



The role of some environmental and man-made factors on big sagebrush (*Artemisia tridentata* Nutt.)
reinvansion
by Faisal Khidir Taha

A thesis submitted to the Graduate Faculty in partial fulfillment of the requirements for the degree of
MASTER OF SCIENCE in Range Management
Montana State University
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Abstract:

Two sagebrush (*Artemisia tridentata* Nutt.) grassland areas in southwestern (Bannack) and southcentral (Wilsall) Montana were examined for causes of reinvansion where the plant had been controlled by plowing, burning, rotocutting, and spraying in 1962. Each area was laid out in a randomized complete block design with four replications and five treatments (plow, rotocut, burn, spray, and control). A grid system of establishing compass lines across the experimental plots was used. Thirty random sample plots, one square yard each, were taken per treatment replicate. Live sagebrush plants encountered within each sample plot were aged to distinguish between plants which reinvaded and ones which survived treatment. The resultant data were subjected to analyses including regression, correlation, variance, and Duncan's Multiple Range Test to evaluate the role of different factors on reinvansion.

Examination of precipitation and sagebrush reinvansion showed that the growing season (May-August) precipitation is the most important precipitation for re-establishment. Direct and inverse relationships between reinvansion and precipitation were found on the control (check) and treated plots, respectively. This indicates that drought is advantageous to brush establishment in treated areas. It also shows that treatment may modify the direct relationship found between shrub establishment and precipitation in non-treated areas (controls).

Average minimum and absolute minimum temperatures did not show significant relationships with reinvansion. Average maximum temperature (July) showed significant negative relationship with reinvansion in control plots. No significant relationship was found on treated plots, an indication that the effect of treatment must have masked this influence.

Treatments differ in their potentiality for reinfestation. Reinvaded sagebrush was found to be influenced by the degree of success of original control and habitat associated with each treatment. The control treatment showed that the establishment of new seedlings is inversely proportional to the thickness of the sagebrush stand.

Consistently low correlation coefficients indicate that factors other than the mere existence of mature sagebrush are involved in reinvansion.

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BIG SAGEBRUSH. (ARTEMISIA TRIDENTATA NUTT.) REINVASION

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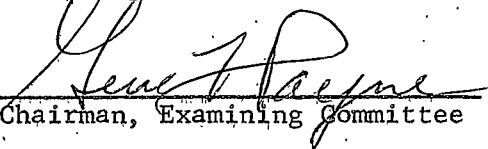
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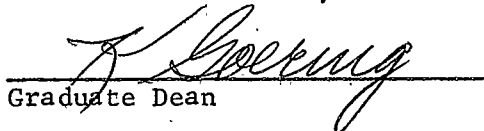
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TABLE OF CONTENTS

	Page
Vita.....	ii
Acknowledgments.....	iii
Table of Contents.....	v
List of Tables.....	viii
List of Figures.....	x
Abstract.....	xi
INTRODUCTION.....	1
REVIEW OF LITERATURE.....	2
Introduction.....	2
Stem Morphology.....	2
Stem Anatomy.....	3
Adaptation to Habitat Conditions.....	4
Reinvasion, How and Why.....	5
Residual and Wind-Borne Seed.....	6
Success of Control.....	8
Initial kill.....	8
Time of control.....	9
Treatment.....	9
Grazing.....	11
Competition Between Sagebrush Seedlings and Other Vegetation.....	12
litter.....	13
Precipitation.....	14
Physiographic Factors.....	15
DESCRIPTION OF STUDY AREAS.....	16
Bannack.....	16
Location.....	16
Climate.....	16
Soils and Topography.....	19
Vegetation.....	20
Wilsall.....	21
Location.....	21
Climate.....	21

TABLE OF CONTENTS (Continued)

	Page
Soils and Topography.....	24
Vegetation.....	24
MATERIALS AND METHODS.....	26
Field Data Procedure.....	26
Bannack.....	26
Wilsall.....	32
Field Data Collection.....	32
Laboratory Data Procedure.....	33
Methods of Analysis.....	34
RESULTS AND DISCUSSION.....	38
Extent of Reinvaded and Mature Sagebrush on Treated Areas.....	38
The Effect of Precipitation on Sagebrush Reinvasion.....	40
Bannack.....	40
Wilsall.....	44
The Effect of Temperature on Sagebrush Reinvasion.....	44
Bannack.....	44
Wilsall.....	47
The Effect of Treatments on Sagebrush Reinvasion.....	47
Bannack.....	47
Effectiveness of the Original Control.....	49
Seedling Habitat.....	54
Wilsall.....	55
Degree of Association of Unkilled Sagebrush and Reinvaded Sagebrush in Close Proximity.....	59
Bannack and Wilsall.....	59
SUMMARY AND CONCLUSIONS.....	65
APPENDIX.....	67
Appendix 1 Soil profile descriptions.....	68
1-A, Replicate 1, Bannack.....	68
1-B, Replicate 4, Bannack.....	69
1-C, Replicate 1, Wilsall.....	70
1-D, Replicate 4, Wilsall.....	71

TABLE OF CONTENTS (Continued)

	Page
Appendix 2 Plot Diagrams.....	72
2-A, Bannack.....	72
2-B, Wilsall.....	73
Appendix 3 Experimental sampling plot in one replicate....	74
Appendix 4 Map showing location of the 30 random sam- pling plots for one replication of the control treatment.....	75
Appendix 5 Temperature records at Dillon.....	76
LITERATURE CITED.....	77

LIST OF TABLES

Table		Page
I	Precipitation at Dillon Airport.	17
II	Precipitation at Lima.	17
III	Monthly temperature means at Dillon Airport.	18
IV	Monthly temperature means at Lima.	18
V	Precipitation at Wilsall 8 ENE	22
VI	Precipitation at Wilsall	22
VII	Monthly temperature means at Wilsall 8 ENE	23
VIII	Monthly temperature means at Wilsall	23
IX	The average number of sagebrush per six square yards in five treatments, Bannack, Montana	39
X	The average number of sagebrush per six square yards in five treatments at Wilsall, Montana	39
XI	Relationships between precipitation and sagebrush reinvasion in five different treatments, Bannack, Montana	41
XII	Relationships between temperature and sagebrush reinvasion in five different treatments, Bannack, Montana.	45
XIII	Analysis of variance summary: mean squares for effect of treatments on sagebrush reinvasion, Bannack, Montana.	48
XIV	The effect of treatments on sagebrush reinvasion, Bannack, Montana	48
XV	Analysis of variance summary: mean squares for effect of treatments on age classes of reinvaded sagebrush, Bannack, Montana.	50
XVI	The effect of treatments on age classes of reinvaded sagebrush, Bannack, Montana.	51

