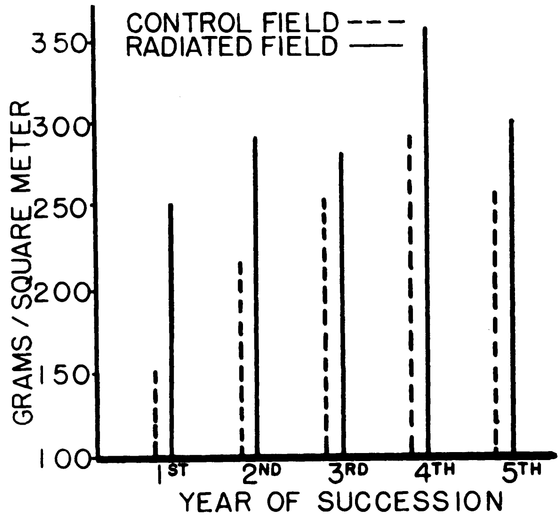

FIG. 14. The October standing crop for 5 yrs of succession. Note the reversal in productivity for June (Fig. 13) and October between the reactor and control field.

STUDIES IN CONTROLLED GAMMA IRRADIATION FIELD

Subjectively collected seeds-contained-in-soil were transported to the Emory University campus in flats in 1960 and again in 1961 after the December flood. In a productivity test, the standing crop from such seed from the irradiated field was only 64% of the standing crop produced by similar seed from the control field. This test was made in 1960 with uniform climatic and edaphic factors and with radiation doses of 8,000 to 100,000 R of gamma radiation given over 3 months. When this test was repeated in 1961, after flood but with all other conditions the same, the seeds of the irradiated field gave 88% as much standing crop as that from the control field. In the experiment without irradiation, seeds-in-soil for both fields gave higher production, but the irradiated seed productivity was only 92% of that of the control field seed. In a comparison of the 1960 and 1961 experiments in which exposures to gamma radiation were included, the higher productivity of 88% in 1961 compared with 64% in 1960 is the result of dominance in 1961 of Diodia, *Cyperus strigosus,* and *Digitaria sanguinalis.* These species withstand radiation well.

The effect of radiation at the Air Force Plant 67 site has been described thus far as an effect on plants growing at a uniform distance from the reactor where all plants in a given season received the same dose of irradiation. The effect of different levels of radiation has not been demonstrated for a given community. A 91 day experiment was carried out in the gamma field in which banded dominance developed as a result of the gradient of gamma radiation ranging from 6,900 to 90,000 R accumulated dose.

Soil containing seeds from the control field was carried to the greenhouse and used to fill flats. Randomly distributed seedlings developed when the seeds germinated. These random seedlings were transplanted in blocks (flat size) into bins at the gamma field, one being exposed to irradiation, the other a control, similar but without irradiation. The control produced 477 g/ one-half m^2. For the control *Ambrosia artemisiifolia* (dominant based on biomass productivity) produced 359 g/ one-half m^2, while subdominant *Polygonum pensylvanicum* produced 71 g/ one-half m^2. The bin in the gamma field had one end 5 ft from the source and the other end 22 ft from the source. Each bin was 1 m wide. Irradiation lasted 91 days. Table 13 lists the dominants and their productivity at each range of irradiation. Thirty nine species were observed. *Digitaria sanguinalis* dominated the band where the dose was above 40,600 R. Where dose ranged from 21,800 to 40,600 R with 0.5 sq m area, *Cassia fasciculata* and *Erigeron pusillus* inhibited Digitaria by their shade. Cassia and Erigeron could not tolerate irradiation above 40,600 R sufficiently to compete with *Digitaria.* In the center of the bin 0.5 sq m received 14,200 to 21,800 R where *Oenothera laciniata* had its greatest productivity. Oenothera in this band inhibited Erigeron, Digitaria, and Ambrosia by its shade. Ambrosia dominance was greater at the lower dose range, where it shared dominance with Erigeron and Digitaria.

TABLE 13. Productivity of dominants in a radiation gradient, Emory gamma field.

