Investigation into seed collection practices and shrub manipulations to Improve sustainable seed yield in wildland stands of bitterbrush (*Purshia tridentata*)

by

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Background

The Great Basin is a series of unique ecosystems. Starting at the western edge of the Sierra Nevada mountain range in California it stretches east to the Wasatch Mountains of Utah. In the north it starts in central Oregon and Idaho and stretches south through out most of Nevada. In all the Great Basin is found in five states of the western U.S. (figure 1). The Great Basin supports three dominant plant communities: sagebrush, salt desert, and pinyon-juniper (BLM 2000). Sagebrush communities, consisting of a mix of shrubs, perennial grasses, and forbs, are the Great Basin's most common. The whole basin was at one time a continuous system of native bunchgrasses and plants, woodlands and forests; this is not the case today, what once was described as an "ocean of sagebrush" (Welch, 2005) is now an ocean of exotic weeds and threatened native plant communities.

Since the settlement of the Great Basin humans have been trying to change the land to fit their needs. This has led to an alteration of the natural plant communities that have adapted to surviving in this environment. The introduction of cheat grass (*Bromus tectorum* L.) in the early 1900's has been the single most destructive element in the degradation of the Great Basin ecosystem. The USDI Bureau of Land Management (BLM) estimates that on average cheatgrass takes over 4,000 acres a day and that it currently has infested 25 million acres, nearly one third of the Great Basin (BLM, 1999).

Cheat grass is a winter annual that matures early in the summer. Once its lifecycle is completed, it cures quickly and becomes highly flammable. This has changed the fire regime (annual occurrence of fire) of the Great Basin from 40 to 100 years to 10 or less years (BLM 2000). Native plants that evolved with the less frequent fire regime

can not compete with the introduced plants that evolved with the shorter fire regime. A BLM ecologist noted that "fire follows annual grasses, and annual grasses follow fire" (BLM 2000). The native rangelands of the Great Basin are at risk to be lost forever due to invasive weeds, wildfire, commercial development, and other activities that displace the native plant communities. In order to stop these influences from destroying this unique ecosystem, restoration efforts had to be established and implemented.

In the summer of 1999 this became quite clear when in a weeks time 1.7 million acres of the Great Basin burned. That year, in November the BLM created a team to identify the problems facing the ecosystems of the Great Basin. They found eight resource concerns in the wake of that year's fires. They are: loss of native plant communities; stability of watersheds and soils; declining habitat for wildlife; less forage for wild horses; increase of noxious weeds and exotic annual grasses; reduced livestock grazing; fewer recreation opportunities; more dangerous and costly wildland firefighting (BLM 1999). To address these problems the BLM implemented the Great Basin Restoration Initiative (GBRI). Their goal was restoration of the Great Basin with restoration defined as: "implementation of a set of actions that promotes plant community diversity and structure that are more resilient to disturbance and invasive species over the long term (BLM, 1999)." This created a greater demand for native plant seed indigenous to the Great Basin.

Unfortunately, native plant seed is normally in short supply and very expensive. Demand and costs will only increase as more and more acres are slated for restoration under the GBRI (Davison, 2003). This has prompted the BLM to solicit research on how to acquire more native seed at lower costs. A species priority list was developed using

several criteria. The criteria included: Past agency seed buys for commonly requested native species; Species with broad adaptation throughout the Great Basin; Current availability of native species (Davison, 2003). Antelope bitterbrush (*Purshia tridentata* (Pursh) DC.) was one of the species on the list.

"Bitterbrush is an intricately branched, deciduous shrub varying widely in growth habit from low, decumbent, spreading forms to upright arborescent plants over 4 m in height. Leaves are alternate, simple, pinnatifid or apically three toothed and sometimes glandular. Flowers are insect-pollinated and borne on short spurs of previous year's growth. Plants flower in April to June, and fruits ripen in late June to August depending upon elevation and latitude (Shaw and Monson, 2004)." Bitterbrush is an important browse species in the Great Basin for several reasons. Foremost it is highly palatable to large wildlife such as deer and elk as well as domestic livestock. A second reason is the shrub's abundance and wide distribution. Furthermore, it is considered a hardy plant, able to withstand heavy browsing and environmental extremes, such as heat, cold, and drought (Giunta et. al 1978). This has made it a popular species for re-seeding efforts in the Great Basin. In the future this species is going to be much in demand, and with current seed prices near 25 dollars a pound, a way to acquire this seed at lower cost is a necessity for it to be used in restoration efforts.

Bitterbrush is a slow growing species. According to McConnell and Smith (1977) it does not reach maximum production until the ages between 60 and 70 years. His research is backed by Clements and Young in 2001. This limits the feasibility of planting bitterbrush stands in agricultural production for seed. Instead we proposed that healthy native wildland stands of bitterbrush be used. Simple treatments such as competition

removal, selective pruning, and fertilization that are practiced in orchards today would be implemented to see if they would produce higher seed yields on these native stands of bitterbrush. Two experiments were the focus of this study. The first is to quantify the affect of collection methods on seed yield over two production seasons. The second experiment is to manipulate the environment and shrub to enhance seed production.

Methods

Sites: Site selection was coordinated through the State of Utah, BLM, and USDA Forest Service Intermountain Region and includes one site at each of the following geographical regions. 1) Central Utah, in the Sheeprock Mountains approximately 10 miles west of Vernon at 40.0853°N, 112.5833°W at an elevation of 6300 ft. Average annual precipitation for this area is 10.57 inches. Soils here are a very gravelly loam. This site is managed by the State of Utah. 2) Boise Front, Idaho, approximately 20 miles west of Rogerson off Three Creeks Road at 42.150958°N, 114.982247°W at an elevation of 5700 ft. The average annual precipitation for this area is 12.93 inches. Soils here are a very cobbly sandy loam. This site is managed by the BLM. 3) East-Central Nevada, in the Ruby Mountains next to the Ruby Guard Station off St. Rd. 229 at 40.733012°N, 115.229931°W at an elevation of 6521 ft. The average annual precipitation for this area is 14.52 inches. Soils here are a cobbly loam. This site is managed by the Forest Service. See figure two for a map of the three locations. All three sites are all mixed shrub stands with rabbitbrush (*Chrysothamnus spp.*), sagebrush (*Artemisia spp.*) and understory bunch grasses. Climatic data was provided by the Western Regional Climate Center (WRCC, 2007). All shrubs in the study where selected to be reproductively mature and similar in size and growth form for each respective site.