LIST OF TABLES (Continued)

Table		Page
XVII	Analysis of variance summary: mean squares for mature sagebrush in five treatments, Bannack, Montana	53
XVIII	The effect of treatments on control of mature sagebrush, Bannack, Montana.	53
XIX	Analysis of variance summary: mean squares for effect of treatments on sagebrush reinv=vasion, Wilsall, Montana	56
XX	The effect of treatments on sagebrush reinv=vasion, Wilsall, Montana	56
XXI	Analysis of variance summary: mean squares for mature sagebrush in five treatments, Wilsall, Montana	57
XXII	The effect of treatments on control of mature sagebrush, Wilsall, Montana.	57
XXIII	Analysis of variance summary: mean squares for effect of treatments on age classes of reinvaded sagebrush, Wilsall, Montana.	58
XXIV	The effect of treatments on some age classes of reinvaded sagebrush, Wilsall, Montana	60
XXV	Correlation coefficients between mature sagebrush and reinvaded sagebrush at the same subsample plot within each treatment, Bannack, Montana	61
XXVI	Correlation coefficients between mature sagebrush and reinvaded sagebrush at the same subsample plot within each treatment, Wilsall, Montana	61

LIST OF FIGURES

		Page
1	Control treatment at Bannack, Montana.	27
2	Burn treatment at Bannack, Montana	28
3	Spray treatment at Bannack, Montana.	29
4	Flow treatment at Bannack, Montana	30
5	Rotocut treatment at Bannack, Montana.	31
6	Section through a stem of 6-year-old sagebrush plant.	35
7	Section through a stem of mature sagebrush	36

ABSTRACT

Two sagebrush (Artemisia tridentata Nutt.) grassland areas in southwestern (Bannack) and southcentral (Wilsall) Montana were examined for causes of reinvasion where the plant had been controlled by plowing, burning, rotocutting, and spraying in 1962.

Each area was laid out in a randomized complete block design with four replications and five treatments (plow, rotocut, burn, spray, and control). A grid system of establishing compass lines across the experimental plots was used. Thirty random sample plots, one square yard each, were taken per treatment replicate. Live sagebrush plants encountered within each sample plot were aged to distinguish between plants which reinvaded and ones which survived treatment. The resultant data were subjected to analyses including regression, correlation, variance, and Duncan's Multiple Range Test to evaluate the role of different factors on reinvasion.

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INTRODUCTION

Big sagebrush (Artemisia tridentata Nutt.) occurs throughout the state of Montana in varying degrees of abundance. Although the plant is a valuable forage for sage grouse, mule deer and Pronghorn antelope, it is a poor range feed for livestock, which is a major industry in the state. In view of these differences in forage value of the plant to livestock and wildlife, control of sagebrush has become a point of controversy between land (livestock) managers and wildlife managers. Thus, reinvasion of sagebrush on ranges where it has been controlled is of interest to both wildlife and livestock managers.

Most of the reported work on big sagebrush control indicates that little trouble is encountered in such a program. However, most workers acknowledge the fact that the control of the species is not a permanent management feature but rather a tool that creates a holding action against brush domination similar to the holding action caused by wild fires prior to white man's entry onto the western range (Sneva, 1972). The life expectancies of control programs needs further investigation as there is still a definite lack of adequate studies on this problem.

In an attempt to enhance the understanding of big sagebrush reinvasion, two areas in southcentral and southwestern Montana which were treated in 1962 were examined. The effects of some environmental and man-made (treatments) factors were statistically analyzed to determine their role on shrub reinvasion.^{1/}

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REVIEW OF LITERATURE

Introduction

The prominent place of big sagebrush in the flora of the western portion of the United States stems from its wide distribution and abundance in this part of the country. This important shrubby complex of the Anthemideae tribe of the Compositae family extends north to south from British Columbia to Arizona and New Mexico, east to west from western North and South Dakota, Nebraska and Colorado to Washington, Oregon, and southeastern California. Although the several taxa included in the "big sagebrush" designation cover many acres of these states, its center of dominance lies in the Great Plains (Diettert, 1938).

Estimate of the area covered by sagebrush has varied from 96.5 million acres (McArdle et al., 1936) to 270 million acres (Beetle, 1960). Whatever the true extent of sagebrush may be, it is evident that it occupies vast acreages and is one of the most important constituents of the western range vegetation.

Stem Morphology

Diettert (1938) and Beetle (1960) have described the morphological features of big sagebrush. Plants vary from erect shrubs from one to two meters to occasionally tree-like form. When tree-like, it may reach three meters tall with a trunk 20 centimeters in diameter. It has two types of branching, vegetative and flowering, which differ in both external and internal structure.

Stem Anatomy

Major anatomical features of the sagebrush stem have been reviewed by Ferguson (1964). Highlights of his review are summarized in the following paragraphs.

The pith of the young stem is stellate in cross section and composed of parenchyma cells. With the initiation of secondary growth, the gaps between the bundles gradually are closed by the production of vascular tissue from the interfascicular cambium and by differentiation of some of the outer pith cells into fibers.

The primary xylem consists of annular and spiral vessels and fibers. The secondary xylem is also made of fibers and vessels and a considerable amount of tissue is produced before the end of the first year. The phloem is capped by strands of primary phloem fibers which do not reach maturity until the end of the growing season. The cortex of the stem is comparatively thin and composed of a few layers each of collenchyma and parenchyma cells. Very little cork is produced in the first year. The bark of older stems is loose and shreddy and peels off readily in narrow strips. This feature appears to be due to layers of cork and sclerenchyma which alternate with weak, thin-walled phloem cells. This may result in the removal of the bark by wind and other agencies, thus locally exposing the cambium and causing its death.

The wood is diffuse porous. Vessels are more numerous and have smaller diameters in the early wood (spring) than in the late wood

(summer). Fibers are more numerous and thicker-walled in the late wood than in the early wood. The early wood of a given season merges more or less gradually with the late wood of the same season, but the division line between the late wood of one season and the early wood of the following season ordinarily is sharp. Maturation of the vessels is rapid; that of the fibers is much slower, many of them not reaching maturity until the second year. That is why the latest annual ring has a lighter appearance than do the older rings,

Adaptation to Habitat Conditions

Big sagebrush has a highly developed system of lateral roots in the upper soil and also a deeply penetrating taproot. The former can secure the moisture which penetrates only to a small depth during light rain and thus big sagebrush is able to compete with the shallow-rooted herbaceous species which grow in association with it. By means of its taproot, a plant can obtain moisture stored at greater depths in the readily permeable soils which are preferred by this species. When the available moisture is exhausted by the end of summer due to rapid growth of plants during this period, plants lose many of their leaves and make no further growth until the following spring (Kearney et al. 1914; Robertson, 1943).

