THESIS

ASEXUAL PROPAGATION OF BLACKBRUSH

(*COLEOGYNE RAMOSISSIMA* TORR.).

Submitted by

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In partial fulfillment of the requirements

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY EUGENE WEGLINSKI ENTITLED ASEXUAL PROPAGATION OF BLACKBRUSH (*COLEOGYNE RAMOSISSIMA* Torr.) BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

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Abstract of Thesis

Asexual Propagation of Blackbrush (Coleogyne ramosissima Torr.)

Mining disturbances in Canyonlands National Park occur, in part, in monotypic stands of blackbrush (Coleogyne ramosissima Torr.). Blackbrush does not readily reseed itself following disturbance, therefore, stem cuttings and mound layering were evaluated as methods for asexual propagation as a means of providing plants to be used in a revegetation program. Rooted cuttings were planted to evaluate their use in revegetation.

Rooting of stem cuttings was evaluated using talc, 0.3% (w/v) indole-3-butyric acid (IBA), 0.8% (w/v) IBA, and Rootone, a commercially available rooting hormone mixture. Treatments were applied to cuttings collected from new, one-year-old, and older wood (2+ years) at three separate dates. Propagation by stem cutting proved successful with highest rooting percentages achieved using current year's growth with application of supplemental rooting hormone. Differences between hormone treatments were insignificant. However, differences were found in comparisons between hormone treatments and a talc control.

Mound layering was investigated with 20 plants at each of three sites and involved removal of all growth over 2.5 cm above ground level. Supplemental water

was applied to half the plants for the duration of the study. Plants were buried to one-half of the height of new growth on a monthly basis. Plants responded to the treatment with a flush of growth but did not root.

Thirty-eight cuttings rooted the prior year were planted in spring 1989 in an abandoned roadbed to evaluate field establishment. Treatments included application of supplemental water at two week intervals. Results were inconclusive.

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Introduction

Many areas within National Parks and Recreation Areas of the southwest have been disturbed by road construction, public use, mining, and other forms of development. Disturbance in Canyonlands National Park has resulted from overgrazing, mineral exploration, and mining activities prior to establishment of the Park (Loope, 1978).

Blackbrush (Coleogyne ramosissima Torr.) is a small to medium sized shrub of the Rosaceae. It is considered to be a paleoendemic species that once disturbed on a site does not reestablish. Its distribution is a narrow band ranging from eastern California to extreme western Colorado. It occupies a niche between the major species of the Great Basin and Mojave deserts (Bowns, 1973; Harrington, 1964; Wallace et al., 1970). Populations at Arches and Canyonlands national parks occupy the northern most region of its range. Its occurrence in Canyonlands, particularly in the Island in the Sky district, parallels sites where uranium mining was most actively pursued (Loope, 1978).

Roads, seismic lines, and air strips built through stands of blackbrush in these areas during uranium exploration and development destroyed the indigenous plants. National Park Service personnel have placed a high priority on restoring some of these sites. Since blackbrush does not reestablish itself, part of the reclamation program includes development of propagation methods and revegetation procedures for these areas (Kate Kitchell, pers. comm.).

Guidelines exist for seed propagation of blackbrush (Vories, 1981). However, seed acquisition is difficult as a result of infrequent and inconsistent seed set, while establishment is hampered by herbivores that feed on seedlings (Bowns, 1973).

Techniques for asexual propagation may provide a solution to producing plant material to be used for revegetation because a relatively large number of plants may be produced with a minimal amount of effort once a successful methodology is established. Rooted stem cuttings result in a mature plant more rapidly than do seedlings. This may reduce herbivore induced mortality. Mother plants which are well adapted to a specific site may be asexually propagated thus increasing the probability of success once the plants are reintroduced into the field. Asexually propagated plants may also maintain a local gene pool (Landis and Simonich, 1984).

Reclamation in Canyonlands, as in other parts of the southwest, is complicated by climatic factors (Ries and Day, 1976). Precipitation is infrequent and subject to surface runoff and evaporation. Temperatures fluctuate widely on both a diurnal and seasonal basis (Noy-Meir, 1973). Procedures developed to reestablish plants into these regions must overcome such limitations.

Research for this thesis was proposed to develop procedures for propagation and reestablishment of blackbrush into Canyonlands National Park. It could also contribute to reclamation efforts in other National Parks and public lands in the western U.S.

Literature Review

Blackbrush Ecology

Blackbrush (Coleogyne ramosissima Torr.) is a densely branched roseaceous shrub with a rounded shape, 0.5 to 2 m tall. It has an opposite leaf and branching pattern and a perianth consisting of four lobed yellow sepals, both traits are unusual for members of the rosaceae. The fruit is a one ovuled achene 3 mm long with a bent, exserted, villous style (Harrington, 1964).

The shrub has multistem segments vascularly attached to separate portions of the root system. This mechanism, known as stem splitting, is thought to be an adaptation to drought and allows part of the plant to die while other portions persist (Wallace and Romney, 1972). Analysis of leaves showed that they contained low sodium and high calcium and aluminum concentrations compared to other shrubs at the Nevada Test Site. Nitrogen fixation was found to occur in the roots which Wallace and Romney (1972) suggested may result from an actinomycetal symbiosis similar to that formed in other roseaceous shrubs although their observation was not confirmed.

Blackbrush is distributed along a narrow geographical band from western Colorado to eastern California, the distribution coinciding with a transition zone between the Great Basin and Mojave deserts. Its occurrence is limited to areas with higher annual precipitation than typical Mojave species, where temperatures are intermediate to both deserts. Blackbrush is additionally restricted to calcareous soils within these regions (Beatley 1976; Wallace, et al., 1970; West, 1983b).

Blackbrush occurs on aridisols, and is restricted to well-drained benchlands, colluvial slopes, and bajadas at 800 to 1800 m above sea level (West, 1983b). It is usually the dominant species in the landscapes it occupies, comprising 6 to 30% of the plant cover.

Beatley (1976) spent a decade studying vegetation at the Nevada Test Site and found blackbrush occurring on upper bajadas and well-drained basin floors at elevations of 1200 to 1850 m on shallow, gravelly soils containing a predominantly sand matrix. She determined its occurrence with Larrea and Artemisia was limited by precipitation and temperature. Vegetative cover in these nearly monotypic blackbrush stands averaged between 45 and 51 percent.

Bowns (1973) completed an autecological study of blackbrush on three southwestern Utah sites. Soils at each site contained an A-C horizon sequence underlain by a petrocalcic layer. The A horizon was found to be twice as thick beneath plants than in the spaces between them. Soil analysis indicated higher levels of nitrogen and phosphorus beneath plants than between them; both levels decreased with soil depth.

Wallace and Romney (1972) found blackbrush on the stony textured soils of the upper bajadas (elevation 900 to 1800 m) of the Nevada Test Site. These soils were found to be nonsaline and usually calcareously derived from sandstone, while shale derived soils, higher in salts, apparently served to restrict the plant's distribution.

Soil moisture both restricts the shrub's distribution and influences its growth patterns. Precipitation in blackbrush regions ranges from 9 to 40 cm, averaging 15 to 20 cm, with most precipitation occurring in winter (Beatley, 1976; Bowns, 1973). Wallace et al. (1970) and Bowns (1973) report that flower production was closely related to early spring soil moisture levels. They noted that growth began in March following peak soil moisture. Flower initiation occurred within two weeks. Growth continued into June as soil moisture was depleted. Blackbrush undergoes a summer dormancy characterized by the dropping of its older leaves and cessation of growth. Field observations and laboratory experiments indicate that this is a result of low soil moisture rather than high temperatures. Plants will occasionally resume growth following late summer storms of sufficient intensity to affect soil moisture levels (Wallace and Romney 1972).

Wallace et al. (1970) studied the effects of soil temperature on seedlings of shrub species native to the Great Basin and Mojave Deserts and found that blackbrush seedlings produced the greatest biomass at a temperature regime intermediate to that of the two deserts. An experiment using rooted cuttings yielded similar results (Wallace and Romney, 1972).

Seed germination occurred at higher rates for seeds stratified for two weeks at 5° C (Wallace et al., 1970). Light was not required for germination. Additionally, fungal contamination was consistently observed on blotter germinated seeds although it did not affect survival (Bowns, 1973).

Blackbrush does not reestablish itself following a disturbance and seedlings are found infrequently (Bowns, 1973; Loope, 1978; West, 1983b; Callison et al., 1985). Seeds are produced on a highly irregular basis while many seedlings are eaten by small mammals. Additional complications are imposed by climate as many desert shrubs require two consecutive growing seasons with favorable conditions for germination and establishment (Ackerman, 1979).

The area occupied by blackbrush is largely owned by the federal government and includes a number of national parks (West, 1983b). The greatest economic use of blackbrush-dominated rangeland in Utah is as winter forage for desert bighorn sheep and mule deer, with limited winter and spring use by livestock (Bowns and West, 1976).