Range of radiation	Biomass of dominants in g/ 0.5 sq m		Biomass of community in g/ 0.5 sq m
6,900 r to 9,600 r	Erigeron	75	259
	Digitaria	74	
	Ambrosia	70	
	Oenothera laciniata	9	
9,600 r to 14,200 r	Ambrosia	59	223
	Digitaria	47	
	Erigeron	44	
	Oenothera laciniata	2	
14,200 r to 21,800 r	Oenothera laciniata	95	269
	Erigeron	56	
	Digitaria	50	
	Ambrosia	26	
21,800 r to 40,600 r	Oenothera laciniata	47	205
	Cassia	34	
	Erigeron	25	
	Digitaria	11	
	Ambrosia	7	
40,600 r to 90,000 r	Digitaria	127	312
	Oenothera laciniata	80	
	Ambrosia	68	
	Erigeron	22	

Digitaria productivity of 127 g/ 0.5 m^2 close to the source represented a radiation-induced stimulation where this species could tolerate the irradiation and was released from shade inhibition. Total productivity of all species 312 g/ 0.5 m^2 for this area, however, was only 64% of that of the control. Stimulation may have occurred in the center area of the bin where *Oenothera laciniata* had its greatest productivity.

COMMUNITY SIMILARITY AND SPECIES FRENQUENCY

An often used index of similarity, was used to compare closeness of frequency distribution in two communities. In the equation:

$$k = \frac{w}{a + b} (100)$$

k = index of frequency similarity, a = sum frequencies of field *a*, b = sum of frequencies of field *b*, and w = sum of the frequencies of the species found in both field *a* and *b*. Species present and common to both communities contribute to a closer relationship, while species which occur in only one community lower the index value and contribute to a more distant relationship. A value of 100 would indicate two identical communities. A zero value indicates maximum dissimilarity. This method analyzes the community as a whole rather than by dominants.

The communities present in 1959 by frequency comparison can be used to indicate the justification of the selected control for the reactor area. Large scale sampling began in the fall of 1959 in both fields. The 8,500 rad burst in June, 1959, resulted in little visible community damage, although the small pines present died during the summer. The data of Table 14 produce a fall index of frequency similarity of 88, indicating a close relationship. Of the 66 total observed species for 5 yrs of sampling, 39 were common to both fields. For this initial 1959 fall sample, 28 species were in the reactor field and 22 in the control field. Of these, 19 were common to both fields. No species occurring in only one field was a dominant, and most had low frequency values.

Third year communities analyzed above had many perennials, a few biennials and scattered annuals. First year fields have many annuals but few perennials. The index of frequency similarity for first year reactor and control fields of June, 1959 (Table 15) was 64. Seven nondominant perennials were present, including two widely scattered tree species. Annuals and biennials included 27 species. The index value of 64 indicates that first-year fields with annual dominants were less closely related than later stages of succession.

While the third year control (1959) field was dominated strongly by the perennials *Monarda* and *Smilax,* the third year (1961) reactor recovery community was dominated by low annuals. Frequency similarity index for these two communities is 67 (fall data, Tables 8, 14). A Chi square test for goodness of fit for the frequency similarity index value of 88 (obtained for third year communities unchanged by irradiation) and 67 (obtained where one community had been changed by irradiation resulted in a very significant value of 6.58 (N = 1).

Table 16 shows a progressive series of index of

TABLE 14. Species frequency of third and fourth years.