Goodwin (1956) indicated that the roots of big sagebrush possess two important characteristics which help draw more moisture. The first is the apparent ability to penetrate impervious layers of soil by slow

vertical extension. The second is the extensiveness which allows the plant to draw upon a large volume of soil.

Another character of big sagebrush to withstand drought is the small transpiring surface the plant has in proportion to its size. This helps in preventing rapid exhaustion of the available moisture (Kearney et al. 1914).

Kearney et al. (1914) have found that big sagebrush plants are rarely crowded and so competition for moisture is greatly reduced. As the average soil moisture condition departs more and more from the optimum for this species, the plants are spaced further and further apart. Moreover, individual plants are usually surrounded by a space of ground which is bare during the greater part of the year.

Reinvasion, How and Why?

Increasing the forage yield of rangeland by controlling big sagebrush with fire, chemical or mechanical means has become a common practice in the infested areas. All three methods of control have proved to be effective in killing established sagebrush. However, the main problem confronting investigators is the remarkable ability of the plant to re-establish itself after a control program. A heavy stand of young sagebrush often becomes re-established within a few years.

The reported work on reinvasion attributes this phenomenon to several factors. These factors are interrelated in one way or another. This makes the study of each influence complicated because the

investigator must attempt to keep the remaining factors as nearly constant as possible if he wants to show the significance of an individual factor. Most of the literature pertaining to reinvasion shows that these factors have been studied individually without really keeping the remaining factors constant due to obvious difficulties encountered in controlling such factors. The author in reviewing the factors influencing reinvasion was forced to follow the same approach.

Residual and Wind-Borne Seed. Many investigators have attributed the re-establishment of big sagebrush to seed either lying dormant in the soil or being carried in from surrounding areas.

Frischknecht and Plummer (1955) discounted the possibility that established sagebrush on burned areas (less than 45 acres) resulted from the seeds from prior years lying dormant in the ground and germinating the spring following burning. Their argument is based on the fact that the sagebrush seed would not have survived the hot fire which consumed all litter as well as brush. Studies of big sagebrush germination in Montana support this argument (Payne 1957). The results showed that sagebrush seeds are quite susceptible to damage by heat.

Blaisdell (1953) reported on sagebrush re-establishment after planned burning in the upper Snake River Plains. The seedlings became established during the first two years before a vigorous stand of perennial grasses and forbs developed. He attributed this reinvasion to seeds blown from surrounding areas at the time of dissemination. The

soil factor: was rejected on the basis that seedling establishment was not the highest during the improved moisture condition the year after burning. If the soil had held the dormant seed and was responsible for reinvasion, the results would have shown greatest seedling establishment during the first year.

Goodwin (1956) has found that the maximum distance of dissemination by wind is 33 meters. He concluded that such a short distance movement is unlikely to cause rapid reinvasion of large cleared areas.

Johnson (1966) and Johnson and Payne (1967) examined two sprayed and six reseeded areas in Montana to determine if adjacent untreated areas were a source of reinvasion by wind blown seed. Their results showed that sagebrush adjacent to large treated areas (more than 1000 acres) is of no practical importance as a seed source for reinvasion. This conclusion is based on their findings that wind did not move sagebrush seed to treated areas.

Mueggler (1956) investigated the seed source of reinvaded sagebrush on large burned areas (more than 1000 acres) in the upper Snake River in Idaho. He found that the wind-borne seed is restricted to within a few hundred feet of the treatment boundary and residual seed is by far the greatest source of reinvasion.

It is clear from the above studies that the size of experimental plots seems to have influenced the conclusions drawn from each study. This might have led to the contradictory results found as to seed source

of reinvaded sagebrush. It appears that large areas tend to be influenced more by residual seed whereas small areas appear to be affected more by wind-borne seed.

Success of Control. Highly successful control of big sagebrush results in fewer reinvaded plants. Investigators have reported different factors which contribute to such results. These are:

a) Initial kill. The studies of Weldon (1956) and Weldon et al. (1958) in the Big Horn Mountains of northern Wyoming have shown that areas of 75 percent or more initial kill of big sagebrush had fewer young sagebrush plants than areas of lesser initial control. Significantly fewer young plants were found in areas of 91 to 100 percent initial kill than in areas of less than 75 percent control.

Johnson (1958) reported on big sagebrush reinvasion in Wyoming. He found that the number of sagebrush seedlings was related to the percentage of plants killed by spraying with 2,4-D. As kill increased, the number of seedlings increased up to a maximum in the 40-60 percent kill classes. Few seedlings became established on unsprayed areas or those with a small percentage of kill.

Other studies have shown that plants which survived the treatments were the source for many of the reinvaded plants (Frischknecht and Bleak, 1957; Johnson, 1969; Johnson and Payne, 1968; and Sneva, 1972).

~~Rechanec et al.~~ (1954), believed that no matter what success in initial control of big sagebrush is achieved, the species will sometimes

come in again. They attributed this to seed stored in soil or on its surface or seeds blown by wind or carried in fleeces or hair of animals from areas occupied by sagebrush. However, no experimental evidence was presented.

In the Big Horn Mountains of Wyoming the abundance of big sagebrush seedlings immediately after treatment is attributed to the initial kill of the plants. The abundance thereafter is related to climatic, microclimatic, and/or soil factors (Johnson, 1969).

b) Time of control. Season of treatment has profound effect on survival and regeneration of sagebrush following control. Control after seeds start to ripen may effectively scatter and plant the sagebrush seed.

Frischknecht and Bleak (1957) in a 10-year study have found that fall treated areas, and especially mechanically treated ones, contain more sagebrush that invaded shortly after treatment than areas treated before seed maturity. Cook (1958), Johnson (1966), Fenley (1955) and Johnson and Payne (1968) have reported that fall eradication has resulted in greater germination of sagebrush the following spring than has earlier eradication. This is attributed to distribution of seed throughout the freshly prepared seedbed. The reduced competition following mechanical treatment serves to insure high rates of early brush re-establishment.

c) Treatment. Some investigators have placed more emphasis

on effect of treatment on reinvasion rather than its effect in initial kill as a major contributor to this phenomenon. Hedrick et al. (1966) examined a sagebrush range which had been sprayed and rotobated eight years previously. Sagebrush was shown to increase slightly on sprayed, poor-condition plots and greatly on the rotobated ones. Sagebrush density following treatment was 110 percent and cover 33 percent as much as before treatment in rotobated plots. By contrast, seedling establishment was almost non-existent on sprayed plots.