Recent studies of grazing effects on blackbrush communities indicate blackbrush can withstand heavy continuous grazing. With overgrazing, a loss of palatable species associated with blackbrush occurs along with destruction of cryptogamic groundcover. A heavily grazed site after 10 years of recovery showed no indications of reverting to the vegetation composition of an ungrazed community (Jeffries and Klopatek, 1987). Intensive browsing followed by a one to two season rest period resulted in plants which produced more new twig growth which was higher in crude protein and phosphorus levels than ungrazed plants (Provenza et al., 1983a).

A related study reported a linear relationship between current season's growth and precipitation received between December and June. Soil depth and presence of stones had a positive correlation with growth on heavily grazed plants. Outer branches of heavily grazed plants produced 4.6 times more new growth than sprouts or basal branches. Heavily grazed plants also produced 3.6 times more new growth than control plants (Provenza et al., 1983b).

Manipulation of blackbrush stands to produce more desirable forage using fire have yielded highly variable results and have often led to establishment of less palatable species (Bowns, 1973). Callison et al. (1985) studied blackbrush stands which had been burned from one to 37 years before. Cover values of annual grasses and forbs increased immediately following fire. Annual species cover values peaked after six years while shrubs dominated after 10 years, with shrubs eventually reaching cover values similar to unburned areas. However, blackbrush was not included in the shrub populations which became established.

Blackbrush is a paleoendemic species, these plants which show little variability are often specialists and may be on their way to extinction (Stebbins and Major, 1965). Paleoendemics exist in relict ecosystems following extinction of closely related species, changes in climate, and the advancement of species more ecologically suited to these areas.

Stem Cuttings

Asexual plant propagation involves formation of a new plant from vegetative parts of the mother plant. Sources for new plants range from single cells to woody shoots. The resulting plant is a genetic duplicate of the mother. There are widespread applications of asexual propagation in forestry, horticulture, and agriculture.

Vegetative propagation may be performed using a number of methods which have different applications depending on source material and desired outcome. Common methodologies include cuttings, layering, and tissue culture. Application of these techniques to desert plants has been limited compared to more economically important plants.

Numerous studies have been made on the propagation of woody plants by stem cuttings. This discussion is confined to its application to desert plants although some basic propagation literature is also cited.

Many factors have been reported for the successful rooting of woody plants (Hartmann and Kester, 1983). The season during which the cuttings are taken

(Alverez-Cordero and McKell, 1979; Everett et al., 1978; Felker and Clark, 1982; Hartmann and Kester, 1983; Hess, 1963; Institute for Land Rehabilitation, 1979; Richardson et al.,1979; Wieland et al., 1971), growth hormone treatment (Alverez-Cordero and McKell, 1979; Chase and Strain, 1966; Everett et al., 1978; Felker and Clark, 1982; Hackett, 1964; Hartmann and Kester, 1983; Hess, 1963; Institute for Land Rehabilitation, 1979; Richardson et al., 1979; Wieland et al., 1971), stage of maturity of the cutting itself (i.e. softwood, hardwood) (Everett et al., 1978; Hartmann and Kester, 1983), and the vigor of the parent plant (Hartmann and Kester, 1983) are potentially important factors relative to successful cutting propagation.

Blackbrush propagation was included in only one study which investigated the rooting of cuttings of numerous plants of the Nevada Test Site (Wallace and Romney, 1972). Blackbrush was rooted in a low humidity propagation chamber although specific treatments and methodologies were not outlined.

Chase and Strain (1966) attempted to root cuttings of 14 Mojave Desert woody perennials, 8 of which were successfully rooted. Cuttings were taken in March and June and treated with one of three concentrations of indole-3-acetic acid (IAA), or Rootone. (Rootone is a commercially available rooting hormone mixture.) Their findings indicated that the addition of hormones had an effect on rooting although differences in hormone concentration in most cases did not.

Wieland et al. (1971) studied the rooting response of a group of Mojave and Great Basin desert plants to indole-3-butyric acid (IBA) at two concentrations. Rooting response to environmental factors was evaluated by placing groups of cuttings in a mist house, a lathhouse, an unheated glasshouse, and two glasshouses containing bottom heat, one at high humidity and one at low humidity. Results were variable although 14 of 16 species were rooted successfully. IBA facilitated rooting in most cases. The most favorable responses occurred with cuttings placed either under mist or in a glasshouse without bottom heat.

A study of 53 native Nevada species representing 32 genera and 15 families was carried out by Everett et al. (1978) to determine rooting capacity. Rooting response was evaluated on shoots at various stages of development (softwood, semi-hardwood and hardwood). All cuttings were treated with 0.8% (w/v) IBA and placed in a mist bench containing perlite as the rooting medium. Results from the 10 roseaceous species were mixed. Most species had relatively low rooting percentages (0% to 11%). Prunus andersonii and Rosa woodsii, however, showed a high of 85% and 65% rooting, respectively. The best results were obtained from semi-hardwood cuttings while cuttings taken during the vegetative or flowering stages rooted more successfully than those taken while plants were dormant.

Prosopis cuttings treated with IBA produced more roots per cutting than cuttings treated with IAA (Felker and Clark, 1982), however, there was no difference in the number of cuttings which rooted.

Artemisia tridentata was studied by Alverez-Cordero and McKell (1979) to determine the effect of collection date (season) , IBA at different concentrations, and source of plants on rooting of cuttings. In most cases, rooting increased with increased hormone concentrations, however, there was a marked decline in root production at all IBA concentrations by cuttings collected after growth initiated in spring. Although their sample size included only five plants, they consistently noted, over time, significant differences in the rooting ability among the same individuals.

The Institute for Land Rehabilitation (1979) examined a number of propagation methodologies for the regeneration of several native species. They demonstrated variations in rooting ability of Atriplex canescens cuttings among individuals within the same population and variation between two separate populations. Variability occurred in rooting of three Atriplex species based on season of collection with different species having different optima. Additionally, rooting reflected a seasonal sensitivity to IBA with rooting occurring at different IBA concentrations in cuttings collected at different seasons. Finally, cutting size had an effect on the rooting of Atriplex cuttings. Larger shoots (12 cm) rooted better than shorter ones (6-9 cm).

Richardson et al. (1979) collected cuttings during different seasons and cuttings of different sexes in the case of dioecious plants, to determine if these factors affected rooting. Rooting was evaluated in response to IBA at different concentrations. The effect of cutting length on rooting was also evaluated. Atriplex species were found to root more readily in spring and summer than in winter while sex of the plants had no effect. IBA had a variable affect depending on concentration and season with an increase in hormone concentration generally resulting in an increase in rooting. Seasonal changes in rooting response was of greater significance than hormone treatments. The work of Richardson et al. (1979) concurred with the Institute for Land Rehabilitation (1979) in that longer cuttings (12 cm) rooted better than shorter cuttings (6 cm).

Mound Layering

Mound layering is a method of asexual propagation commonly used in production of apple rootstocks and other plants which are difficult to root from cuttings (Hartmann and Kester, 1983). This method involves establishing a mother plant and cutting it back to near ground level (2.5 to 5 cm) before new growth begins in spring. After shoots reach a height of 7 to 12 cm a soil-sawdust mixture is mounded around new shoots to half their height. The mounding process is continued throughout the growing season with rooting evaluated in the fall. Plants are then separated from the mother plant and either planted out or stored in a cooler to overwinter. The process can then be repeated over a period of years with the mother plants (Hartmann and Kester, 1983).

Mound layering has potential application to blackbrush for two reasons. First, blackbrush has responded to simulated brushbeating, pruning to near ground level, with a flush of new growth (Bowns and West, 1976). Blackbrush therefore would likely survive the mound layering process. New basal growth consists of juvenile tissue which generally responds to rooting treatments more readily than adult tissue (Hartmann and Kester, 1983). The second reason is that plants are rooted while still attached to the mother plant. Mycorrhiza are reportedly associated with many desert plants (Aldon, 1978; Bjugstad, 1983). Mound layering would allow this association to form in situ as new plants rooted, resulting in a plant better adapted to the local environment.

Reestablishment

Revegetation research has been conducted primarily in response to large scale needs of the surface mining industry. Reviews, conferences, and symposia exist to exchange ideas on the problems associated with this field (Aldon et al., 1976; McKell, 1986; Packer and Aldon, 1978; Paone et al., 1978; Ries and Day, 1978). Problems associated with revegetation fit into three major categories: soil condition, plant material, and climatic limitations. This discussion will be limited to overcoming climatic limitations, as it is the most serious factor in this study. Noy-Meir (1973) discusses climatic influences on arid and semiarid zones while West (1983a) gives a general overview of the ecology of these zones in the western United States.