Experiment 1: At each site two different collecting treatments were initiated, imitating standard seed collecting practices. The most common method of seed collection for bitterbrush is to place bins or tarps under shrubs and begin hitting the shrub to dislodge the seed. This type of collection tends to be aggressive, trying to collect as much seed in the shortest amount of time. It is not known if this method has a negative effect on future year's seed production. A tennis racket and 10 gallon bin were used for this treatment. Tarps were spread around each of the selected shrubs to collect litter/seed not collected into the bin. Five shrubs per treatment at each of the three different sites were selected during the 2004 field season. Shrub selection utilized a plotless method based upon site characteristics and shrub density.

The second method of collection was hand-stripping. This was thought to be a less invasive method of seed collection. Once again tarps were spread around the selected shrubs to collect litter/seed missed by stripping the seed from the branches by hand. The stripped seed was placed into sacks while collecting. Pounds PLS (pure live seed) was and will be determined and a litter weight to seed weight ratio calculated. This objective was implemented in the 2005 field season; seed collection from this year will be used to establish base line data for future seed collections. The 2006 collection was to be the first year that treatment effects where expected to be seen, but only the Idaho site produced seed this year for comparison. Statistical analysis was performed on total seed production between treatments. The ratio of seed collected by method of total seed recovered was calculated for comparison of treatments.

Experiment 2: This experiment was conducted using bitterbrush on the same three sites. A split block plot design was used at each site with a one-acre fenced eight

foot tall field fence exclosure installed to prevent livestock or wildlife from disturbing the experiment. Within each exclosure, 5 reproductively mature shrubs of equal size and similar condition where randomly selected for each treatment combination. A total of 7 treatment combinations and controls where compared. The same design was then applied outside of the exclosure in order to determine the effect of browsing on seed production. An exclosure at each of the three sites was built in the summer and fall of 2004, after approval of sites from all participating agencies was received. All treatments where applied in the fall of 2004. For complete treatment matrix see table 1.

Treatments

Competition removal: Since water is a limiting resource in arid environments, we wanted to see if removal of plants in direct competition for water resources encouraged seed production on sample units. All vegetation was removed that was within one meter of the canopy drip line. Large vegetation was removed with a chainsaw and loppers in the fall of 2004. Grasses and small forbs where removed by herbicide application by backpack sprayers starting the spring of 2005. Two herbicides were used in the 2005 field season. Gly-4 Plus™ (Glyphosate, N (phosphonomethyl)glycine in the form of its isopropylamine salt, 41% active ingredient) at 2 2/3 fluid ounces per gallon and Weedmaster™ (Dimethylamine salt of dicamba(3, 6-dichloro-o-ansic acid) 12.4% active ingredient and Dimethylamine salt of 2,4-dichlorophenoxyacetic acid 35.7% active ingredient) at 3 fluid ounces per gallon of water. Nonionic surfactant was added at the rate of 1 fluid ounce per gallon of water, as well as blue dye to make treated areas

visible for applicators to see. Three applications of herbicide were used in the 2005 field season.

The same basic mix of herbicide was used in the 2006 field season. In addition to the Gly 4™ and Weedmaster™ mix, Gramoxone™ (paraquat 200grams per liter active ingredient) was used at the rate of 2/3 fluid ounce per gallon of water. This was done to control more persistent vegetation such as rabbitbrush and *Whyethia spp.* Gramoxone™ and Gly-4™ are both non-selective contact herbicide and Weedmaster™ is a selective broadleaf contact herbicide. By early June of 2006 it was apparent that grasses growing within the canopy of selected shrubs would have to be treated. Select® (Clethodim, 26.4% active ingredient) a selective grass herbicide was used at 1/3 fluid ounce per gallon of water. Only two applications (early May and June) where required for vegetation control during the 2006 field season.

Selective pruning: The lowermost limbs and any decadent branches were removed. This was done in the fall of 2004 by hand sheers. All dead or decadent branches were removed over the entire shrub. Due to the fact that seed borne on lower limbs is more difficult to collect the lowermost limbs of selected plants were removed to allow the collection bins to better fit under the shrub canopy. It was hypothesized that actual seed loss from lower limb removal (seed that would normally have developed on the lower limbs) may be replaced by increased seed production on upper limbs over time, and place seed in a more collectable position.

Broadcast fertilizing: Sample units were treated with fertilizer by broadcasting over the root zone area. A local farm supply company suggested a 25-5-10 slow release fertilizer with iron 4.8% for application to selected shrubs. This is a standard

commercially available fertilizer with nitrogen derived from: urea, ammonium sulfate, ammonium phosphate, and sulfur coated urea; phosphorous from ammonium phosphate; and potassium from muriate of potash. Iron was from iron sucrate which is more available to plants even though the iron was part of the fertilizer mix the effects of iron are not known or being analyzed in this study. The fertilizer was applied at the manufactures recommended rate of 50 lbs per 6,250 square feet. One square meter was fertilized around the base of each of the selected shrubs. The proper rate was determined to be 39 grams per square meter. Plastic cups were zeroed on a scale and fertilizer was added until the 39 grams was reached then the cups were marked at the appropriate level, this was done to ease field application of the fertilizer. Application happened annually in the fall of 2004, 2005, and 2006.

Seed Collection: Monitoring of all stands was extensive during the field seasons of 2005 and 2006. All three stands where checked weekly starting the first week of June and continuing until seed collection occurred. Seed from all shrubs in this experiment was collected using a short length of pvc pipe to dislodge the seed from the shrub into bins placed under the canopy. Care was taken to collect as much seed from the shrub with out inflicting permanent damage to it. Since seed maturity differed among and within stands, collections were repeated on shrubs and at each site over the entire time seed was mature, usually about a week.