Data in % values Species list	Radiated third yr. July 59	Control third yr. Oct. 59	Radiated third yr. Sept. 59	Radiated fourth yr. June 59
Allium vineale	30	—	—	—
Ambrosia artemisiifolia	40	17	50	70
Amphicarpa bracteata	20	42	20	10
Andropogon virginicus	80	—	80	—
Aster pilosus	—	—	—	10
Bulbostylis capillaris	—	42	20	10
Campsis radicans	100	8	90	80
Cassia fasciculata	50	92	90	10
Cerastium viscosum	10	—	10	—
Convolvulus arvensis	—	42	10	—
Croton glandulosus	40	67	50	30
Cyperus strigosus	60	33	50	30
Digitaria sanguinalis	10	42	90	30
Diodia teres	90	100	100	100
Erigeron pusillus	40	17	50	40
Fragaria virginiana	—	—	—	10
Geranium carolinianum	—	—	—	20
Gnaphalium purpureum	10	17	30	—
Haplopappus divaricatus	40	8	50	90
Hypericum gentianoides	—	8	—	—
Krigia virginica	—	—	—	20
Lepidium virginicum	—	33	10	—
Lespedeza procumbens	—	—	—	10
Monarda punctata	30	100	30	20
Oenothera biennis	—	8	—	10
Oenothera laciniata	30	—	10	—
Oxalis stricta	—	—	10	20
Panicum spp.	30	—	50	40
Pinus taeda	10	—	10	—
Plantago virginica	—	—	—	10
Rumex acetosella	10	—	20	10
Senecio smallii	30	—	30	60
Silene antirrhina	—	—	—	20
Smilax bona-nox	60	75	50	60
Smilax glauca	80	42	80	100
Solanum carolinense	10	17	—	—
Solidago altissima	—	—	10	—
Specularia perfoliata	—	—	—	10
Trichostema dichotomum	40	25	70	70
Viola kitaibeliana	—	—	—	20
Yucca samlliana	20	75	20	10
Mean fequency percent	38.8± 5.3	41.4± 6.5	42.5± 5.6	34.3± 5.5
Cumulative Radiation dose in rads	9,000	bk. grnd.	9,000	500

TABLE 15. First year succession species frequency counts.

Data in % values Species list	Radiated June 59	Control June 59	Radiated Sept. 61	Control Sept. 59
Allium vineale	28	—	—	—
Ambrosia artemisiifolia	71	93	64	93
Amphicarpa bracteata	100	—	100	—
Bulbostylis capillaris	79	28	71	79
Campsis radicans	79	—	42	—
Cassia fasciculata	93	93	100	86
Cerastium viscosum	21	—	42	—
Convolvulus arvensis	—	79	14	50
Croton glandulosus	50	36	42	14
Cyperus strigosus	79	28	21	36
Digitaria sanguinalis	100	—	100	36
Diodia teres	100	79	100	79
Diospyros virginiana	—	7	—	7
Erigeron pusillus	50	7	14	7
Haplopappus divaricatus	14	14	29	21
Krigia virginica	50	28	—	—
Lactuca canadensis	7	—	—	—
Lepidium virginicum	14	14	—	14
Lespedeza procumbens	—	79	—	—
Lespedeza striata	7	—	7	—
Mollugo verticillata	—	64	—	28
Monarda punctata	—	86	—	50
Oenothera biennis	14	—	14	7
Oenothera laciniata	71	7	—	—
Plantago virginica	21	7	—	—
Polygonum pensylvanicum	—	7	—	—
Sassafras albidum	—	14	—	14
Silene antirrhina	14	57	—	—
Smilax bona-nox	100	79	64	50
Smilax glauca	50	28	71	21
Solanum carolinense	—	86	—	71
Specularia perfoliata	—	14	—	—
Trichostema dichotomum	57	50	50	42
Yucca smalliana	—	79	—	57
Mean frequency percent	52.9± 6.9	44.7± 6.4	52.5± 7.7	41.1± 6.1
Cumulative Radiation dose in rads	500	Bk. grnd.	45,650	Bk. grnd.

TABLE 16. Indices of frequency similarity for control field succession.

First year summer 1960 frequency compared with later succession.	First year autumn 1960 frequency compared with later succession.
Index value Year compared with	*Index value Year compared with*
83.........First year autumn 1960	
95.........Second year summer 1960	91.........Second year autumn 1960
85.........Third year summer 1961	85.........Third year autumn 1961
96.........Fourth year summer 1960	88.........Fourth year autumn 1960
83.........Fifth year summer 1961	75.........Fifth year autumn 1961

frequency similarity values in which first year summer control and first year fall control frequency series are compared first with one another and then with the later succession years of the same season through the fifth year. Using a Chi square goodness of fit test at the five% significance level none of these values are significantly different. This suggests that in the controls of this study species frequency changes from one succession year to the next are not significantly different.

Table 17 lists the reactor field indices of frequency similarity for first year summer succession compared as above with the fall, and same season comparisons for subsequent years. Two values are given for the third year to include 1959 data before significant radiation change and 1961 data after 44,650 rads had been released. By the Chi square method for goodness of fit, at five% probability, in no samples is a significant difference found when first year frequency is compared with frequency distribution of the later years sampled.