A study on foothill ranges of central Utah has shown that reinvasion of sagebrush was higher on plowed areas than on burned or bladed areas. Nine years after the control activities, sagebrush cover had increased 1.55 times on plowed as compared to 0.67 and 0.46 times on the railed and harrowed areas respectively, (Cook, ⁶³1958).

Control of sagebrush in Montana has demonstrated that different treatments have different reinfestation potentials. Plowed areas have the highest potentiality, followed by burned areas. Rotocut and deferred areas have the lowest potentiality; and chemically treated areas are intermediate. (Montana Agricultural Experiment Station, 1965).

Other investigators reported the findings of single treatments on reinvasion. Johnson (1969) found that sagebrush reinvasion was pronounced five years after the area had been sprayed with 2,4-D. Seventeen years later sagebrush stands were denser than before spraying.

Sneva (1972) reported on a big sagebrush sprayed area treated

twenty years previously. He observed that the re-establishment of big sagebrush was slow during the first eight years, during which herbage production increased. After this time, a declining trend in herbage production and an increase in the number of the sagebrush plants occurred. By 1971, nearly all plots (200 square feet each) had at least one sagebrush plant.

A 3-year sagebrush spraying study in Wyoming has shown that reinvasion was not apparent at the close of the study (Tabler, 1969). It is clear that the experiment was not carried long enough to be conclusive.

Grazing. The role of grazing in reinvasion has received considerable attention of many investigators. Studies have indicated that the establishment of new sagebrush stands is promoted by poor grazing management.

Two factors associated with grazing practices have been reported to contribute to brush re-establishment. The first is heavy grazing, which is held responsible for disseminating seed, weakening the grass plants, removing litter and breaking the sod, the result of which is an increase in number of reinvaded sagebrush plants (Branscomb, 1958; Frischknecht et al., 1953; Frischknecht and Plummer, 1955; Robertson and Pearse, 1945; Pickford, 1932; Cooper, 1953; Johnson, 1969; and Pechanec et al., 1954).

The second factor influencing reinvasion is time of grazing.

- Side after photo

Laycock (1967) summarized the results of a 40-year sagebrush-grazing study in Idaho. Spring rest with heavy fall grazing of the sagebrush-grass range by sheep resulted in less sagebrush and more grasses and other herbaceous species. Similar results were obtained by Craddock and Forsling (1938), Mueggler (1950) and Pechanee and Stewart (1949). The lower reinfestation when grazing is practiced in the fall has been attributed to the growth habits of the vegetation. Native grasses and forbs generally stop growth in early summer. Fall growth occurs only if it rains and is only a small part of the total year's production. On the other hand, sagebrush and most other shrubs continue to grow until late fall. Thus, fall utilization is injurious to the physiologically active sagebrush but may have little or no effect on the dormant grasses and forbs. The grasses and forbs, vigorous from spring deferment, can then easily keep out sagebrush.

Smith's (1969) study in Wyoming showed that length of deferment had no effect upon the density of sagebrush. The effects of 0, 1, 2 and 3 years of grazing deferment after sagebrush was sprayed indicated no year-to-year increase in sagebrush density.

Competition Between Sagebrush Seedlings and Other Vegetation. Sagebrush competition has received considerable attention in connection with range reseeding. Many investigators have reported that sagebrush competition must be partially or entirely eliminated to insure success of reseeded grasses. Despite these control measures of sagebrush, most

of these workers acknowledge that the possibility of the return of the brush is always there.

Frischknecht and Bleak (1957) and Cook and Lewis (1963) have shown that reinvasion of sagebrush in reseeded areas occurs within the first two years following treatment. The former found that 60 percent of the reinvading sagebrush plants were established in the second year of the brush removal. The latter reported that 71 percent of reinvading sagebrush present in the seeded grasses was established within two years of reseeded.

A study in Idaho has shown that grasses seeded concurrently with sagebrush had an initial advantage to suppress the sagebrush seedlings (Blaisdell, 1949). This conclusion agrees with Hull's (1941) results where 3-year-old grass significantly decreased vegetative growth and reproductive vigor of 3-year-old sagebrush plants.

Robertson et al. (1966) reported on the responses of grasses seeded in a sagebrush habitat in Nevada. The results of the 18-year study indicated that sod forming wheatgrasses are more effective than bunchgrass wheatgrasses in preventing sagebrush reinvasion. The average sagebrush density on plots seeded to the sod forming wheatgrasses was 1.6 shrubs per plot (9.6 ft²), with 3.6 shrubs per plot for those seeded to bunchgrass wheatgrasses.

Litter. The amount of litter present on the range has been reported to influence sagebrush re-establishment. Frischknecht and

Plummer (1955) noted that the heavy grass litter inside an enclosure (amounting to 2500 pounds per acre) made it difficult for brush seedlings to become established. Johnson (1958) attributed the absence of sagebrush seedlings on areas protected from grazing partly to the accumulation of litter in the absence of grazing. Beetle (1960) indicated that the more the litter, the more the likelihood of seedling establishment of grasses, and the less the litter, the more the likelihood of sagebrush seedling establishment. This is attributed to complex changes in factors of the habitat, including seed burial, soil moisture, soil and air temperatures and light intensities.

Precipitation. Lommason (1948) correlated a 50-year-old stand of big sagebrush in Montana with periodic weather conditions. He found that its age coincided with a period of favorable growing conditions for seedling establishment. He concluded that above-average precipitation is necessary for the development of a thick stand of sagebrush.

A study in Wyoming has shown that there are favorable and unfavorable years for sagebrush re-establishment. 1953 was found to be an excellent year for seedling establishment, whereas 1954 and 1955 were poor years. Climatic factors were held responsible though no data were given to support the conclusion (Johnson, 1958).

Johnson (1966) studied the yearly precipitation, as well as the growing season precipitation, to determine if either influenced the rate of reinvasion. The results showed that no relationship existed.

The author concluded that other unknown factors might have masked any relationships between precipitation and reinvasion.

Beetle (1960) makes the statement that "drought gives an advantage to sagebrush, but in absence of drought, the grass shoot may shade the sagebrush shoot enough to kill it". During favorable moisture conditions the grass shoot is more vigorous and quick to grow than are sagebrush shoots.

Physiographic Factors. Soil, slope and exposure have been mentioned frequently in sagebrush studies. Literature pertaining to their effect on reinvasion is rare. Most of the studies which mention the role they play on reinvasion are more or less observations rather than concrete results, and lack data to support them.