Irrigation has been used in agriculture to overcome drought conditions in semiarid lands for thousands of years. Sprinkler and drip irrigation methodologies have been adapted to reclamation applications. Sprinkler irrigation systems apply water uniformly over large areas while drip irrigation systems concentrate application to limited zones. Outputs from sprinklers are measured in terms of inches or centimeters per hour while emissions from drip irrigation are measured in gallons per hour. Differences in the way water is applied and measured makes direct comparisons of the two systems difficult. Aldon and Springfield (1975, 1977) and Aldon, et al. (1976) evaluated sprinkler and drip irrigation for the establishment of Agropyron smithii, Sporobolis airoides, and Atriplex canescens on mine spoils in New Mexico where annual precipitation averages 150 to 200 mm. Both types of irrigated plots had better plant establishment than nonirrigated plots even after the second growing season when no additional water was applied.

Sprinkler irrigation was applied in an area of Montana which receives an average of 290 mm annual precipitation. After one year of application, irrigation stimulated productivity of perennial grasses and increased stand diversity. After a second year of irrigation, total productivity was elevated in irrigated plots compared to nonirrigated. However, species diversity dropped, as a result of an increase in the cool season species which were better adapted to using the available water (Depuit et al., 1982). Evidence to support these findings was reported by Ries et al. (1976), who initiated a study on a

North Dakota mine reclamation site evaluating the use of limited irrigation on plant establishment. Limited quantities of water at certain critical times greatly influence species composition.

A study of the establishment of seeded plant communities in western Colorado (average annual precipitation 300 mm) included irrigation as one of the cultural practices evaluated (Doerr, et al. 1983). Irrigation increased grass production in the first two years, but had no significant effect when compared to nonirrigated plots the second two years. Shrub densities were reduced on irrigated plots all four years, presumably resulting from increased grass competition. One of their conclusions was vegetation on irrigated plots became established more rapidly than on nonirrigated plots but irrigation was not an absolute requirement. Another conclusion was that irrigation could be applied selectively to establish either grasses or shrubs and forbs depending on desired results and available resources.

Hand-planted shrubs were established using drip irrigation on steep mine spoils in Arizona where annual precipitation averages 150 to 200 mm. Additionally, six drip irrigation systems were evaluated for performance. Hydroseeding was applied with a grass/forb/shrub mixture at a rate of 300 pounds per acre with 1 ton per acre hydromulch over five typical drip systems. The sixth system consisted of drip tubing woven into erosion control fabric which was then stapled over a hand seeded area. Seed germination and establishment was rapid when systems functioned properly. Some systems functioned better than others although animals chewing holes in the driplines was a common problem (Bengson, 1977). Excellent plant establishment and growth were reported at the end of the first growing season. No mention was made of plant survival upon discontinuation of irrigation.

A tailings berm on an Arizona mine site remained unvegetated after two years of natural precipitation (average precipitation 75 mm). DeRemer and Bach (1977) successfully established shrubs on the berm using drip irrigation and after three years reported vegetation covering sixty percent of the berm. Supplemental irrigation at that point had not been discontinued leaving final establishment results unreported.

The adaptability of drip technology was demonstrated by Kolarkar et al. (1983) who used discarded hospital infusion sets to successfully deliver steady, small scale irrigation to a cauliflower (Brassica oleraceae sp.) crop in India. Water was applied daily based on evapotranspiration (ET) rates and consisted of 100%, 75%, and 50% of ET demand. Significant differences in yields and head weights were found between treatments with higher rates producing greater yields. The use of infusion set methodology for crops was extended to use in establishing Anjan trees (Harkwickia binata). Two drip treatments consisted of 0.5 l and 1.0 l water applied every other day while a third group of saplings received flood irrigation (9.0 l) at two week intervals. Water application for the duration of the experiment totalled 91, 173, and 216 liters per plant respectively. Plants which received drip irrigation produced significantly more growth than plants which received traditional flood irrigation while using less water (Kolarkar and Muthana, 1984).

Sprinkler and drip irrigation both have advantages and disadvantages. Generally, sprinklers are best suited for establishing grasses on gentle slopes where water availability is not a problem (Packer and Aldon, 1978; Scholl, 1986). It is also advantageous when soluble salts must be leached out of spoils prior to planting (Ries and Day, 1978).

Drip irrigation is particularly advantageous when applied to steep slopes, areas with limited water supplies and where weed establishment may be a problem (Bengson, 1977; DeRemer and Bach, 1977; Ries and Day, 1978). Disadvantages of drip irrigation include susceptibility of pipes to rodent damage (Bengson, 1977; DeRemer and Bach, 1977) and a buildup of salts just outside the wetted zone which may present a problem with plant growth following establishment (Bengson, 1977; Hanks and Keller, 1972).

Materials and Methods

Site Descriptions

This study was conducted over a period of two years and involved five study sites. Sites were located within the Island in the Sky district of Canyonlands National Park, Moab, Utah. Precipitation in this region ranges from 150 to 200 mm and is highly variable over small areas. Total precipitation over the duration of the study was 170 mm in 1988 and 115 mm in 1989. Annual temperatures range from -26°C to 42°C. Sites were selected based on their proximity to disturbances in various stages of recovery. In 1988, mound layering was established and plants to be used for cuttings were selected and tagged at each of three sites. The first 1988 site was located approximately 1.5 km north of the Grand View Point turnaround on the west side of the road (R. 19E. T. 28S. S.32) at an elevation of 1850 m.

The second and third 1988 sites were located on the White Rim at an elevation of 1540 m. The Lathrop Canyon site was located west of the White Rim Trail approximately 300 m up the upper Lathrop Canyon drainage (R. 19E. T. 27S. S.35). The Buck Canyon site was also located on the west side of the White Rim Trail from 200 to 400 m up the south hillside of the upper Buck Canyon drainage (R. 19E. T. 28S. S.4).

New collection sites were selected in April 1989 because of difficult access to the White Rim sites and lack of suitable quantities of plant material for cuttings at the Grand View site.

One 1989 site was located at the Island in the Sky 3.7 km north of the visitors center on the west side of the main access road (R. 19E. T.27S. S.2), elevation 1830 m. A second site was located on the White Rim, 2.25 km south of the Musselman Arch pullout on the south side of the road (R. 19E. T. 27S. S. 25) at an elevation of 1350 m. Reestablishment was initiated in March 1989 at the 1988 site located near Grand View Point. This site was associated with an abandoned road in need of reclamation and is readily accessible.

Information on soils within the Park is general and incomplete. Soils at the Island in the Sky sites are classified in the Rizozo series by the Soil Conservation Service (unpublished). They are characterized as shallow, well drained, and moderately permeable, formed in eolian deposits over residuum derived predominantly from sandstone interbedded with shale. The soil texture is gravelly to fine sandy loam with a pH of 8.2. The sites have 0 to 2% slopes with soil depths of 10 to 20 cm.

The soils at the White Rim sites are of the Moenkopie series. They consist of shallow, well drained, moderately to rapidly permeable soils derived mainly from sandstone. The texture is typically gravelly loam with a pH of 8.8. The slopes are 1 to 3% with soil depths of 10 to 40 cm.

Stem Cuttings

Preliminary studies were conducted in 1988. Stem cutting research reported here took place in 1989.

Cutting material was collected from 100 plants at each of two sites. At each site, one branch was removed from each plant. Whenever possible, the branch consisted of both older wood (more than 2 years old), and 1-year-old wood. After current season's growth became available (second and third sample dates), this material was included in the sampling. Branches containing all three types of growth (ages) were collected when present. One or two extra branches were removed from plants where all types of growth were not present on one branch. Branches were placed immediately in a cooler containing moistened newspaper. The process from collection to placement in the mist system took approximately 24 h.

Cuttings were prepared one site at a time. Branches were cut into appropriate age sections of four to six nodes. Lower leaves were stripped from the lower 2 nodes of each cutting. Cuttings were then placed into moist paper towels by separate age groups. When enough material for all treatments was prepared, plants from each age group were dipped in a Benlate fungicide solution then divided into four groups, one for each hormone treatment.

The bottom 5 to 7 mm of each cutting was dipped into one of four powdered hormone treatments and placed immediately into the mist bench. Treatments consisted of a talc control, 0.3% (w/v) IBA, 0.8% (w/v) IBA, and Rootone (0.067% (w/v) 1-naphthaleneacetamide, 0.033% (w/v) 2-methyl-1-naphthaleneacetic acid, 0.013% (w/v) 2-methyl-1-naphthaleneacetamide, and 0.057% (w/v) IBA).

Perlite was used as the rooting medium in the mist bench. Bottom heat provided by electrical coils was maintained at approximately 26°C throughout the bench. Ambient air temperatures ranged from 15°C to 25°C during the study. The mist system was controlled by an evaporative demand switch (Mist-o-Matic) which activated the mist system when a minimal moisture threshold was detected. Mist duration was on average 4 to 5 s every 10 min on warm, sunny days which represented peak demand.

Cuttings were placed in a completely randomized block with four replications (six cuttings per replication) for each site/age/treatment combination. The cutting process was initiated on April 17, 1989 (spring) and repeated on July 13, 1989 (summer), and October 10, 1989 (fall).