DISCUSSION

Diverse successional communities occurred on both reactor and control flood plains of Air Force Plant 67. This was the result of differences in available soil moisture and mineral matter where soil ranged from a xeric condition in flood ways with 95% sand to hydrarch succession where surface clay trapped hillside drainage. Gradients of soil textural composition on these flood plains result from progressively

TABLE 17. Indices of frequency similarity for reactor field succession.

First year summer 1960 frequency compared with later succession.		First year autumn 1960 frequency compared with later succession.	
Index value	*Year compared with*	*Index value*	*Year compared with*
84	First year autumn 1960		
91	Second year summer 1960	78	Second year autumn 1960
86	Third year summer 1961	80	Third year autumn 1961
75	Third year summer 1959	74	Third year autumn 1959
91	Fourth year summer 1960	89	Fourth year autumn 1960
84	Fifth year summer 1961	86	Fifth year autumn 1961

slower currents depositing greater quantities of silt and clay.

The experimental reactor field and control field 2 mi northwest were abandoned after corn in 1956. Observations began in the summer of 1958. Original fields were first sampled in 1959 as third year succession. To observe the summer of abandonment community, soil was turned in the spring and planted in corn, cropped until July 1, and then abandoned. In the late summer of 1958 areas of the reactor and control field were turned and raked to remove roots. These latter areas were observed for first, second, and third year succession in 1959, 1960, and 1961 respectively. Fourth and fifth year succession were studied in 1960 and 1961 respectively in areas where the original community had developed after abndonment in 1956. Thus it was possible to study 5 yrs of succession within a period of 3 yrs.

On the Buncombe loamy fine sand of the control field, the initial invaders in the corn rows were dominant because of their life histories and because of agricultural practices. *Diodia teres,* the dominant of initial invasion, and subdominants *Croton glandulosus* and *Digitaria sanguinalis* did not germinate until June and were still in germination in July when the farmer ceased cultivation. In the crop rows a copious seed supply was on hand in the surface soil where germination took place, yielding a community of about 30 species in the summer of abandonment. Cultivation had destroyed most of the seedlings of the later succession dominants whose seed germinate in the spring.

Following frost and fall rains, *Oenothera laciniata* germinated and was dominant through early summer, when its seed were released. *Erigeron pusillus* germinated in the fall and spring to form a rosette, but with warm weather its stem did not elongate until May 1, when daylight lasted 14 hrs. Daniel (1962) reported that *Erigeron canadensis* and *Erigeron pusillus* were retarded by photoperiod control of stem elongation which permitted Aster to dominate second year fields of upland succession and Oenothera to dominate lowland flood plains. In late summer on the flood plain *Erigeron pusillus* and *Haplopappus divaricatus* became dominant following the death of Oenothera in July. Monarda and Haplopappus seed had germinated in the spring of the second year and with more seedlings present from windborne seed, Erigeron and Haplopappus were both early and late summer dominants. Monarda became dominant in late summer of the second year, its seeds probably brought in by flood water. Most flooding occurred between November and March. Monarda is a perennial much like Andropogon in its dominance role. Where established it forms clumps by vegetative budding. Its fibrous roots tie up the plow layer as the roots of Andropogon tie up the plow layer in upland fields. In the third year of succession Monarda was the most important dominant with *Smilax bona-nox* as subdominant. The invasion of Smilax was accomplished by flood-transported stolons and rhizomes which, once established in the sandy soil, spread by vegetative budding of new rhizomes, stolons, and aerial stems. Smilax produces very little seed. In the later years of succession Monarda clumps, established from seeds, enlarge and join as a result of vegetative budding. Andropogon of upland fields as reported by Rice, Penfound & Rohrbaugh (1960) broadcast its seed within a fairly short range of about 6 ft. Thus this perennial establishes new seedlings between clumps which then form new clumps whose roots meet (Keever 1950) and Monarda is similar.