Johnson's (1966) study in Montana showed some relation between soil texture and reinvasion. Higher incidence of reinvasion occurred on silty soils as opposed to sandy and clayey soils. Exposure data indicated that reinvasion was greatest on northern exposure. This was attributed to moisture differences. Comparison of different degrees of slope revealed that no relation existed with rate of reinvasion.

DESCRIPTION OF STUDY AREAS

Bannack

Location. This study area is located approximately 3 miles northwest of Bannack, Section 19, Township 7 South, Range 11 West MPM. It is at an elevation of approximately 6150 feet above sea level. This location will be referred to as Bannack in the discussion of experimental results.

Climate. The climate is characterized by long, cold winters, short, warm summers, low rainfall and low humidity. The prevailing winds are westerly. One of the more important topographically-induced climatic effects is the wintertime warming of the "chinook" wind, occasionally producing temperature rises of 50°F or more within a few hours.

Complete records of climatological data were unavailable in the study area. Dillon and Lima were found to be the closest stations to the study area and so were selected for analyses of precipitation and temperature data. Dillon is 23 air miles east of Bannack and Lima is 40 air miles south southwest of the study area. Precipitation and mean temperature patterns of the two stations appear to be similar (Tables I, II, III and IV.) Most of the precipitation falls between April and September, with May and June the wettest months. Annual precipitation since the initiation of the study in 1963 ranged from 6.26 to 12.41 inches, with a mean of 10.39 inches, for Dillon (Table I). The long term mean precipitation is 11.34 inches. Lima records show annual

Table I. Precipitation (in inches) at Dillon Airport^{1/}.

Month	1963	1964	1965	1966	1967	1968	1969	1970	1971	9 Year Average
Jan.	.25	.05	.45	.27	.36	.28	.48	.14	.16	.27
Feb.	.14	.10	.02	.11	.16	.36	.36	.02	.32	.14
Mar.	.08	.15	.18	.17	1.07	.75	.21	.61	.13	.37
Apr.	1.35	1.00	.44	.21	1.98	.54	1.29	.54	1.32	.96
May	2.10	1.71	1.84	.77	1.43	1.58	.71	3.24	.92	.59
June	4.50	5.07	2.88	1.47	3.32	1.72	3.38	1.93	1.83	2.90
July	.30	.35	.96	.37	1.36	.17	1.32	2.37	.32	.84
Aug.	.64	1.29	2.36	.64	.24	1.20	1.03	.47	1.35	1.02
Sept.	.99	.14	.57	1.28	.46	1.59	1.13	1.42	1.06	.96
Oct.	.44	.38	.35	.18	1.47	.33	.48	.15	.35	.46
Nov.	.32	.87	.36	.56	.43	1.20	.71	.48	.37	.59
Dec.	.43	.40	.24	.23	.13	.51	.18	.28	.23	.29
Annual	11.52	11.51	10.65	6.26	12.41	9.88	11.28	11.65	8.36	10.39

^{1/} U.S. Department of Commerce, Weather Bureau, 1963-71.

Table II. Precipitation (in inches) at Lima^{1/}.

Month	1963	1964	1965	1966	1967	1968	1969	1970	1971	9 Year Average
Jan.	.19	.04	.02	.38	.19	.55	.32	.22	.56	.27
Feb.	.18	.10	.05	.09	.32	.02	.60	.02	.66	.23
Mar.	.34	.16	.12	.37	1.11	.69	.39	.88	.45	.50
Apr.	1.97	1.08	.43	1.01	1.77	.60	1.41	1.36	2.20	1.31
May	1.93	1.62	2.29	.66	.83	1.55	.64	2.20	1.83	1.51
June	4.20	4.45	2.78	1.33	3.40	2.91	3.35	1.47	2.16	2.89
July	.03	.95	1.88	.21	1.48	.13	2.68	2.59	.45	.93
Aug.	1.49	1.38	1.38	1.75	.46	2.77	1.16	.83	1.53	1.42
Sept.	2.33	.30	.91	.96	.32	1.95	1.20	.95	2.33	1.25
Oct.	.82	.91	.38	.23	.87	.15	.42	.16	2.13	.67
Nov.	.15	.34	.30	.22	1.21	.67	.34	.38	.80	.49
Dec.	.43	.69	.16	.25	.37	.37	.17	.59	.68	.41
Annual	14.06	12.02	10.70	7.46	12.33	12.36	12.68	11.56	15.78	11.88

^{1/} U.S. Department of Commerce, Weather Bureau, 1963-71.

Table III. Monthly temperature means ($^{\circ}\text{F}$) at Dillon Airport^{1/}.

Month	1963	1964	1965	1966	1967	1968	1969	1970	1971
Jan.	12.6	22.5	27.8	23.8	27.4	19.4	13.4	23.3	23.6
Feb.	36.0	24.8	28.3	25.3	30.1	29.4	18.3	32.8	26.7
Mar.	34.5	27.9	23.5	33.1	30.6	36.2	23.2	29.4	30.9
Apr.	39.0	39.4	43.4	40.8	35.9	38.2	44.2	35.5	40.4
May	52.0	50.6	46.6	55.7	49.8	47.6	54.3	51.2	51.4
June	56.5	56.4	57.6	58.6	57.4	57.5	55.8	61.7	58.5
July	65.3	68.6	65.6	69.8	68.3	67.4	66.7	68.4	66.0
Aug.	65.9	61.5	63.7	64.6	67.8	61.3	68.3	68.8	70.1
Sept.	60.7	52.7	45.1	59.8	60.0	53.9	57.5	50.4	50.0
Oct.	50.2	46.9	50.4	45.0	45.4	45.0	36.9	40.0	40.6
Nov.	34.1	30.0	37.4	33.6	32.2	30.1	34.9	32.9	32.8
Dec.	21.9	23.5	25.9	24.4	17.8	18.0	25.8	21.0	17.5

^{1/} U.S. Department of Commerce, Weather Bureau, 1963-71.

Table IV. Monthly temperature means ($^{\circ}\text{F}$) at Lima^{1/}.