Data collected after 8 weeks included number and length of roots produced by each cutting. A class value (1 to 5) was assigned to each rooted cutting depending on size of the root system, allowing a qualitative analysis of roots produced. The classes were: class 1= roots 1 to 3 mm long, class 2= roots 3 to 10 mm, class 3= roots 10 to 30 mm, class 4= roots over 30 mm long and class 5 roots which were highly branched (and generally greater than 30 mm long). Averages were taken in cases where cuttings had roots in more than one class.

Data from each date were subjected to analysis of variance (ANOVA). Dependent variables consisted of the percentage of rooted cuttings in an experimental unit, length of roots produced (CLASS), and average number of roots produced per rooted cutting per experimental unit. An experimental unit consisted of 24 cuttings of a single site, age and treatment, resulting in a total of 24 units. The numerical values of the percentage of cuttings rooted were transformed by taking the asin^{-2} of the means, allowing the data to be measured on a scale such that the data were normally distributed. Asin^{-2} transformations are used when data expressed as percentages cover a wide range of values (Steel and Torrie, 1980).

Dependent variables were analyzed individually using site, age, and treatment as independent variables. Site and age themselves were not directly responsible for differences in cutting response. Differences, where present, resulted from factors associated with site and age. These factors may include temperature, precipitation, and soil properties for site and biochemical and/or structural changes associated with aging. To simplify discussion, site and age will be used to refer to the more complex interactions associated with each.

The three dates were considered independently as unquantified differences in temperature, precipitation and day-length made statistical comparisons difficult. The least significant difference (LSD) method was used to separate individual means when ANOVA indicated a variable was significant.

Mound Layering

The study was carried out in 1988 and involved 20 plants at each of three sites. A gravity fed drip irrigation system was used to supply supplemental water to 10 plants at each site. Selection of the location of mound layers was based on suitability for use of 55 gallon drums which served as water reservoirs. The drums required a level area and relatively easy access for monthly refilling. Since the drip system was gravity fed, plants selected to receive supplemental water had to be downhill from the drums.

All above ground growth over 50 to 60 mm was removed from the mound layered plants in March, 1988. Growth from the bases resumed by April. Beginning in May, soil was mounded so that half the height of the new growth was covered. The mounding process was repeated in June after which shoot elongation had apparently stopped. Watering was applied from April through October 1988, ending with the onset of freezing temperatures. Final height of mounds was approximately 100 to 120 mm above soil level.

Supplemental water was supplied through 1/8" drip irrigation tubes placed at the base of each plant. Tubes were connected to a header pipe beneath the drums.

Tubing was buried to the greatest extent possible to avoid tampering and damage. Water flow through tubes was controlled by brass needle valves, calibrated to deliver approximately 1 ml min^{-1}. The water supply lasted two weeks, resulting in an irrigation schedule of two weeks on, two weeks off. A total of 20 liters per plant was delivered per month.

Reestablishment

Rooted cuttings from preliminary experiments in 1988 were planted from a mist propagation bed into tube packs and placed in a greenhouse to overwinter. The potting media consisted of native Canyonlands soil mixed with 15-20% by volume peat moss.

Thirty-eight of the 60 rooted cuttings survived the winter and were planted out in March 1989 at the Grand View Point site on the Island in the Sky. Planting consisted of preparing a hole 30 cm (1 ft.) in diameter and 20 cm (8 in.) deep. Cuttings were placed such that the roots were one node below soil level (at initial soil line). One of three treatments was assigned randomly to each cutting at planting time. Treatments consisted of (1) a control which received only natural precipitation; (2) supplemental irrigation; or (3) supplemental irrigation plus incorporation of a moisture-retaining compound 'Agrosoke' into the backfilled soil. Cuttings were watered immediately following planting.

Plants to be irrigated were planted with a 1/8" plastic drip tube buried near their base. The 1/8" drip tubes were attached to a 3/4" plastic header pipe. The header pipe was attached to a 55 gallon drum which served as a water reservoir. The drip tubes and the header pipe below the drum attachment were buried 5 to 10 cm (2 to 4 in.) below ground level. Water was regulated by a valve on the drum so that 1 liter of water was applied to each plant over a period of 5 min. Brass needle valves located at the end of each drip tube were calibrated at the time of installation to assure an even distribution of water to each plant. Water was applied at two week intervals.

Observations on plant survival were made at eight week intervals throughout the growing season. Final counts were completed in November 1989.

Results and Discussion

Stem Cuttings

Analysis of variance for the spring and summer collection dates indicated significance only among main effects (age, site, treatment), the results of which are presented in table form. Two-way interactions between main effects in the analysis of the fall sample necessitates the use of figures in presenting the data from that date. Similar results were observed at each date, therefore, to avoid redundancy, the discussion follows presentation of the results.

Age was the only significant factor to affect rooting of cuttings collected in spring (Tables 7, 8, and 9). One-year-old growth produced a higher percentage of rooted cuttings, more roots, and longer roots than old growth (Table 1).

Table 1. Effects of cutting age on the percent of blackbrush cuttings rooted, average roots per cutting and root length for cuttings collected in Spring 1989.

AGE*	% CUTTINGS ROOTED	AVERAGE # ROOTS	CLASS
New Growth	-	-	-
One-Year Growth	34.00a	4.00a	2.52a
Old Growth	14.12b	1.70b	1.32b
LSD ($p<0.05$)	8.47	1.67	0.69

* Means within a column followed by the same letter are not significantly different.Analysis of

Data collected from the summer sample resulted in significance of all three main effects on the dependent variables (Tables 10, 11, and 12). Results of mean separation tests are displayed in Tables 2, 3, and 4. Dependant variables which were not found to be significant using ANOVA are listed as N.S.

Cuttings collected in summer showed a similar rooting response to spring collected cuttings in terms of cutting age (Table 2). Younger growth (new and one-year-old) responded better than old growth for all dependant variables. Additionally, new growth produced a higher percentage of rooted cuttings than one-year-old growth.

Table 2. Effects of cutting age on the percent of blackbrush cuttings rooted, average roots per cutting and root length for cuttings collected in Summer 1989.

AGE*	% CUTTINGS ROOTED	AVERAGE # ROOTS	CLASS
New Growth	42.50a	3.87a	2.55a
One-Year Growth	24.69b	4.36a	2.04a
Old Growth	3.75c	2.50b	0.53b
LSD ($p<0.05$)	7.78	1.22	0.56

* Means within a column followed by the same letter are not significantly different.

Cuttings treated with hormones produced a higher percentage of rooted cuttings and more roots than cuttings given the talc control (Table 3). The only difference between hormone treatments occurred with 0.3% IBA which did not exceed control values in terms of the average number of roots produced.

The site at which the cuttings were collected had an effect on the percent of cuttings rooted and root length (Class) with cuttings collected at site 2 outperforming

Table 3. Effects of treatment on the percent of blackbrush cuttings rooted, average roots per cutting and root length for cuttings collected in Summer 1989.

TREATMENT	% CUTTINGS ROOTED	AVERAGE # ROOTS	CLASS
Control (Talc)	15.62a	1.41a	N.S.
0.3% IBA	27.34b	1.76a	N.S.
0.8% IBA	24.92b	3.30b	N.S.
Rootone	26.45b	3.73b	N.S.
LSD (p<0.05)	8.98	1.41	_

* Means within a column followed by the same letter are not significantly different.

those collected at site 1 (Table 4). There was no difference between the average number of roots produced.

Table 4. Effects of site on the percent of blackbrush cuttings rooted, average roots per cutting and root length for cuttings collected in Summer 1989.

SITE	% CUTTINGS ROOTED	AVERAGE # ROOTS	CLASS
1	19.48a	N.S.	1.34a
2	27.73b	N.S.	2.07b
LSD (p<0.05)	6.35	_	0.48

* Means within a column followed by the same letter are not significantly different.

Analysis of the data collected in fall resulted in significance of both a treatment effect (Table 5) and a site-age interaction (Figure 1) for the average number of roots produced. Age-site interactions were significant for the percentage of cuttings rooted (Figure 2) and root length (Figure 3).

Hormone treatments on cuttings collected in fall exceeded control values for the average number of roots per rooted cutting although again no one treatment performed better than the others (Table 5).

Table 5. Effects of treatment on the percent of blackbrush cuttings rooted, average roots per cutting and root length for cuttings collected in Fall 1989.

TREATMENT	% CUTTINGS ROOTED	AVERAGE # ROOTS	CLASS
Control (Talc)	N.S.	1.18a	N.S.
0.3% IBA	N.S.	2.29b	N.S.
0.8% IBA	N.S.	2.69b	N.S.
Rootone	N.S.	3.00b	N.S.
LSD ($p<0.05$)	_	0.97	_

* Means within a column followed by the same letter are not significantly different.

The age-site interaction (Figure 1) shows new and one-year-old growth produced more average roots per rooted cutting than older growth. New growth collected from site 2 also produced significantly more roots than new growth collected at site 1.