Methods Modification

Seed was collected in late July and early August 2005 at all three sites. Environmental factors necessitated the modification of the methods described above for the 2006 collection. The primary problem with the outlined methods was the assumption

that seed would all ripen at the same time at each site. Monitoring of all sites showed that in 2005 the fertilizer treatment had accelerated the ripening of seed on those plants. This caused a span of several weeks for complete collection of the seed to take place at each site.

In addition to the extended ripening time, on Saturday July 23, 2005 a heavy thunderstorm occurred at the Idaho bitterbrush site. The wind and rain knocked a large portion of the seed of some shrubs to the ground while it had little effect on others. This caused the data from this site to be unreliable for analysis. For the 2006 field season to overcome potential problems, with uneven ripening times or weather, a random sample of 3 branches of each shrub was selected to be covered. This was done to insure that seed from each of the treated shrubs would be collected. A fine mesh available at fabric stores was purchased to cover branches. The openings in the mesh were approximately 1/8" in diameter. This type of mesh is commonly referred to as petticoat mesh. Two foot square sections of the mesh were cut and then wrapped around three randomly selected branches, starting from the branch tip. This assured an equal distance of branch wrapped for all samples. The mesh was placed on the plant after pollination, when the seed had started to form. Seed formation was tested be squeezing a seed between the fingers. If a red juice is secreted then seed has started to form. By insuring that all seed is trapped in the mesh, problems with the weather and ripening time where hopefully to be overcome. Wrapping occurred at the Idaho site the last week of June 2006.

In early June 2006 it was apparent that the Utah bitterbrush site was not going to produce seed for the current year. It is speculated that this was due to two nights of sub-freezing temperature that occurred over Memorial Day weekend of that year. By early

July it was also apparent that the Nevada bitterbrush site was also not going to produce a seed crop for the current year. This was due to an insect infestation that was causing developing seed to shrivel and blacken. Two suspect insects were collected at the site; Say's stinkbug (*Chlorochroa sayi* Stål) and a seed midge (*Mayetiola spp.*). Both insects are commonly associated with the blackened shriveled seeds that were collected at the Nevada site.

The loss of two sites necessitated a complete change in data collection. Since seed is borne individually on the spurs produced during the previous year's growth potential seed production for any given plant could be calculated by counting the number of spurs on a leader. A one meter square quadrat was built using PVC pipe, this was divided into 16th using thin wire. This created a quadrat with 16 boxes and 25 points from which to collect data from. We determined to collect five data sets from each plant. A data set included the following: the closest new leader to the selected point was measured, the number of spurs counted along the measured length, and the number of new leaders whose growth point started in the $1/16^{th}$ of a meter box that was closest to the selected point through out the depth of the canopy. The same measurements were repeated for the previous year's growth. All measurements were taken in centimeters and rounded to the nearest half. In addition a length/width/height measurement was taken of each plant to form a correction factor for unevenness in plant size. These measurements were repeated at each of the sites for the 80 plants that were associated with the competition removal/prune/fertilizer treatments.

To estimate potential seed yield the average number of spurs per leader was multiplied by the average number of leaders per box. This number was then multiplied

by sixteen to come up with the average number of spurs per meter^2. The amount of spurs produced in one square meter of each shrub was used for statistical comparison of treatments.

In addition to the mentioned measurements taken, each plant was also given a girdling and health score. This was necessary because the Nevada site had a small mammal come and remove cambium from the base of the bitterbrush plants. By late summer of 2006 it was apparent that plants that had been girdled showed a decrease in health. The girdling was not specific to treated plants however certain treatments did seem to show a higher amount of girdling. Since the exclousre was not a barrier to small mammals the browse treatment had no effect and replicates at the Nevada site were lumped for statistical analysis. The scores were applied by one reporter to all plants and the criteria were as follows: Girdling Score: 4-extreme; 3-severe; 2-moderate; 1-minor; 0-none. Health Score: 4-excellent; 3-good; 2-fair; 1-poor; 0-dead.

Soil samples were also taken at each site; five of the ten shrubs that were fertilized were randomly selected to test for nitrogen, phosphorus, and potassium. For comparison an equal number of samples were taken for analysis from control shrubs. All samples were taken from under the canopy of the selected shrubs.

Statistical Analysis

All statistical tests were performed with SAS (SAS Institute 2006). A mixed model analysis of variance was used to analyze the effects of treatments on seed production and potential seed production. For all analysis, $\alpha = 0.05$ was used for statistical significance. The fixed effects for the model in experiment one of the study were site (Idaho, Nevada, Utah), year (2005, 2006), and treatment (beat, handstrip). Two

models were used in experiment two of the study. The fixed effects in the first model for experiment two of the study were browse (browsed, unbrowsed), year (2005, 2006), and treatment (competition removal, prune, fertilizer, and all possible combinations). Sites were used as replications to apply treatments to the whole region that the study encompasses (regional scale). The second model was to specifically compare treatment effects at each of the three sites (local scale). The same fixed effects were used with the individual treated shrubs used as replications. Two additional mixed models were created for the girdling score and soil analysis results. The fixed effect for the girdling model was treatment. The fixed effects for the soil analysis model were NO_{3-}, P, and K.

Results

Experiment 1 Results: Results showed that there was a significant difference between the years of 2005 and 2006 ($p < .01$) this is to be expected due to the variability of environmental factors such as precipitation or temperature over which we have no control. There was no significant difference between the beat or handstrip treatments for the 2006 season ($p = .88$). However, this is the first year of data collection for these treatments and some other observations must be noted. First is the fact that while all the beat treatments produced seed in 2005 and 2006 only 3 of the five handstrip treatments produced seed in 2006. Also the ratio of seed collected by method of total seed production stayed fairly constant at 69 percent for 2005 and 78 percent for 2006 by the beat treatments (table 2). The handstrip treatment collected 51 percent of the seed in 2005 and only 28 percent of the total seed production in 2006 (table 2). Since only the Idaho site produced a harvestable seed crop this year there are no between site comparisons for this part of the study currently.