In the Conagree fine sandy loam of the reactor field, more mesic conditions were present. This enabled *Aster pilosus* and *Andropogon virginicus* to invade, although these species could not compete with the more vigorous Monarda and Haplopappus at the low available soil moisture occurring in the sandy, well-drained soil. Adjacent to the Conagree fine sandy loam a strip of plow layer soil was 70% sand but the water table was held at a level of 12 to 16 in. by underlying clay. With 6% greater soil moisture in summer on an average, typical succession as described by Keever (1950) and Oosting (1942) for Piedmont North Carolina took place. Thus the initial invader was *Digitaria sanguinalis,* followed each year in order by *Erigeron canadensis, Aster pilosus,* and *Andropogon virginicus.*

Two other succession series occurred on these flood plains. In one case sedges and rushes invaded areas where the water table was above the surface from poor drainage. In the other case in flood ways with the highest sand percentage, dominants of the Buncombe and Conagree soil were found, but the rate of dominance change was very slow. Diodia persisted 2 yrs and Haplopappus 3 yrs with Monarda not invading strongly until the fifth or sixth year.

Muller (1958) and others have shown that gradients of habitat factors may be very steep, as between a clay and a sand. Along such steep gradients the clines of genetic material are also very steep. Many species found on clay are not found on sand and others found on sand are not found on clay. In this study with fairly similar soil types in the reactor and control field, 27 species were in this category. Odum (1960) suggested that from the percent of silt and clay present which affected available soil moisture one could predict the dominance series which would occur and therefore the nature and pattern of the succession. Like Quarterman (1957) and Bard

(1952), he found a diversity and delayed invasion of dominant species. Quarterman historically reviews this diversity. Since the flood plains of Air Force Plant 67 have such diverse soil types and consequently such diverse communities, an initial decision was made to correlate these as closely as possible with their environmental conditions. In determining the identity of species and their flowering and germination conditions, greenhouse observations were set up for comparison with observations in the field. Further, the radiation stress in the reactor field changed other environmental conditions through its effect on dominancy patterns.

Two periods of radiation were inhibitory because of the relatively large radiation doses. In June, 1959, 8,500 rads were released in a 2-week period and in August, 1960, 30,000 rads in a 3-week period. A first and third year community received the 1959 irradiation, and a first year community the 1960 irradiation, while the second and fourth year communities of 1960 received irradiation from both bursts. Monarda, for example, occurred in the 1959 succession fields but was unable to invade new areas the following year when it produced sterile seed.

This was also true for *Haplopappus divaricatus,* a tall shade-producing dominant, because of the killing of its flowers and stems. The 8,500 rads of 1959 had little effect on Haplopappus but the 30,000 rads of 1960 virtually eliminated this species. In a protected area which received in 1960 only 8,500 rads, it was not visibly damaged. In the second year community, *Diodia teres* and *Trichostema dichotomum* were severly inhibited by the shade of Haplopappus. In the third year, however, these species were branched and bushy dominants which provided greatly increased cover and biomass as a result of release from this shade. *Yucca smalliana* and *Andropogon virginicus,* present in 1959, were eliminated by the 1960 dose, but persisted in protected areas where the dose did not exceed 6,000 to 8,000 rads.

The first year dominant, *Oenothera laciniata,* received the 8,500 rad burst during its seed production stage. The resulting seed produced over-wintering rosettes with short roots and distorted small leaves. These rosettes, unable to withstand frozen soil, wilted and then died in large numbers. The control plants survived.

Community productivity in June for each of the 5 succession years sampled was lower in the reactor field than in the control field. This condition was reversed in the fall, when the reactor field had a greater productivity than the control field. The reversal could be accounted for as a soil moisture effect, since the reactor field vegetation with higher available soil moisture produced a greater biomass than the control field during the hot summer months, and thus masked the radiation effects. To further experiment with this problem of reversal in biomass, a controlled experiment was carried out in which seed-in-soil from both the reactor and the control fields were layered side by side in two experiments. In one case, gamma radiation in a gradient of 6,900 to 90,000 R accumulated dose was released through the growing season. In the other case only background radiation was present. In both cases the seed from the control field had greater productivity.

Irradiation shortened life cycles by delaying germination and initiating earlier blooming. The 30,000 rad dose of 1960 resulted in various pigment breakdowns and plant deformities for the more sensitive species.

For some species, growth was increased as a result of release from competition from radiation sensitive species. Increased growth of *Trichostema dichotomum* and *Diodia teres* cited above was a result of the elimination of the tall forbs Haplopappus and Monarda and their shade. In the spring following the 1960, 30,000 rad dose, the spring annuals, *Specularia perfoliata, Gnaphalium purpureum,* and *Plantago virginicus,* showed greatly increased production, and became dominants of the early summer counts. The seeds of these species were dormant on the ground during the 30,000 rad burst of irradiation.