New growth produced a greater percentage of rooted cuttings (Figure 2) and longer roots (Figure 3) than older wood while one-year-old growth showed an intermediate response. Treatment effects were negligible except for one-year-old growth in both cases. It appears that cutting age has a greater effect than hormone treatment for differences in the rooting response illustrated in Figures 2 and 3.

The percentage of cuttings rooted and the average number of roots per rooted cutting of cuttings collected in summer were higher for hormone-treated cuttings.

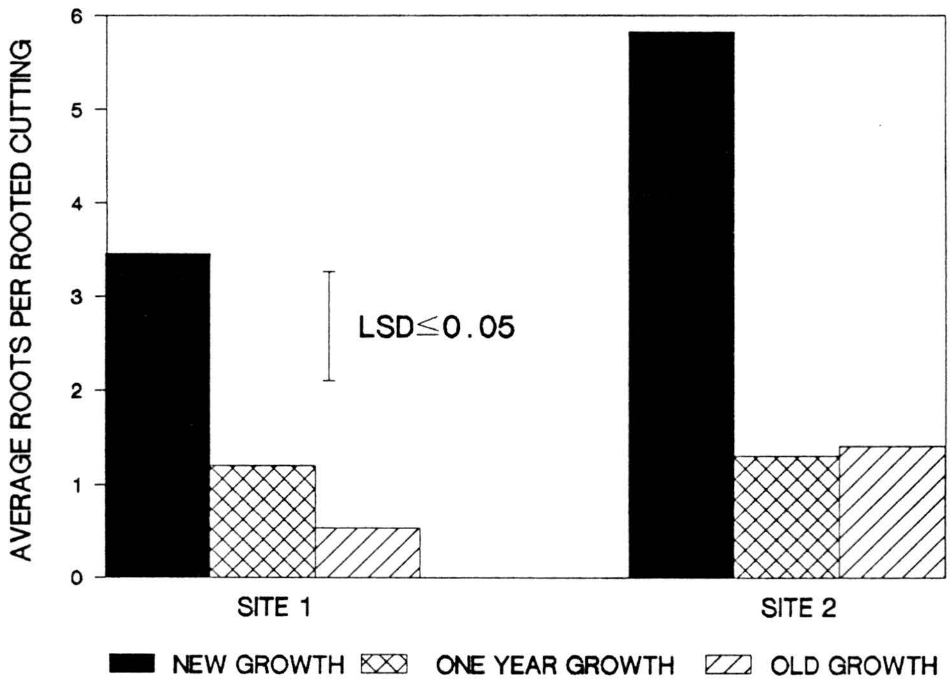

Figure 1. Interaction of site and age on the average number of roots per rooted blackbrush (Coleogyne ramosissima Torr.) cutting (collected Fall 1989).

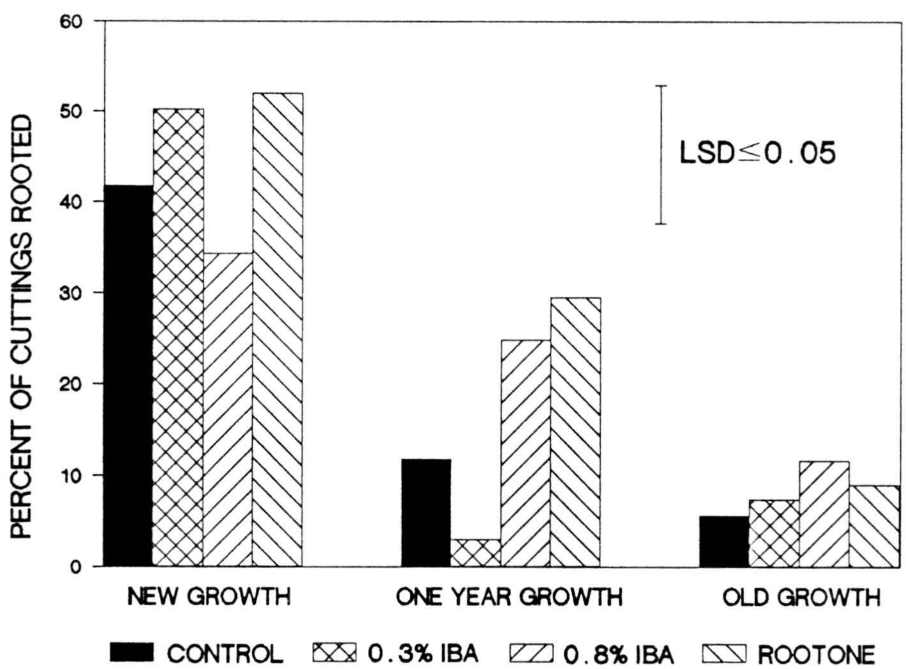

Figure 2. Interaction of age and treatment on the percent of rooted cuttings of blackbrush (Coleogyne ramosissima Torr.) collected in Fall 1989.

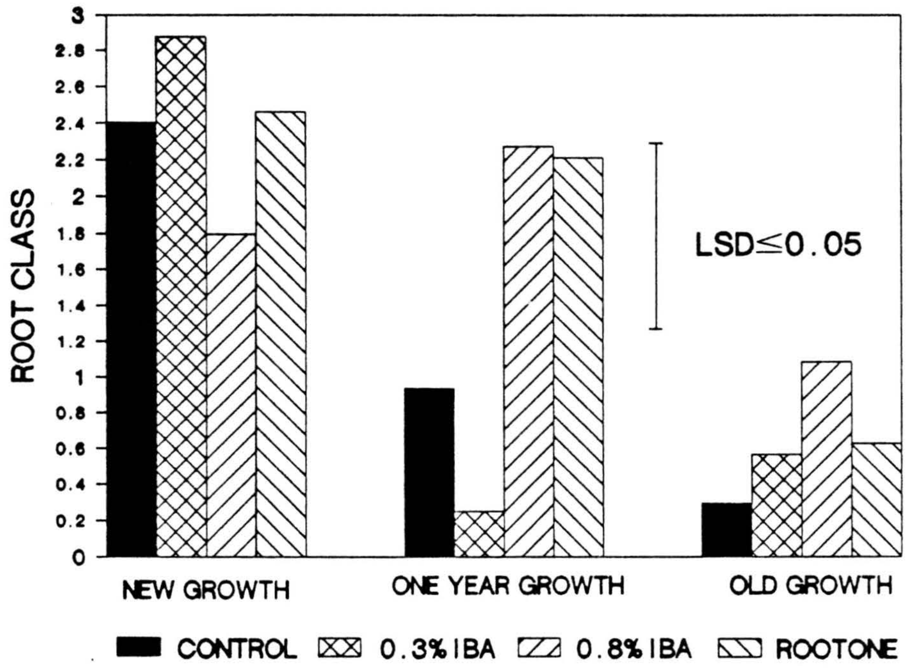

Figure 3. Interaction of age and treatment of root length (CLASS) of blackbrush (Coleogyne ramosissima Torr.) cuttings collected in Fall 1989.

Differences between treatments occurred only with 0.3% IBA treated cuttings whose values did not exceed the controls for the average number of roots produced (Table 3). One-year-old cuttings collected in fall and treated with 0.3% IBA also failed to exceed control values in the percent of rooted cuttings and root class (Figures 2 and 3).

Although the age of the cutting itself is not directly correlated with differences in rooting response, younger wood produced a greater number of rooted cuttings, more roots, and longer roots than older wood at each date. Structural and physiological changes associated with organ age such as lignification and differences in enzymatic activity and auxin levels respectively affect rooting in a number of species (Hartmann and Kester, 1983).

The nutritional status of stock material may also have an effect on rooting response in some species. Cuttings taken from tissues which are high in carbohydrates and have a balanced mineral nutrient status root more readily than tissues low in carbohydrates or showing nutrient deficiencies (Hartmann and Kester, 1983). Young growth, such as that sampled in this study, is typically a resource sink (Salisbury and Ross, 1978) and therefore may be better physiologically suited for rooting than older wood.

Differences in rooting response based on site differences were apparent during the summer and fall dates. Cuttings collected from site 2 outperformed those from site 1 in terms of the number of cuttings rooted, root length (Table 4), and the average number of roots produced (Figure 1).

The Institute for Land Rehabilitation (1979) found differences in rooting ability of Atriplex between two separate populations as well as among individuals. They speculate that the differences may be a result of environmental or genetic differences. Chase and Strain (1966) and Alvarez-Cordero and McKell (1979) drew similar conclusions based on results from similar experiments with relatively small sample sizes. Although plants at both sites were of similar size and general vigor, it is possible that moisture regimes and phenological stage differed between the two sites resulting in a site effect. Genetic aspects of blackbrush remain uninvestigated.

There were no treatment effects on cuttings collected in spring 1989. Differences did occur in the later sample dates between treatments and the control within some variables. The general result is that rooting hormones increased the rooting response over the controls. IBA at 0.3% was the only treatment, in some cases, which did not exceed controls. These findings are similar to those reported by Chase and Strain (1966) and Wieland, et al. (1971) in that hormone treated cuttings of various species rooted better than controls although hormone concentration was often insignificant.