Experiment 2 Results: Due to variability of environmental conditions between the two years of our study we separated the analysis by year for comparison of experimental factor level responses.

The model using states as replications showed that there were no interactions of treatments that had a significant difference on spur production. Only competition removal had a significant effect on spur production ($p < .01$). This result was constant for both 2005 and 2006 (figure 3).

Analysis of each site independently indicated that there was some variation in results by state and year. At the Utah site both years showed that browsing (figure 4) had a significant negative effect on spur production ($p < .01$). Also competition removal (figure 5) had a significant positive effect on spur production in 2006 only ($p < .01$). At the Nevada site in 2005 the three main treatments, competition removal (figure 5), prune (figure 6), and fertilizer (figure 7) all had a significant positive effect on spur production ($p \leq .01$). In 2006, however, only competition removal showed a significant effect on spur production ($p < .01$). At the Idaho site, competition removal (figure 5) increased spur production both years while the other treatments showed no significant effect on spur production ($p < .01$).

Statistical analysis of the girdling scores showed that there were not any significant differences between treatments in the amount of girdling that they received. Graphing the average of the girdling scores shows that there was a trend with shrubs that received the fertilizer treatment showing the highest score of all the treatments (figure 8).

Soil Sample Results: Soil samples were tested in the Brigham Young University Soils Lab according to approved procedures (AOAC 1995). Nitrate (NO_{3-}), phosphorus

(P) and potassium (K) were extracted analyzed. All results and recommendations were reported in parts per million (ppm). The lab found that while the soils sampled were below what they view as required in an agricultural setting (< 40ppm NO_{3-} , < 15ppm P, < 120ppm K), the requirements of native plants are generally much lower than that of crops. They concluded that no nutrients were likely critically limiting for shrub production. Statistical analysis of soils under fertilized shrubs relative to soils under control shrubs showed no differences in the applied nutrients. The soils lab attributed this to the low rate that was applied to the selected shrubs.

Discussion

At the current time there is no literature on the effects of collection methods on future seed production of native plants. Though there were no significant differences between the amount of seed produced by the two treatments in experiment one of this study some trends may be appearing at the Idaho site. Of the two treatments the beat treatment collected the highest percentage of seed produced by the shrub (table 2). Seed literally rains from the shrubs when it is mature and the shrub is disturbed. The beat treatment had tubs placed under the canopy that caught the majority of this seed. The handstrip treatment only allowed the seed caught in your hand to be collected, while still disturbing the shrub and causing the majority of the seed to fall to the ground.

The fact that two of the five shrubs produced no seed this year in the handstrip treatment could also be an appearing trend. When first comparing methods we felt sure that this method of collection would be less harmful to the shrubs, but comparison of the amount of litter that is collected shows that for the current year (2006) approximately seventy percent of material collected was litter (see table 2). We think that this collection

method maybe breaking spurs from the limbs. As the seed is pulled towards the end of the limb the young growth that will produce the next years seed maybe damaged to the point that seed production is negatively effected. Future collections will demonstrate if this hypothesis is true.

Currently there has been no research investigating the potential to husband native stands as seed orchards, so little literature is available for review. However, since the 1950's bitterbrush has been studied due to its value as a forage species. Many studies focused on the improvement of forage value and the effects of browsing. Concepts that where found in these studies can be inferred about the effects of competition removal, pruning, and fertilization for the current study.

On a regional scale competition removal was the only treatment that had a significant positive impact on spur production. Since fertilizer did not have significant impact on spur production and competition removal and fertilizer treatments affect the resources that are available to the shrubs, water is likely the limiting resource in our study on a regional scale. Results on the local scale show that pruning and fertilizer can have a significant effect on spur production. This discussion centers on the potential of the shrubs to produce seed relative to husbandry practices and whether or not current literature supports our data.

Hubbard (1957) conducted a study on the effect of plant competition on bitterbrush seedling survival rate. In areas of relatively low precipitation the most important factor in seedling establishment is soil moisture. He established plots that were not weeded, weeded once, and weeded annually across three years. These plots simulated heavy, light, and no competition. He found that as plant competition was

reduced that soil moisture remained fairly stable through out the growing season at a depth of 21 to 54 inches. Even surface moisture (depth of 1.5 inches) was not depleted until mid August in the no competition plots. The increase in soil moisture allowed higher seedling recruitment and over the three years of the study allowed the no competition plants to grow to a height of 26 inches. In comparison the plants in the heavy competition plots only grew to a height of 4.5 inches.

Results similar to this was also demonstrated by Ferguson (1972) with a study that demonstrated that reducing competing vegetation within $3ft^2$ had significant impact on the survival of bitterbrush seedlings. His study also watered seedlings, but he noted that while the watered seedlings did have significantly higher survival, he felt that even un-watered seedling survival with competing vegetation removal was satisfactory for bitterbrush stand establishment. Since water is almost always the limiting resource in the Great Basin, it stands to reason that in the current study competition removal will allow more resources for our target plants.

Our findings applied at the regional and local scale were consistent with these two earlier studies. Regionally in 2005 competition removal improved spur production from 1144 to 1804 (figure 3). We found that with the exception of the Utah site in 2005 competition removal was the only factor that consistently resulted in significant improvement on spur production. All other treatments and combinations of treatments on regional scale had no consistent impact on spur production. This suggests that in our system that water maybe the limiting resource on improving potential seed production on bitterbrush plants in the Great Basin (figure 5).

As mentioned, few studies have been done as to the effects of fertilizer on seed production. However studies have been done to enhance the growth of current year twig elongation. If current year twig elongation could be increased, then it is possible that an increased seed crop or potential seed crop could be seen. If fertilizer treatments can enhance seed yield, broadcasting may be the most simple and economical delivery method. Broad application of fertilizer however may also enhance growth of weedy species which may become the sole nutrient beneficiaries, which would also increase competition for water resources.