Month	1963	1964	1965	1966	1967	1968	1969	1970	1971
Jan.	9.2	15.9	22.6	17.4	23.6	16.4	19.1	21.6	18.1
Feb.	30.8	16.0	21.0	18.1	24.4	22.9	18.9	23.5	22.2
Mar.	30.5	19.9	21.4	28.4	30.3	31.3	21.3	26.5	25.7
Apr.	36.1	35.7	40.1	36.8	34.4	34.9	41.3	31.8	37.5
May	47.4	46.2	42.9	51.6	46.6	43.3	50.6	47.7	47.4
June	52.7	52.8	52.7	54.8	53.4	53.6	52.3	56.7	55.0
July	60.7	63.8	60.1	65.0	63.4	62.2	62.2	63.3	61.0
Aug.	61.6	59.0	M	60.2	63.2	63.8	63.8	65.0	64.8
Sept.	56.5	50.0	43.5	56.3	56.6	55.4	55.4	48.3	48.1
Oct.	M	44.5	46.2	41.6	42.5	41.2	36.2	37.9	39.0
Nov.	30.9	28.6	33.5	31.7	30.0	26.1	31.8	29.6	27.8
Dec.	19.0	20.2	21.0	14.0	13.0	16.4	24.7	17.8	15.7

^{1/} U.S. Department of Commerce, Weather Bureau, 1963-71.

precipitation ranging from 7.46 to 14.78 inches in the 1963-71 period, with a mean of 11.88 inches (Table II). The long term average of precipitation is 10.50 inches.

Average monthly temperatures for both stations are shown in Tables III and IV. Thirty-year climatological data of Dillon show an average of 95 days of freeze-free season. An average season of 143 days between 28°F occurrences (May 9 and September 29) is reported. This 143-day period is enough time for maturation of grasses, hays and grains (Weather Bureau, 1964).

Soils and Topography. The soils at the Bannack site have not been classified as yet. Description of the soil profile of the study area (Appendix 1, A and B) reveals that these soils resemble the Avalanche series of the Borollic Calciorthids subgroup, order Aridisol in the new soil taxonomy system (National Cooperative Soil Survey, USA, 1971).

These soils were formerly classified in the Calcisol great soil group.

The Avalanche series soils are generally formed of loess deposits. They have a light brownish-gray Ap horizon and a light gray mottled C1ca horizon. The texture is loam or silt loam to clay loam. Some fine gravel may occur throughout the soil but it becomes more distinct 15 inches below the surface. The lime layer occurs 15 inches below the surface which indicates low leaching as a result of low precipitation (11 to 14 inches). They are well drained and permeability is moderate to slow (National Cooperative Soil Survey USA, 1971).

It is clear from the above description of the Avalanche series and Bannack soils (Appendix 1, A and B) that the latter have a somewhat coarser texture. However, none of the other series fit the description of the soils at this site better than the Avalanche.

Vegetation. The area can be thought of primarily as a big sagebrush-bluebunch wheatgrass (Agropyron spicatum) type. Cover of big sagebrush in the study area, as determined by the line intercept method, is 13 percent (Payne, 1971). Other woody species present are fringed sagewort (Artemisia frigida), winterfat (Eurotia lanata) and broom snakeweed (Gutierrezia sarothrae).

The understory vegetation is dominated by perennial grasses, sedges, and forbs with almost no annual grasses. Percent composition by basal intercept shows that bluebunch wheatgrass is the most conspicuous of the perennial grasses (87 percent); sandberg bluegrass (Poa secunda) is second with 9 percent and western wheatgrass (Agropyron smithii) is third with 3 percent (Payne, 1971). Other grasses and sedges which occur include Siberian wheatgrass (Agropyron sibericum), plains reedgrass (Calamagrostis montanensis), needleleaf sedge (Carex eleocharis), Indian ricegrass (Oryzopsis hymenoides) and cheatgrass brome (Bromus tectorum). Forbs of importance are cragaster (Aster scopulorum), Canadian aster (Aster canadensis), fernleaf fleabane (Erigeron compositus), dandelion (Taraxacum officinale), townsendia (Townsendia hookeri) and American vetch (Vicia americana).

Wilsall

Location. This study area is situated southwest of Wilsall, Section 32, Township 3 North, Range 8 East MPM. The elevation at the area is approximately 5400 feet above sea level. This location will be referred to as Wilsall in the discussion of results.

Climate. The climate in the Wilsall area is similar to that of the Bannack area. It is semi-arid with long, cold winters and short summers. However, the effects of the "chinook" wind are more pronounced at Wilsall than at Bannack as it is drier and warmer.

Climatological stations near the study area are at Wilsall and Wilsall 8 ENE. The Wilsall station is 6 air miles northeast of the study area and Wilsall 8 ENE is 14 air miles east northeast. The patterns of precipitation and mean temperatures of the two stations appear to be similar (Tables V, VI, VII and VIII). Most of the precipitation comes during the warmer half of the year. During the period of the study (1963-1971), Wilsall annual precipitation ranged from a high of 18.93 inches in 1963 to 12.49 inches for 1966 with a mean of 15.36 inches (Table VI). Precipitation records for 1969-71 were not available

Wilsall 8 ENE annual precipitation ranged between 15.49 to 24.34 inches with a mean of 20.66 inches (Table V) for the same period. Long term means of precipitation for the two stations were not available,

Average monthly temperatures for the 9-year period of the study in both stations are shown in Tables VII and VIII. The average freeze-free

Table V. Precipitation (in inches) at Wilsall 8 ENE^{1/},

Month	1963	1964	1965	1966	1967	1968	1969	1970	1971	9 Year Average
Jan.	1.45	.69	1.66	.69	1.03	1.53		1.16	.88	1.01
Feb.	.36	.90	.44	.64	.54	.78	.14	.94	.94	.64
Mar.	.94	1.80	.85	1.26	2.65	2.03	.37	1.46	1.18	1.39
Apr.	1.81	1.59	2.79	1.14	1.11	1.80	.97	1.54	2.05	1.65
May	4.09	3.57	2.99	2.25	2.70	3.98		4.30	1.98	3.23
June	4.18	4.03	3.48	2.19	5.04	5.22	7.88	1.30	3.28	4.07
July	1.01	.57	1.68	1.44	1.65	1.13	1.55	2.19	.12	1.43
Aug.	.31	4.17	2.83	1.08	.82	2.67	1.74	.72	.61	1.66
Sept.	3.20	T	4.42	1.07	1.39	2.71	.49	2.86	2.15	2.03
Oct.	1.17	1.11	.13	1.54	3.05	1.29	2.55	1.94	.94	1.53
Nov.	.73	1.37	.84	1.31	.87	1.11	.35	.89	.69	.90
Dec.	1.70	1.19	.72	.88	1.52	.89	1.02	.79	1.19	1.10
Annual	20.95	20.99	22.83	15.49	22.37	24.34		20.09	16.01	20.66

^{1/} U.S. Department of Commerce, Weather Bureau, 1963-71,

Table VI. Precipitation (in inches) at Wilsall^{1/}.