One-year-old growth is apparently in a transition in its ability to produce rooted cuttings. The 0.3% IBA response on one-year-old growth could possibly be explained in two ways. First, it is possible that rooting cofactors (Hess, 1965) may be involved in the change in rooting ability of blackbrush cuttings. Second, it may be that the sample size may not have been large enough to accurately reflect the true rooting response of this material.

The rooting cofactor theory has been investigated for more than 20 years although few absolute conclusions can be drawn. Hartmann and Kester (1983) summarize three possible rooting responses based on a rooting cofactor theory. One response is that the plant possesses the required factors necessary to produce roots naturally and cuttings produce roots without the addition of external hormones. The second response is that the plant possesses the cofactors necessary for rooting although auxin is lacking or limiting. Cuttings from these plants will root with the addition of external hormone. It is also possible in this case that destruction of auxins occurs before rooting can be initiated at which time the addition of higher levels of exogenous auxin may compensate allowing rooting to occur (Hess, 1965). The final response is that the plant is lacking rooting cofactors and cuttings will not produce roots even with the addition of rooting hormone. Studies have been undertaken to characterize the nature of the cofactors with the hope that addition of these missing metabolites may allow rooting of species difficult or impossible to root. Seasonal changes in rooting response have been correlated to the activity of endogenous cofactors in some species (Fadl and

Hartmann, 1967; Bassuk and Howard, 1981). A study of changes in cofactor activity in response to age however, was inconclusive (Al Barazi and Schwabe, 1985).

Blackbrush may be among the plants which have the potential to produce roots but are lacking sufficient amounts of an auxin which must be added exogenously for roots to form. Additionally, it is possible that rooting cofactors are produced only in younger wood which accounts for the poor rooting response of older wood.

The objective of the study was to determine optimum conditions for production of rooted blackbrush cuttings. New growth at the semi-hardwood stage was clearly the optimal age for successful rooting. A hormone treatment is beneficial to rooting success, while sample date, although difficult to compare statistically, is likely to affect physiological factors enough to influence rooting. The optimum regime for cutting production as determined by this study is to collect cuttings from current season's growth in early summer and treat cuttings with 0.8% IBA. An interesting study by Klass et al. (1985) reported that optimizing air temperature, light intensities, and photoperiod had a greater effect than hormonal treatments in rooting mesquite (Prosopis alba). This type of approach might be valuable in propagation studies of species with highly variable rooting responses.

The results from this investigation indicate possible directions for future study. A closer examination of hormone response on younger wood (new and one-year-old growth) might provide further clarification of hormone effects. Additionally, the use of rejuvenated plant material such as that produced in the attempted mound layering study versus typical cutting material may yield valuable results in production of rooted cuttings. Physiological investigations with climatic monitoring might assist in assessing the differences in rooting response between populations at different sites.

Mound Layering

Evaluation was completed in November 1988 when the mounded soil was carefully removed and shoots were examined for rooting. Only one plant in the entire study produced a root. The lack of rooting could be attributed to the inability of blackbrush to produce adventitious roots, the lack of vigor of the mother plants, a lack of moisture in the mounding material, or other unforseen possibilities.

Fifty-eight of the 60 plants produced vigorous new growth initially following the shoot removal. Plants receiving irrigation visually produced more growth than the nonirrigated plants. All new growth following shoot removal on eight plants (3 irrigated, 5 non-irrigated) eventually died. Varying degrees of mortality were observed in shoots of other plants. Irrigated plants were the most healthy in appearance at the time of final evaluation.

Problems with the delivery system occurred at different times at each of the sites. The drip tubing occasionally became clogged and rodents chewed through some of the exposed tubing at the Grand View Point site. Water ran freely from the damaged tubes depriving the plants fed by those tubes of their regular water supply and causing the barrel to drain faster as a result of the unchecked water flow. Clogged and damaged lines were repaired at the monthly recalibration, however, the plants watered by those particular lines went without water from the time of the problem until the lines were rechecked. Plant mortality was not associated with these interruptions.

The study was unsuccessful in its goal of establishing a procedure for mound layering blackbrush. The production of a single root may indicate that conditions around that shoot were conducive for rooting. The appearance of a root might also be explained as an unusual natural occurrence. The study supports the findings of Bowns and West (1976) that removal of older growth to near ground level resulted in a flush of new growth. The success of the cutting aspect of this research indicates this treatment may provide excellent material for cuttings.

Reestablishment

The survival of the cuttings throughout the 1989 growing season is summarized in Table 6. More than half of the cuttings died in the first month following planting, while survival apparently stabilized by mid-summer. Fifteen percent (4/26) of the cuttings receiving supplemental irrigation survived through November when the final evaluation was completed. An inspection in March 1990 revealed no additional mortality.

Statistical analysis within the study was not possible as a result of the small sample size. An analysis using Fisher's exact test (Steel and Torrie, 1980)

Table 6. Survival of Blackbrush (Coleogyne ramosissima Torr.) cuttings over the 1989 growing season.

Date	March 15	April 17	June 15	July 15	Nov 12
Control	14	3	0	0	0
Irrigation	12	5	3	2	2
Irrigation + Agrosoke	13	6	4	2	2

to compare survival of cuttings planted in March 1989 to survival (0/50) of blackbrush seedlings planted at the same site by a private contractor in fall 1988 was made. Fisher's test allows comparison of two unrelated sets of numbers. The two sets of numbers were significantly different at the 0.05 level. Although there were a great number of variables involved in this comparison, including planting dates, plant material, and planters, one could assume that irrigation influenced the survival rate.

A possible explanation for the initial mortality rate is that the cuttings were barerooted at the time of planting. The potting soil in which the cuttings were planted contained a large percentage of native soil which was not bound by the roots when cuttings were removed from the tube packs.

Mortality in bare-root plantings is not uncommon. The Institute for Land Rehabilitation (1979) evaluated the survival of nine shrub and five grass species in containerized versus bare-root plantings on a site in Bonanza, Utah. They reported better survival with containerized plants for both life forms. Similar results were obtained by Sloan et al. (1987) who studied the establishment of ponderosa pine seedlings. They noted that survival and heights of containerized plants after five years were significantly better on harsh sites than that of bare-root plants. They present a review of similar research which indicates various results in comparisons of containerized and bare-root plantings. Although survival of bare-root plantings equals or exceeds that of containerized in some cases, it is likely that this occurrence coincides with more mesic environments.

Survival after two growing seasons has been the generally accepted standard to judge success in field establishment. The cuttings will be evaluated again in fall 1990 to accurately evaluate survival. Final results will be reported to the National Park Service.

Conclusion

Stem cuttings proved to be a successful method for asexual propagation of blackbrush. The highest percentage of rooted cuttings within a treatment was nearly 50%. Cuttings taken in summer or fall from current year's growth and given supplemental rooting hormone produced more rooted cuttings with a greater number of roots and longer roots than older cuttings, cuttings collected in spring, or cuttings not given a hormone treatment.

Mound layering was not a successful approach for asexual propagation. Plants produced luxuriant growth in response to the mound layering process and supplemental irrigation. This type of new growth was not evaluated for its ability to root; however, it is likely that such growth would root as readily as the new growth reported in this study.

The use of a rejuvenation treatment such as cutting growth back to ground level as in the mound layering process may provide a valuable tool in producing source material for other methods of propagation. Rejuvenated and irrigated plants in the case of blackbrush produced on the order of ten times more new growth than untreated plants. This approach may be especially useful when source material is limited. The addition of supplemental water also serves to increase growth and vigor of new growth and is likely to increase the success of producing rooted cuttings in species which have the potential to root.

Literature Cited

Aldon, E. F. 1978. Endomycorrhizae enhance shrub growth and survival on mine spoils. *In*: R.A. Wright (ed.) The Reclamation of Disturbed Arid Lands University of New Mexico Press, Alburquerque, NM. pp. 174-179.

Ackerman, T.L. 1979. Germination and survival of perennial plant species in the Mojave Desert. Southwest Nat. 24(3):399-408.

Al Barazi, Z., and W.W. Schwabe. 1985. Studies on the possible internal factors involved in determining case of rooting in cuttings of Pistacia vera and Prunus avium cvs Colt and F 12/1. J. Hort. Sci. 60(4):439-445.

Aldon, E.F. and H.W. Springfield. 1975. Problems and techniques in revegetating coal mine spoils in New Mexico. *In*: M.K. Wali (ed) Practices and Problems of Land Reclamation in Western North America. pp. 122-132.

Aldon, E.F. and H.W. Springfield. 1977. Reclaiming coal mine spoils in the Four Corners. *In*: J.L. Thames (ed.) Reclamation and Use of Disturbed Land in the Southwest. Univ. of Arizona Press, Tuscon. pp. 229-237.