Bayoumi and Smith (1976) applied four rates of nitrogen, phosphorus, and both in combination over two years on bitterbrush. In 1972, they applied both nitrogen and phosphorus, but in 1973, they only applied nitrogen since phosphorus showed no effect on the growth of bitterbrush. They found that long shoot growth was increased by the application of nitrogen as well as seed produced per stalk. They noted, however, that they had a better response in 1973 because they had a higher amount of summer precipitation. This suggests that in their study that water was a confounding factor and likely was a significant part of higher production in 1973. Once shrubs had sufficient moisture the effects of the fertilizer on twig growth and seed production were more visible.

Young et. al. (1997) conducted a study in which nitrogen enrichment, immobilization, and inhibition of nitrification were used to see the effects of available nitrogen on the recruitment of bitterbrush seedlings. They found that seedling establishment, survival, and growth was much higher in plots were nitrogen was immobilized with carbon in the form of sucrose. They attribute this to the fact that

nitrogen immobilization suppressed the growth of herbaceous annuals such as cheat grass and tumble mustard (*Sisymbrium altissimum* L.) and had little effect on bitterbrush since it has naturally low nitrogen requirements due to its symbiotic relationship with the actinomycete genus *Frankia*. This study also demonstrates that fertilizer is less important in arid environments than water. In plots that competition was reduced, seedlings established and grew. Our study agrees with these findings that the addition of fertilizer as a general practice had little effect on seed production. The exception to this in our study was in 2005 at the Nevada site. Here fertilizer did have a positive effect on spur production. This suggests that in localized areas and specific environmental conditions, fertilization could have a positive effect on seed production

Tiedemann (1983) conducted a study similar to ours with one rate of fertilizer and shrubs excluded from browsing. He refers to the treatment that excludes browsing as covered. Eight replications were formed with unfertilized/not covered, unfertilized/covered, fertilized/not covered, and fertilized/ covered. He found that there were not any significant differences in twig growth among the treatments. The fertilized plots did show a significant increase in understory biomass. This study also noted that growth seemed to be more in response to precipitation rather than fertilization. Tiedemann's results are supported by our data which shows that fertilizer did not have a significant effect on spur production generally.

Our study did not investigate different rates or combination of nutrients. We applied the manufactures rate and combination of nutrients that they suggested for use on shrubs. We found that the nutrients in the fertilizer applied were not limiting resources in the production of bitterbrush spurs. We also did not measure understory biomass of

treated shrubs, however, it was visually apparent that the fertilized shrubs did have much more understory biomass, especially compared to that of competition removal which had none.

Limb removal of unproductive plant parts may allow a reallocation of resources to more actively growing plant tissue. This may translate to increased flowering or larger seed. It also shapes shrubs to be more collection friendly. We found that pruned shrubs were easier to place collection bins under. In addition to the ease of placement of collection bins shrubs also incurred less disturbance to seed bearing limbs which means more seed was collected into bins rather than lost on the ground.

As mentioned previously Bayoumi and Smith (1976) found that applying fertilizer to bitterbrush improved the long shoot growth of plants. Ferguson conducted two studies in the 1960's and 70's (Ferguson and Basile, 1966, Ferguson 1972) that also found methods that increased twig growth on bitterbrush. In his first study he topped the shrubs in the study with a chainsaw from a height of six feet to 3-4 feet. This stimulated a two fold increase in the total inches of twig growth over control shrubs. The effect was still apparent 4 years after the treatments were applied. In his second study loppers and chainsaws were used to top bitterbrush. As in his previous study, the topped shrubs showed a severalfold increase in total length of twig production. The effects of the treatments could still be seen several years after the study was concluded and no shrubs died or seemed to lose productivity in future years. Topping is a different form of pruning than was applied in the current study. Even though topping in these studies increased twig growth, in our study pruning had no significant effect on spur production on a regional or local scale with the exception of 2005 at the Nevada site. Here pruning

did increase spur production per meter^2 from 1093 to 1705 (figure 6). In the current literature all forms of pruning on bitterbrush focus on removing apical growing points. This stimulates an increase in total number and length of leaders. Our experiment did not prune in this same manner. By reducing dead/decadent growth and lower limbs we expect over time that this treatment might have a positive effect on seed production due to the shrubs smaller biomass and the same amount of resources.

One study that was conducted by Kituku et. al. (1994) found results that were similar to ours. In this study mowing of bitterbrush was performed as well as a 2,4-D herbicide application to clear competing shrubs such as sagebrush (*Artemisia tridentata* Nuttall) and rabbitbrush. Mowing, another form of pruning, did improve twig growth. In addition they found that the herbicide application did not decrease twig growth and on very productive sites improved growth. Their study showed a better response of treatments on years that had above normal precipitation. Our study supports their findings in that shrubs that had competition removal performed better than shrubs with out this treatment. However at the current time, we did not find an increase of spur production by pruning on a regional scale nor a local scale with the exception of the 2005 Nevada site as mentioned previously.

Wambolt, et. al. (1998) found that browsing had a positive effect on the length that twigs grew after browsing occurred, but that the even though the twigs were longer the amount of flowers along there length decreased. This suggests that there is not a positive relationship between the length of the twig and the amount of flowers, borne on that twig. Since browsing and topping or mowing both are applied to terminal growth points of the shrubs that the findings of this study could also apply to the pruning studies.

This would allow results to ah show an increase in twig elongation but not an increase in potential seed production. Our current study supports this in that our pruning treatment did not produce more leader length or growth and did not increase the potential of the shrub to produce seed. However over time there is the possibility that the reallocation of resources to a smaller canopy might increase seed production.