Woodwell & Oosting (1965) at Brookhaven National Laboratory subjected old-field succession to chronic gamma irradiation. They found species do not parallel one another in their response to the irradiation gradient, but that they tend to have humped or binomial distributions along the gradient with peaks at some optimum intensity. Gradual decreases in density occur with increasing distance from the peak in both directions. Thus 49 R/day was optimum for *Chenopodium album* and 230-320 R/day for *Erigeron canadensis* in first and second year fields respectively. *Digitaria sanguinalis* in second year fields had a peak at 49-100 R/day and a second peak at 840-1000 R/day. Our chronic gamma irradiation studies showed a peak for *Erigeron pusillus* at 155-244 R/day and for Digitaria at 444-1000 R/day. Competition with other species prevented a peak at a lower intensity for Digitaria. Daniel (1960 a, b) describes these peaks as dominance bands around the source. At the nuclear reactor site, the irradiated field received a fairly uniform dose, since its distance from the radiation source was such that the inverse square law had little effect. Thus in this area, there was a single dominance band with a very large number of stems.

Certain shielding effects from the radiation were also observed. Chappell (1963) pointed out in a study of Smilax *spp.* that if the bud is located in the ground or at the ground surface it receives less irradiation because radiation attenuation is greater in the soil than in the air. Buds on underground stolons and rhizomes survived the intense gamma-neutron radiation of August, 1960, but all aerial stems were killed. *Campsis radicans* with buds at and just below the surface on stems, *Monarda punctata* with surface buds, and similar species such as Fragaria, *Lespedeza cuneata,* and *Desmodium canescens* regenerated from rootstocks and lower stems.

The season of turning of the soil seemed most significant. When turned in spring and cultivated until July, normal succession occurred. If turned before late summer, annuals and perennials produced seed and the succession pattern began with the first year community, omitting the summer of abandonment. If turned in winter or spring the initial invaders were Haplopappus and Monarda, whose cold vernalized seed germinated, but turning killed Oenothera's rosettes. These results are similar to those of Bonck & Penfound (1945) in principle, but not in species. If these fields were not cultivated in a row crop such as corn or cotton and abandoned after hay, Smilax would be an early important species since this perennial can be controlled only by very deep plowing followed by a rake. These initial invaders as described in this paper would not necessarily occur as dominants on abandoned wheat, pasture, or hay fields.

No sampling of arthropods was undertaken. Insects, however, were much more numerous in the control field than in the reactor field. Without radiation stress and other introduced experimental variables affected by that stress both fields would be expected to have similar arthropod populations. Schnell (1963) introduced cotton rat populations into both fields before the short term August, 1960, 30,000 rad burst which decimated the irradiated rats. In the control field the rat population persisted and rabbits also invaded. Deer have bedding areas and paths in both fields but are more numerous in the control field with less human activity. Droppings of these animals serve for insect breeding. Trees not damaged by radiation provide a dense cover for hives and nests of bees and wasps. These plague the control area but are of no consequence in the reactor field. A food chain of insects, to lizards and toads, to snakes and hawks is very apparent in the control field but not obvious in the reactor area. Grasshoppers, aphids, and scale insects are not noticeably different in both fields.

The dominance index method is different from that of Odum (1960) where biomass alone determined dominance. Quarterman (1957) used the DFD index method, adding percent values of density, frequency, and total cover or basal area. DFD gives a maximum value of 300 for a pure stand. The method adapted for the present study is to multiply percent biomass times one-half the sum of percent density and percent frequency. This places equal emphasis on biomass and on its distribution in the community. Since the maximum value is 10,000, a wider separation of the dominant species is obtained.

The frequency similarity method is advantageous in that variation expressed is that of the entire community. By the dominance method of analysis, nondominant species receive little recognition. In this study, variation analyzed by frequency similarity has been on a summer to summer or autumn to autumn basis. Certain annuals occur only in one season, and excessive variation would result if summer were compared to autumn.