Aldon, E.F., H.W. Springfield, and W.E. Sowards. 1976. Demonstration test of two irrigation systems for plant establishment on coal mine spoils. Fourth Symposium on Surface Mining Reclamation. NCA, BCR. pp. 201-214.

Alvarez-Cordero, E. and C.M. McKell. 1979. Stem cutting propagation of big sagebrush (Artemisia tridentata Nutt.). J. Range Mgmt. 32(2):141-143.

Bassuk, N.L., and B.H. Howard. 1981. A positive correlation between endogenous root-inducing cofactor activity in vacuum-extracted sap and seasonal changes in rooting of M.26 winter apple cuttings. J. Hort. Sci. 56(4):301-312.

Bengson, S.A. 1977. Drip irrigation to revegetate mine wastes in an arid environment. J. Range Mgmt. 30(2):143-147.

Bjugstad, A. J. 1983. Establishment of trees and shrubs on lands disturbed by mining in the west. *In*: New Forest for a Changing World. Proceedings of the 1983 Society of American Foresters National Convention. pg. 434-438.

Beatley, J.C. 1976. Vascular plants of the Nevada Test Site and central-southern Nevada. Technical Information Center, Energy Research and Development Administration. 308 pp.

Bowns, J.E. 1973. An autecological study of blackbrush (Coleogyne ramosissima Torr.) in southwestern Utah. Ph.D. Thesis. Utah State Univ. Logan, Utah. 114 pp.

Bowns, J. E. and N. E. West. 1976. Blackbrush (Coleogyne ramosissima Torr.) on southwestern Utah rangelands. Utah Agri. Exp. Sta. Res. Rep. 27.

Callison, J., J.D. Brotherson, and J.E. Bowns. 1985. The effects of fire on the blackbrush (Coleogyne ramosissima Torr.) community of southwestern Utah. J. Range Mgmt 38:535-538.

Chase, V. C. and B. R. Strain. 1966. Propagation of some woody desert perennials by stem cuttings. Madrono. 18:240-243.

Depuit, E.J., C.L. Skilbred, and J.G. Coenenberg. 1982. Effects of 2 years of irrigation on revegetation of coal surface-mined land in southeastern Montana. J. Range Mgmt. 35(1):67-74.

DeRemer, D. and D. Bach. 1977. Irrigation of disturbed lands. *In*: J.L. Thames (ed.) Reclamation and Use of Disturbed Land in the Southwest. Univ. of Arizona Press, Tucson pp. 224-228.

Doerr, T.B., E.F. Redente, and T.E. Sievers. 1983. Effect of cultural practices on seed plant communities on intensively disturbed soils. J. Range Mgmt. 36(4):423-428.

Everett, R. L., R. O. Meeuwig, and J. H. Robertson. 1978. Propagation of Nevada shrubs by stem cuttings. J. Range Mgmt. 31(6):426-429.

Fadl, M.S. and H.T. Hartmann. 1967. Relationship between seasonal changes in endogenous promotors and inhibitors in pear buds and cutting bases and the rooting of pear hardwood cuttings. Proc. Am. Soc. Hort. Sci. 91:96-112.

Felker, P. and P. R. Clark. 1982. Rooting of mesquite (Prosopis) cuttings. J. Range Mgmt. 34(6):466-468.

Hackett, W. P. 1964. Growth phases in relation to plant propagation. Proceedings Int. Plant Prop. Soc. Ann. Meet. 14:119-123.

Harrington, H. D. 1964. Manual of the plants of Colorado. Sage Books. Swallow Press, Chicago, IL. 666 pp.

Hartmann, H. T. and D. E. Kester. 1983. Plant propagation: principles and practices. Prentice-Hall Inc., Englewood Cliffs, NJ. 727 pp.

Hanks, R.J. and J. Keller. 1972. New irrigation method saves water but, it's expensive. Utah Sci. 33:79-82.

Hess, C. E. 1963. Why certain cuttings are hard to root. Proceed. Int. Plant Prop. Soc. Ann. Meet. 13:63-70.

Hess, C.E. 1965. Rooting cofactors- identification and function. Int. Plant Prop. Soc. Comb. Proc. 15:181-186.

Institute for Land Rehabilitation. 1979. Selection, propagation, and field establishment of native plant species on disturbed arid lands. Utah Agri. Expt. Sta. Bull. 500. pp. 49.

Jeffries, D.L. and J.M. Klopatek. 1987. Effects of grazing on the vegetation of the blackbrush association. J. Range Mgmt. 40:392-392.

Klass, S., R.L. Bingham, L. Finkner-Templeman, and P. Felker. 1985. Optimizing the environment for rooting cuttings of highly productive clones of Prosopis alba (mesquite/algarrobo). J. Hort. Sci. 60(2):275-284.

Kolarkar, A.S. and K.D. Muthana. 1984. Sub-surface watering of tree seedlings in arid regions using discarded plastic infusion sets. Desert Plants 6(1):5-8.

Kolarkar, A.S., Y.V. Singh, and A.N. Lahiri. 1983. Use of discarded plastic infusion sets from hospitals in irrigation on small farms in arid regions. J. of Arid Environments 1983 (6):385-389.

Landis, T.d. and E.J. Simonich. 1984. Producing native plants as container seedlings. *In*: P.M. Murphy (compiler) The challenge of producing native plants for the Intermountain area: proceedings: Intermountain Nurseryman's Association 1983 conference. General Technical Report INT-168. U.S.D.A. Forest Service, Intermountain Forest and Range Experiment Station, Ogden UT. pp. 96.

Loope, W.L. 1978. Prospects for revegetation of disturbed sites in Canyonlands National Park, Utah. Canyonlands Natural History Society. 9 pp.

McKell, C.M. 1986. Propagation and establishment of plants on arid saline land. Reclam. Reveg. Res. 5:363-375.

Noy-Meir, I. 1973. Desert ecosystems: environment and producers. Ann. Rev. Ecol. Syst. 4:25-41

Packer, P. and E.F. Aldon. 1978. Revegetation techniques for dry regions. *In*: F.W. Schaller and P. Sutton (eds.) Reclamation of Drastically Disturbed Land. ASA, CSSA, SSA. pp. 425-450.

Paone, J., P. Struthers, and W. Johnson. 1978. Extent of disturbed lands and major reclamation problems in the United States. *In*: F.W. Schaller and P. Sutton (eds.) Reclamation of Drastically Disturbed Land. ASA, CSSA, SSA. pp. 11-22.

Provenza, F.D., J.E. Bowns, P.J. Urness, J.C. Malechek and J.E. Butcher. 1983. Biological manipulation of blackbrush by goat browsing. J. Range Mgmt. 36:513-518.

Provenza, F.D., J.C. Malechek, P.J. Urness, and J.E. Bowns. 1983. Some factors affecting twig growth in blackbrush. J. Range Mgmt. 36:518-520.

Richardson, S.G., J.R. Barker, K.A. Crofts, G.A. Van Epps. 1979. Factors affecting root of stem cuttings of salt desert shrubs. J. Range Mgmt. 32(4):280-283.

Ries, R.E. and A.D. Day. 1978. Irrigation in reclamation in dry regions *In*: F.W. Schaller and P. Sutton (eds.) Reclamation of Drastically Disturbed Land. ASA, CSSA, SSA. pp. 505-519.

Ries, R.E., J.F. Power, and F.M. Sandoval. 1976. Potential use of supplemental irrigation for establishing vegetation on surface-mined lands. N. Dak. Farm Res. 34:21-22.

Salisbury, F.B. and C.W. Ross. 1978. Plant Physiology. Wadsworth Publishing Co. Inc. Belmont, CA. p. 94.

Scholl, D. 1986. The study of soil water in mine reclamation. *In*: C.C. Reith and L.D. Potter (eds) Principles and Methods of Reclamation Science. Univ. New Mexico Press. pp. 135-149.

Sloan, J.P., L.H. Jump, and R.A. Ryker. 1987. Container grown ponderosa pine seedlings outperform bare-root seedlings on harsh sites in southern Utah. Res. Paper INT-384. Ogden, Ut: U.S.D.A. Forest Service, Intermountain Res. Sta. pp. 14.

Stebbins, G.L. and J. Major. 1965. Endemism and speciation in the California flora. Ecol. Monogr. 35:1-35.

Steel and Torrie. 1980. Principles and Procedures of Statistics: a Biometrical Approach. McGraw-Hill, New York, New York. pp. 633.

Vories, K. C. 1981. Growing Colorado plants from seed: a state of the art. Vol 1:Shrubs. USDA For. Ser. Gen. Tech. Rep. Int.-103.

Wallace, A., and E.M. Romney. 1972. Radioecology and ecophysiology of desert plants at the Nevada Test Site. Lab. Nucl. Med. and Radiat. Biol. and Agr. Sci. TID 25954. 439 pp.