Browsing terminal growth has been proven to reduce flower production (Wambolt, et. al. 1998) which effects seed production. They found that shrubs that had been browsed produced significantly fewer flowers. The flowers produced during the current year are that year's potential seed production. Fewer flowers lead to a decrease in the potential of the shrub to produce seed. We expected that browsing would have a similar effect as pruning; it could encourage twig elongation but possibly have a negative effect on potential seed production. On the local scale the Utah site in our study supports this. This site was browsed by sheep during the time of our study. We found that browsed shrubs produced 1123 versus 1801 for 2005, and 1131 versus 1753 for 2006 fewer spur production per meter^2 than unbrowesed shrubs (figure 4). At the regional scale browsing did not have a significant effect on spurs per meter^2 simply because the Utah site was the only site that had heavy browsing during the two years of our study.

It must be noted that the 2006 Idaho site did show a significant increase in spur production for the browse treatment. We find these results to be slightly suspect for two reasons. First the Idaho site has received no browsing in the time our study and second the sampler at this site might have biased the data. Data collection in the field season of 2007 will try to correct or verify if the results for the browse treatment at the Idaho site are correct.

Even though the girdling scores by treatment where not significant presenting the data graphically shows that the fertilized shrubs received a higher amount of girdling. This might be due to the increase in the amount of understory biomass. Even though we did not measure understory biomass, Tiedemann in 1983, noted that fertilizer did increase understory biomass under his study shrubs. We feel that the cover provided by the understory of the fertilizer and control shrubs might be a reason why these two treatments received higher scores.

Conclusions

Since only the Idaho site produced seed in 2006 and that was the first year of data for the beating and handstripping collection methods a conclusion is unwarranted relative to the impact on future year's seed production. However some trends did appear that would suggest that handstripping seed could impair future seed production. Future data collection is necessary to accurately make conclusions for experiment one of this study.

Literature that currently exists on bitterbrush and increased production of twig growth or seed production suggests that the production was less of a factor of treatments and more so that of precipitation which in turn increase the amount of moisture that is available to the shrub. In the current study we were able to control competing vegetation from our study shrubs and thus probably increase the amount of moisture that was available to the shrub.

On a regional scale the limiting resource for potential seed production is water available to the shrub. We found that competition removal was the only treatment that addressed this limiting resource. We suggest that if one treatment was to be made to maximize potential seed production across bitterbrush stands in the Great Basin it should

be competition removal. No other treatments applied in this study made a difference for potential seed production on a regional scale. However other factors on local levels depending on the condition of the site could have an effect on seed production. Heavily browsing shrubs can decrease the amount of potential seed production so if the results of this study were applied and the bitterbrush stand selected was part of a sheep allotment then fencing would be appropriate to maximize seed production.

Similar recommendations can be made from the results of this study for pruning and fertilizer. If a stand has a large amount of dead or decadent branches then pruning could rejuvenate the stand and increase potential seed production. This type of pruning may not produce immediate results such as topping or mowing does since it does not apply to actively growing tissue. It is possible over time though that with the same amount of resources available to the shrub and with a smaller overall biomass that pruning could have a positive effect on potential seed production. In addition the removal of lower branches can improve the amount of seed collected because of the ability to place bins under the shrub canopy. Fertilizer can have a positive effect if a site is nutrient deficient, but requirements of native plants are lower than that of agricultural crops so one application of fertilizer maybe enough nutrient supplementation for several growing seasons. Local results suggest that pruning and fertilizer treatments are site and even year specific requirements for bitterbrush stands.

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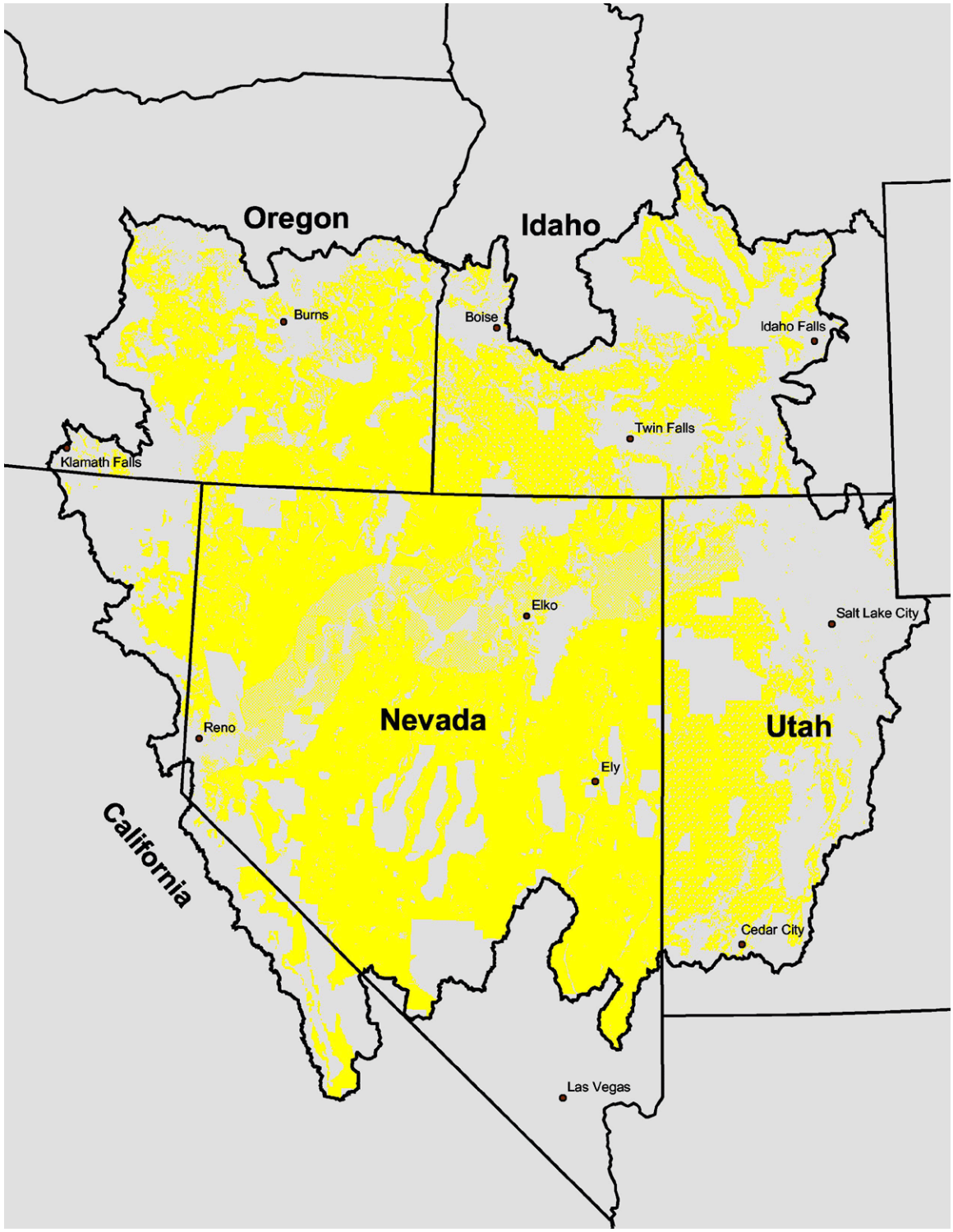