Month	1963	1964	1965	1966	1967	1968	1969	1970	1971	4 Year ^{2/} Average
Jan.	1.18	.53	.70	.36		.68				1.17
Feb.	.13	.42	.09	.23	.53					.22
Mar.	.70	.88	.76	.81	2.68	1.22				.79
Apr.	1.03	.77	2.41	.89		.50				1.27
May	4.50	2.38	2.02	1.59	3.62	2.83				2.62
June	4.14	3.03	2.24	1.74	4.24					2.23
July	1.03	1.05	1.44	1.03	1.27	1.35				1.14
Aug.	1.30	2.54	2.15	.88	.46					1.72
Sept.	2.24	.05	2.37	1.78	1.28	4.23				1.61
Oct.	.75	.69	.09	1.57						.78
Nov.	.56	.86	.86	1.41	3.40					1.14
Dec.	1.37	.95	.20	.20	.63					.67
Annual	18.93	14.15	15.33	12.49						15.36

^{1/} U.S. Department of Commerce, Weather Bureau, 1963-71,

^{2/} Years 1963-66.

Table VII. Monthly temperature means (°F) at Wilsall 8 ENE^{1/}.

Month	1963	1964	1965	1966	1967	1968	1969	1970	1971
Jan.	12.7	23.1	27.6	22.8	26.6	20.9	25.5	21.0	21.0
Feb.	31.1	23.7	23.7	24.3	28.2	28.7	23.9	30.0	25.0
Mar.	31.0	24.3	18.8	31.8	26.6	33.9	25.3	25.6	27.4
Apr.	37.1	36.0	38.6	35.8	34.9	34.3	42.7	31.2	37.4
May	47.7	47.4	44.0	49.7	46.3	44.0	50.0	47.9	48.1
June	54.0	53.6	53.4	53.0	53.9	53.4	52.1	58.1	55.0
July	60.9	64.6	60.6	65.2	63.5	61.7	61.5	64.0	59.5
Aug.	61.2	57.5	58.8	59.2	62.7	58.3	64.4	65.5	70.1
Sept.	48.3	48.8	41.2	57.0	56.8	50.4	55.3	48.4	49.4
Oct.	48.3	45.6	47.6	42.3	43.9	55.6	34.3	39.1	40.5
Nov.	34.2	31.0	35.3	32.6	31.7	30.6	35.7	30.9	32.4
Dec.	25.4	22.2	27.3	26.3	17.9	13.0	27.9	23.0	19.3

^{1/} U.S. Department of Commerce, Weather Bureau, 1963-71.

Table VIII. Monthly temperature means (°F) at Wilsall^{1/}.

Month	1963	1964	1965	1966	1967	1968	1969	1970	1971
Jan.	11.3	20.6	26.0	22.3	M	16.1	43.9		
Feb.	31.1	21.9	26.3	23.5	28.2	M	M		
Mar.	31.7	23.1	19.1	32.2	26.1	M			
Apr.	38.0	37.8	40.1	36.6	35.1	36.5			
May	48.4	48.4	45.6	51.2	47.3	45.0			
June	55.1	54.8	53.7	55.2	M	M			
July	63.1	66.1	62.5	66.9	64.6	63.7			
Aug.	62.8	60.9	60.4	M	63.6	59.3			
Sept.	57.2	50.0	43.7	57.5	55.8	52.6			
Oct.	47.4	43.9	M	M	M	58.7			
Nov.	32.8	M	32.0	30.3	30.2	30.6			
Dec.	22.4	19.2	23.3	22.2	M				

^{1/} U.S. Department of Commerce, Weather Bureau 1963-71.

season (32°F) runs from June 1 to about September 15, a total of approximately 106 days. This 106-day period is enough for the growth of several crop varieties.

Soils and Topography. The soils at this site also were not classified. A soil profile description of the study area (Appendix 1, C and D) indicates that they resemble the Darret series of the Typic Argiborolls subgroup, order Mollisol in the new soil taxonomic system (National Cooperative Soil Survey USA, 1971). These soils were formerly classified as chestnut soils.

The Darret series are of nearly level to sloping and hilly upland, soft bedrock plains of usually reddish-colored, calcareous, soft shale and sandstone. The A1 horizon has a hue of 2.5 YR, value of 5 or 4 dry and chroma of 2 or 3. The B2t Horizon has about 35 to 40 percent clay. Depth to sandstone or shale is 20 to 40 inches. Segregated lime occurs in thin films of CaCO₃ on faces of soil peds or coating shale or sandstone fragments. The bedrock is reddish-colored soft sandstone and shale. The texture is silty clay loam or silty clay to clay loam. They are well drained, slow to medium runoff, and medium in permeability (National Cooperative Soil Survey USA, 1971).

Vegetation. This is a sagebrush grassland with big sagebrush, western wheatgrass and Canada bluegrass (Poa compressa) as dominant species. An estimate of big sagebrush cover as determined by line intercept method is 6 percent (Payne, 1971). Other woody species found

are fringed sagewort and Douglas rabbitbrush (Chrysothamnus viscidiflorus). Important perennial grasses are Canada bluegrass and western wheatgrass, with 44 and 34 percent composition, respectively. Other grasses and sedges which occur include thickspike wheatgrass (Agropyron dasystachyum), crested wheatgrass (Agropyron cristatum), prairie sandreed (Calamovilfa longifolia), plains sandreed (Calamagrostis montanensis), prairie junegrass (Koeleria cristata), timothy (Phleum pratense), sandberg bluegrass, needleandthread (Stipa comata), green needlegrass (Stipa viridula) and cheatgrass brome. Forbs of importance, in approximate order of their abundance, are dandelion, western yarrow (Achillea lanulosa), yellow sweetclover (Melilotus officinalis), salsify (Tragopogon dubius), and pale alyssum (Alyssum alyssoides).

MATERIALS AND METHODS

The Bannack and Wilsall experimental areas were treated for control of sagebrush in 1962. The treatments were plowing, burning, spraying and rotocutting. A fifth plot was left undisturbed (control) for comparisons. Each area was laid out in a randomized complete block with four replications and five treatments (Appendix 2, A and B). Photographs of the sagebrush plots at Bannack nine years after treatment application are shown in Figures 1, 2, 3, 4, and 5.

Field Data Procedure

Bannack. The experimental plots differed slightly in size among the four replications. They were 150 x 90 feet in replications 1 and 2 and 150 x 103 feet in replications 3 and 4 (Appendix 2-A). This difference in width of experimental plots resulted from the construction of a road between replicates 2 and 3 after establishment of the main plots.

Twelve feet from each side of the experimental plots of replicates 1 and 2 and 18½ and 12 feet from the width and length, respectively, of the experimental plots in replicates 3 and 4 were discarded in sampling to allow for any edge effect. This reduced the usable experimental plot in every replicate to an area 126 feet long and 66 feet wide.