These flood plain studies are only part of an extensive analysis of the reactor valley ecosystem. Pedigo (1963) described effects on pines, while McGinnis (1963) studied the effects on oak-hickory forest. Cotter & McGinnis (1965) studied recovery of vegetation and other effects on the forest area. Platt (1965) extensively discussed these irradiated communities and the implications of irradiation on their recovery. Studies of subsequent successional patterns for these old-field flood plains are being continued.

SUMMARY

1. Old-field succession was studied at two locations on the xeric, sandy flood plain soils of the upper Piedmont Province of Georgia. One study area was near an air-shielded nuclear reactor and received two ecologically significant doses of gamma-neutron radiation, while the other was a control area 2 mi away.

2. Natural succession begins with the summer of abandonment, in which the annuals *Diodia teres, Digitaria sanguinalis,* and *Croton glandulosus* develop in the corn rows. In the fall, *Oenothera laciniata* germinates to a rosette stage and dominates until maturity in July. *Erigeron pusillus* and *Haplopappus divaricatus* are dominants in the late summer and fall of the first 2 yrs, while the perennial *Monarda punctata* becomes the major dominant during the fall of the second year or the spring of the third year of succession. *Smilax bona-nox,* a subdominant perennial, is associated with Monarda. Pines and hardwoods invade in the second year but do not dominate until the seventh or eighth year of succession. This particular successional pattern has not been reported previously, and further illustrates the diversity of old-field succession, as shown by other workers, which occurs on abandoned land in eastern deciduous forests.

3. Differences in the time of invasion and degree of dominance of tall annuals and perennials are due to small variations in the soil texture of the sandy flood plain soils.

4. A short term dose of 8,500 rads of gamma-neutron radiation in June on first-year communities had little observed effects, the exception being that the rosettes of *Oenothera laciniata* were stunted and unable to survive the following winter. However, this did not affect the succession pattern, for surviving plants would have been shaded out, principally by Haplopappus, the following spring.

5. A short term dose of 30,000 rads in August on first and second year annual communities resulted in an open canopy the following year by elimination of the tall forb, Haplopappus, which produced only sterile seed. This release from competition permitted *Specularia perfoliata, Gnaphalium purpureum,* and *Plantago virginica,* whose dormant seed were on the ground during the irradiation, to become early summer dominants. Other annuals, *Diodia teres, Tricho stema dichotomum,* and grasses, which received only minimal injury from this radiation stress, greatly

increased productivity during the following year and became late summer dominants.

6. Soil-shielded buds of perennials were less damaged by radiation. *Monarda punctata,* although producing sterile seed, maintained dominance by vegetative reproduction.

7. Standing crop dry weight biomass was reduced by irradiation on a per unit area basis.

8. Communities receiving a gradient of 6,900 to 90,000 R in an experimental gamma field changed from random distribution to dominance bands around the source, according to the interaction between the relative radiation sensitivity of particularly species and release from competition.

9. Life cycles for many species were shortened by radiation stress, in that germination was delayed and flower and fruit production was earlier.

10. Of the dominants, *Haplopappus divaricatus* was the most sensitive to irradiation. Its upper stems with their flowers were killed by a 30,000 rad dose, but several weeks later produced new growth with sterile flowers.

11. This study demonstrates a very close interaction between radiation stress and other environmental factors. Determination of vegetation patterns and their productivity alone would have given erroneous results, especially in that autumn productivity in the irradiated plots was consistently higher than in the controls. In this case, the interaction of very small but statistically significant differences between temperature, rainfall, and soil texture were more favorable to plant growth in the radiation field and this masked the adverse radiation effects.

12. While not a part of this study, repeated observations indicated without exception that the radiation stress on these communities did not result in an increase, but if anything, a decrease, in the insect fauna. The decrease was due at least in part to the reduction of droppings by the decimated small mammal populations.

13. These old-field communities were more resistant to radiation stress than were the oak-hickory and pine communities also studied at this facility. The old-fields illustrate as do the other communities that a broad effect of radiation stress is to set the community back to an earlier stage of development. Furthermore, the time of irradiation is of great ecological importance, and some effects may be delayed for many months.

14. A modification of a three-component method of determining dominance has been developed, in which the importance index was derived by adding percent density and frequency and multiplying one-half of this sum by percent biomass. This method has the advantage of placing equal emphasis on biomass and on its distribution within the community.

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