Figure 1: Map of the Great Basin provided by the BLM. It extends across five states in the Western U.S. Shaded areas are public land.

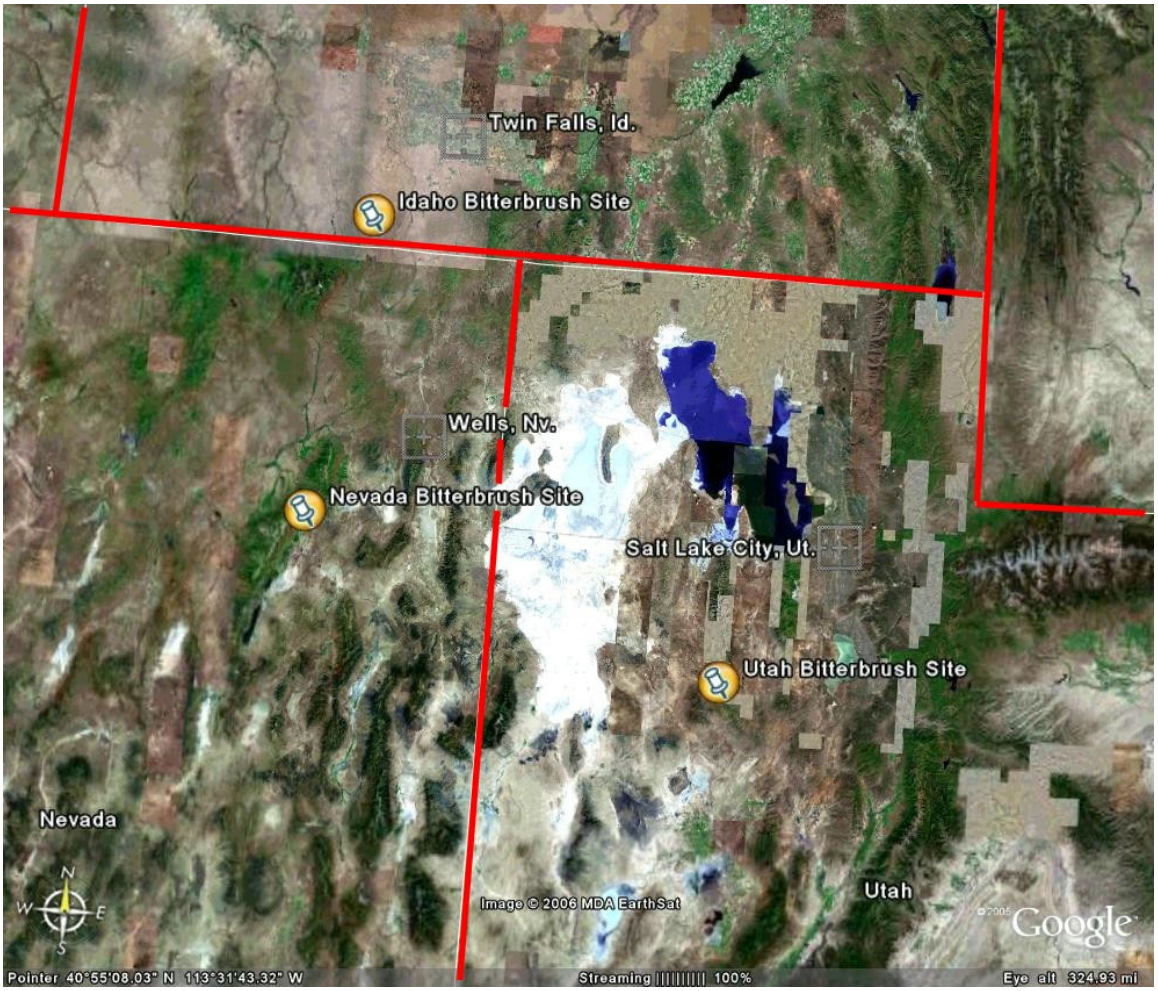

Figure 2: Map of the three bitterbrush sites. The Idaho site is located at 42.150958°N, 114.982247° W. The Nevada site is located at 40.733012°N, 115.229931°W. The Utah site is located at 40.0853°N, 112.5833°W.

Treatment Matrix		
Competition Removal	Fertilizer	Prune
Competition Removal	Fertilizer	No Prune
Competition Removal	No Fertilizer	No Prune
Competition Removal	No Fertilizer	Prune
No Competition Removal	Fertilizer	Prune
No Competition Removal	Fertilizer	No Prune
No Competition Removal	No Fertilizer	Prune
No Competition Removal	No Fertilizer	No Prune

Table 1: Experiment two treatment matrix. Competition removal, fertilizer, pruning and all possible combinations of treatments. Treatments were applied to five shrubs inside and outside excloures at three sites in Idaho, Nevada, And Utah.