A grid system of establishing compass lines across the experimental plots was used. Pre-stretched strings 126 feet long and marked at every 6 feet, making 21 divisions, were run across each plot. The strings were located 6 feet apart and thus there were 11 strings across each plot since the plot width was 66 feet. Eleven flags were staked on both



Figure 1. Control treatment at Bannack, Montana. A general view of the experimental plot 9 years after treatment (upper). A close-up view of plants found within one square yard. (lower). Note the presence of many mature sagebrush.



Figure 2. Burn treatment at Bannack, Montana. A general view of the experimental plot 9 years after treatment (upper). A close-up view of plants found within one square yard (lower). Note the non-existence of live sagebrush plants.



Figure 3. Spray treatment at Bannack, Montana. A general view of the experimental plot 9 years after treatment (upper). A close-up view of plants found within one square yard (lower).



Figure 4. Plow treatment at Bannack, Montana. A general view of the experimental plot 9 years after treatment (upper). A close-up view of plants found within one square yard (lower). Note the presence of the high number of young sagebrush.

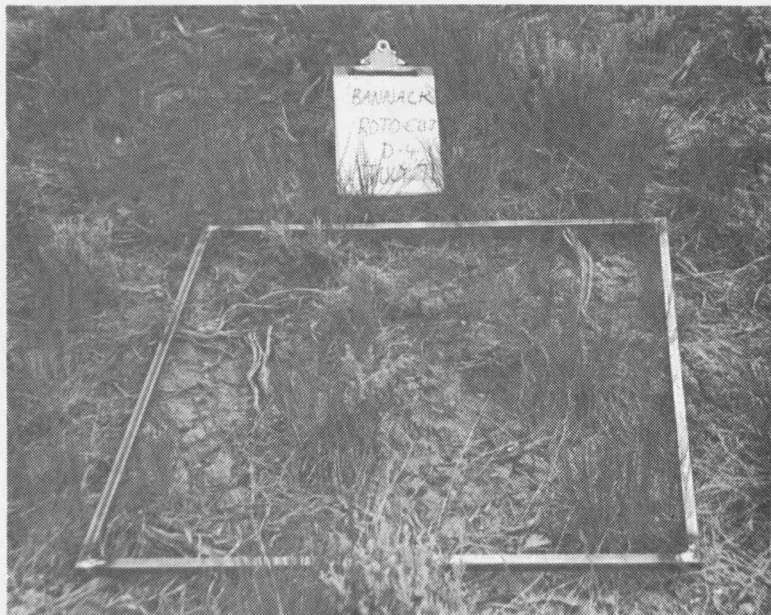


Figure 5. Rotocut treatment at Bannack, Montana. A general view of the experimental plot 9 years after treatment (upper). A close-up view of plants found within one square yard (lower).

widths of the experimental plot to show the location of strings. Each experimental plot thus contained 21 x 11, or a total of 231, plots six feet square (Appendix 3). Thirty sampling plots were randomly selected from the 231 possible plots in each treatment plot. A map showing the location of each of the 30 sampling plots of each experimental plot was used (Appendix 4). One 3 x 3 feet subsample for sagebrush plant collection was randomly selected in each sampling plot.

Wilsall. Essentially the same procedure of sampling used in Bannack was applied at Wilsall. However, the experimental plots were smaller at Wilsall than at Bannack. They measured 68 x 60 feet. Four and six feet from each length and width, respectively, of every experimental plot were excluded from sampling to allow for edge effect. Thus, the length was reduced to 60 feet and the width to 48 feet. The sample plots and the number of samples per experimental plot were treated the same as at Bannack.

Field Data Collection

A 3-foot square frame was placed at the selected subsample locations. All big sagebrush plants with green foliage having their base within that plot were either pulled out by hand where possible or dug out using a hand spade. A portion of the stem of each plant was then cut between the lateral roots and the crown using either a Lewis 3-way knife or a cross-cut finishing saw. These portions were then placed in sacks labeled with replicate, treatment and plot sample numbers.

Laboratory Data Procedure

Plants of each sample plot were brought to the laboratory for annual ring counts using Ferguson's method (1964). A cross section of each stem was made using Lewis 3-way knife or a cross-cut finishing saw. The section was then surfaced with a sanding block. A drop of household oil on the section proved helpful in making the rings stand out more clearly. The section was then placed under a Bausch and Lomb dissecting microscope. A 15X power was satisfactory in distinguishing growth rings.

Considerable practice in sagebrush ring counting had shown some difficulty in determining the earliest or the first annual ring, especially in older plants. The literature was thoroughly reviewed to better clarify this matter. Unfortunately none of the available reported work had ample information on how to determine the first annual ring, especially in older plants. Dr. Booth^{1/} and Mr. Hahn^{2/} were then consulted on the problem. Their guidelines, as well as those of Dr. Sindelar^{3/}, Mr. Eulert^{4/} and Ferguson (1964), were followed closely in determining plant ages.

Examination of stem sections showed that the latest annual ring or the current year's growth had a lighter appearance than the earlier

- 1/ W.E. Booth, Professor Botany, Montana State University.
- 2/ Barton E. Hahn, Associate Professor of Botany, Montana State Univ.
- 3/ Brian Sindelar, Research Associate, Montana State University.
- 4/ Gene Eulert, Graduate Research Assistant, North Dakota State Univ., Fargo, N. Dak.

growth. The rings were counted from the first light-brown ring to the last bright-yellow one (Figure 6). If the plant had more than nine rings, it was classified as mature (Figures 7 and 8) and if it had nine rings or less, it was considered young, in which case the exact age was determined (Figure 6). Mature plants were those which had survived the treatments, whereas young plants were those which had established themselves after treatment application.

Methods of Analysis

Examination of the raw data showed that most of the 30 subsamples per treatment replicate did not contain any plants, or if they did, they seldom exceeded one, especially at Wilsall. Preliminary statistical work showed better tests for differences in reinvaded sagebrush among the five treatments when each six of the 30 subsamples per treatment replicate were grouped into one observation. This was done in a consistent manner in all experimental plots; subsamples 1-6, 7-12, 13-18, 19-24 and 25-30 were added. This resulted in 5 samples per treatment replicate or a total of 20 samples per treatment over all 4 replicates.

Correlation-regression analyses were used to show relationships among big sagebrush re-establishment and precipitation and temperature. Precipitation parameters examined were April, May, June, April-May, May-June, and May-August. Temperature parameters included the minimums for April, May and June; absolute minimum for May 15- June 15; and average maximum for June, July and August.