Wallace, A., E. M. Romney and R. T. Ashcroft. 1970. Soil temperature effects on growth of seedlings of some shrub species which grow in the transitional area between the Mojave and Great Basin Deserts. BioScience 20(21):1158-1159.

West, N. E. 1983a. Overview of North American temperate deserts and semi-deserts. *In*: N.E. West (ed.) Ecosystems of the World V.5 Temperate Deserts and Semi-Deserts. Elsevier Scientific Publishing Co. New York, New York. pp. 321-330.

West, N. E. 1983b. Great Basin-Colorado Plateau sagebrush semi-desert. *In* : N.E. West (ed.) Ecosystems of the World V.5 Temperate Deserts and Semi-Deserts. Elsevier Scientific Publishing Co. New York, New York. p. 331-349.

Wieland, P. A. T., E. F. Frolich, A. Wallace. 1971. Vegetative propagation of woody shrub species from the northern Mojave and southern Great Basin Deserts. Madrono 21(3):149-152.

Appendix

Table 7. Analysis of variance of site, age, and treatment on the percent of rooted cuttings[1] of blackbrush (Coleogyne ramosissima Torr.) cuttings collected in spring 1989.

Source of variation	DF	SS	MS	F
Main Effects	5	8801.019	1760.204	6.131
Site	1	455.61	455.609	1.587
Age	1	6328.99	6328.998	22.045***
Treatment	3	2016.412	672.142	2.341
2-Way Interactions	7	2398.672	342.667	1.194
Site Age	1	69.472	69.472	0.242
Site Treatment	3	1028.373	342.791	1.194
Age Treatment	3	1300.827	433.609	1.510
3-Way Interactions	3	88.120	29.373	0.102
Site Age Treatment	3	88.120	29.373	0.102
Explained	15	11287.811	752.521	2.621
Residual	48	13780.740	287.099	

*** Significant at 0.001 level.

[1] Percentages were analyzed after an $asin^{-2}$ transformation.

Table 8. Analysis of variance of site, age, and treatment on the root length of rooted blackbrush (Coleogyne ramosissima Torr.) cuttings collected in spring 1989.

Source of variation	DF	SS	MS	F
Main Effects	5	29.683	5.937	3.109
Site	1	0.710	0.710	0.372
Age	1	22.944	22.944	12.017***
Treatment	3	6.209	2.010	1.053
2-Way Interactions	7	13.770	1.967	1.030
Site Age	1	6.401	6.401	3.353
Site Treatment	3	1.782	0.594	0.311
Age Treatment	3	5.587	1.862	0.975
3-Way Interactions	3	5.603	1.868	0.978
Site Age Treatment	3	5.603	1.868	0.978
Explained	15	49.055	3.270	1.713
Residual	48	91.645	1.909	

*** Significant at 0.001 level.

Table 9. Analysis of variance of site, age, and treatment on the average number of roots produced by blackbrush (Coleogyne ramosissima Torr.) cuttings collected in spring 1989.

Source of variation	DF	SS	MS	F
Main Effects	5	129.212	25.842	2.312
Site	1	2.588	2.588	0.232
Age	1	84.479	84.479	7.557***
Treatment	3	42.145	14.048	1.257
2-Way Interactions	7	29.322	4.189	0.375
Site Age	1	2.299	2.299	0.594
Site Treatment	3	19.933	6.644	0.594
Age Treatment	3	7.090	2.363	.211
3-Way Interactions	3	64.685	21.562	1.929
Site Age Treatment	3	64.685	21.562	1.929
Explained	15	223.218	14.881	1.331
Residual	48	536.554	11.178	

*** Significant at 0.001 level.

Table 10. Analysis of variance of site, age, and treatment on the percent of rooted cuttings[1] of blackbrush (Coleogyne ramosissima Torr.) cuttings collected in summer 1989.

Source of variation	DF	SS	MS	F
Main Effects	6	23037.305	4006.218	16.560***
Site	2	1632.329	1632.329	6.748*
Age	3	20290.562	10145.281	41.937***
Treatment	4	2114.415	704.805	2.913*
2-Way Interactions	11	2397.422	217.947	0.901
Site Age	2	76.585	38.292	0.158
Site Treatment	3	1215.830	405.277	1.675
Age Treatment	6	1105.008	184.168	0.603
3-Way Interactions	6	1978.729	329.788	1.363
Site Age Treatment	6	1978.729	329.788	1.363
Explained	23	28413.457	1235.368	5.107
Residual	72	17417.888	241.915	

* Significant at 0.05 level.
*** Significant at 0.001 level.

[1] Percentages were analyzed after an $asin^{-2}$ transformation.

Table 11. Analysis of variance for site, age, and treatment on the root length of blackbrush (Coleogyne ramosissima Torr.) cuttings collected in spring 1989.

Source of variation	DF	SS	MS	F
Main Effects	6	93.858	15.643	11.296***
Site	1	12.655	12.655	9.138**
Age	2	70.478	35.239	25.446***
Treatment	3	10.725	3.575	2.581
2-Way Interactions	11	18.864	1.715	1.238
Site Age	2	2.832	1.416	1.023
Site Treatment	3	9.993	3.331	2.405
Age Treatment	6	6.039	1.007	0.727
3-Way Interactions	6	9.561	1.593	1.151
Site Age Treatment	6	9.561	1.593	1.151
Explained	23	122.283	5.317	3.839
Residual	72	99.711	1.385	

** Significant at 0.01 level.
*** Significant at 0.001 level.

Table 12. Analysis of variance of site, age, and treatment on the average number of roots produced by blackbrush (Coleogyne ramosissima Torr.) cuttings collected in summer 1989.

Source of variation	DF	SS	MS	F
Main Effects	6	320.703	53.450	8.967***
Site	1	15.448	15.448	2.592
Age	2	211.984	105.992	17.782***
Treatment	3	93.270	31.090	5.216**
2-Way Interactions	11	88.615	8.056	1.351
Site Age	2	15.891	7.946	1.333
Site Treatment	3	16.189	5.396	.905
Age Treatment	6	56.535	9.422	1.581
3-Way Interactions	6	14.698	2.450	0.411
Site Age Treatment	6	14.698	2.450	0.411
Explained	23	424.016	18.435	3.093
Residual	72	429.178	5.961	

** Significant at 0.01 level.
*** Significant at 0.001 level.

Table 13. Analysis of variance of site, age, and treatment on the percent of rooted cuttings[1] of blackbrush (Coleogyne ramosissima Torr.) cuttings collected in fall 1989.

Source of variation	DF	SS	MS	F
Main Effects	6	25144.172	4190.2695	18.680***
Site	1	767.044	767.044	3.419
Age	2	22703.738	11351.869	50.600***
Treatment	3	1673.390	557.797	2.486
2-Way Interactions	11	4817.745	437.977	1.952*
Site Age	2	1054.605	527.303	2.350
Site Treatment	3	153.461	51.154	0.228
Age Treatment	6	3609.679	601.613	2.682*
3-Way Interactions	6	2190.374	365.062	1.627
Site Age Treatment	6	2190.374	365.062	1.627
Explained	23	32152.291	1397.926	6.231
Residual	72	16152.797	287.099	

* Significant at 0.05 level
*** Significant at 0.001 level.

[1] Percentages were analyzed after an asin^{-2} transformation.

Table 14. Analysis of variance for site, age, and treatment on the root length of blackbrush (Coleogyne ramosissima Torr.) cuttings collected in fall 1989.

Source of variation	DF	SS	MS	F
Main Effects	6	56.848	9.475	9.217
Site	1	1.525	1.525	1.484
Age	2	48.810	24.405	23.740***
Treatment	3	6.513	2.171	2.112
2-Way Interactions	11	25.827	2.348	2.284*
Site Age	2	0.326	0.163	0.159
Site Treatment	3	1.017	0.339	0.330
Age Treatment	6	24.483	4.081	3.969**
3-Way Interactions	6	14.184	2.364	2.300*
Site Age Treatment	6	14.184	2.364	2.300*
Explained	23	96.859	4.211	4.097
Residual	72	74.015	1.028	

* Significant at 0.05 level.
** Significant at 0.01 level.
*** Significant at 0.001 level.

Table 15. Analysis of variance of site, age, and treatment on the average number of roots produced by blackbrush (Coleogyne ramosissima Torr.) cuttings collected in fall 1989.

Source of variation	DF	SS	MS	F
Main Effects	6	341.675	56.946	21.450***
Site	1	29.471	29.471	11.101***
Age	2	266.579	133.290	50.206***
Treatment	3	45.626	15.209	5.729***
2-Way Interactions	11	50.851	4.623	1.741
Site Age	2	20.985	10.493	3.952*
Site Treatment	3	1.408	0.469	0.177
Age Treatment	6	28.457	4.743	1.786
3-Way Interactions	6	25.426	4.238	1.596
Site Age Treatment	6	25.426	4.238	1.596
Explained	23	417.952	18.172	6.845
Residual	72	191.150	2.655	

* Significant at 0.05 level.
*** Significant at 0.001 level.