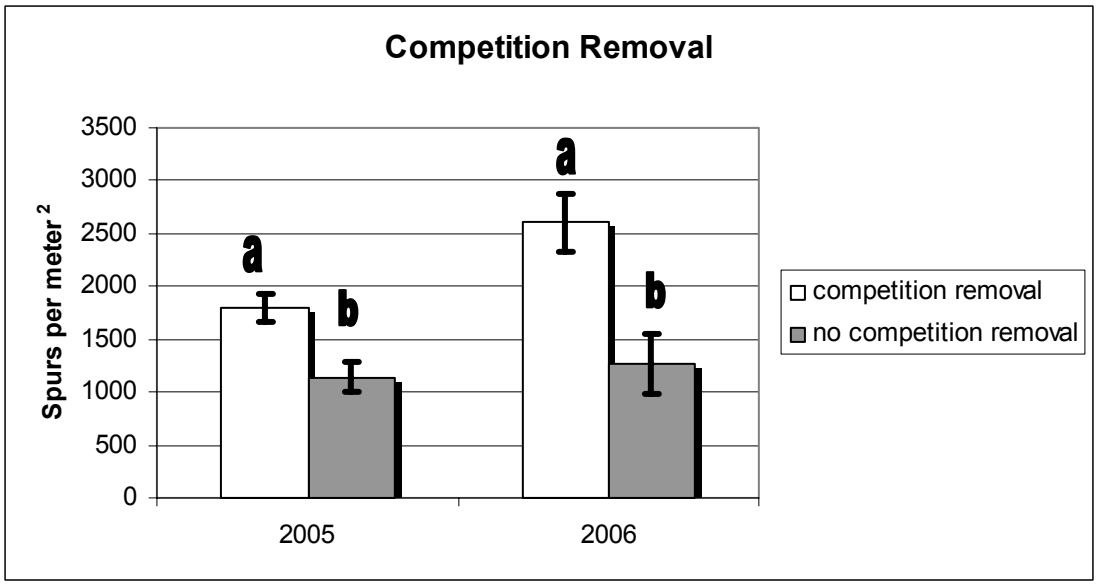

Figure 3: Competition removal across all sites (regional scale). This treatment was the only treatment that had a significant positive effect ($p < .01$ for 2005 and 2006) on spur production in 2005 and/or 2006.

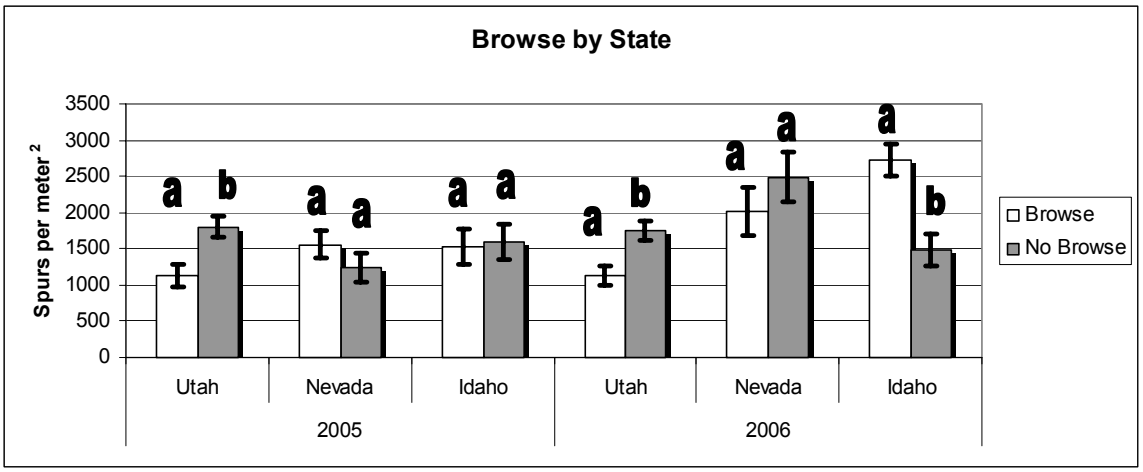

Figure 4: Browse by state. Statistical significance is specific to state and year i.e. Utah 2005 to Utah 2005. At the Utah site in 2005 and 2006, browsing by sheep had a significant negative effect on spur production ($p < .01$ for both years).

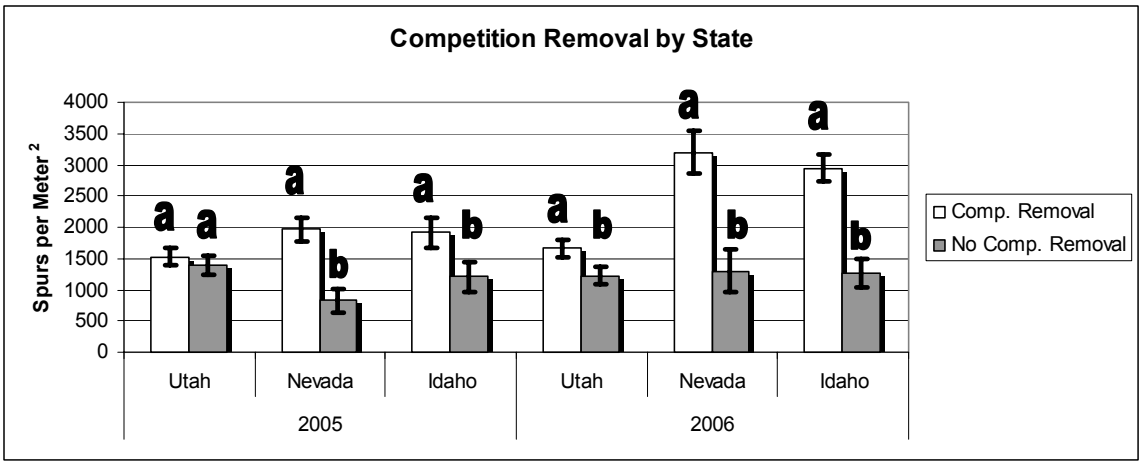

Figure 5: Competition removal by state. Statistical significance is specific to state and year i.e. Utah 2005 to Utah 2005. The 2005 Utah site was the only site not to show a significant response to the competition removal treatment (p = .45). All other sites and years had significant positive response (all p values ≤ .01) to the competition removal treatment.

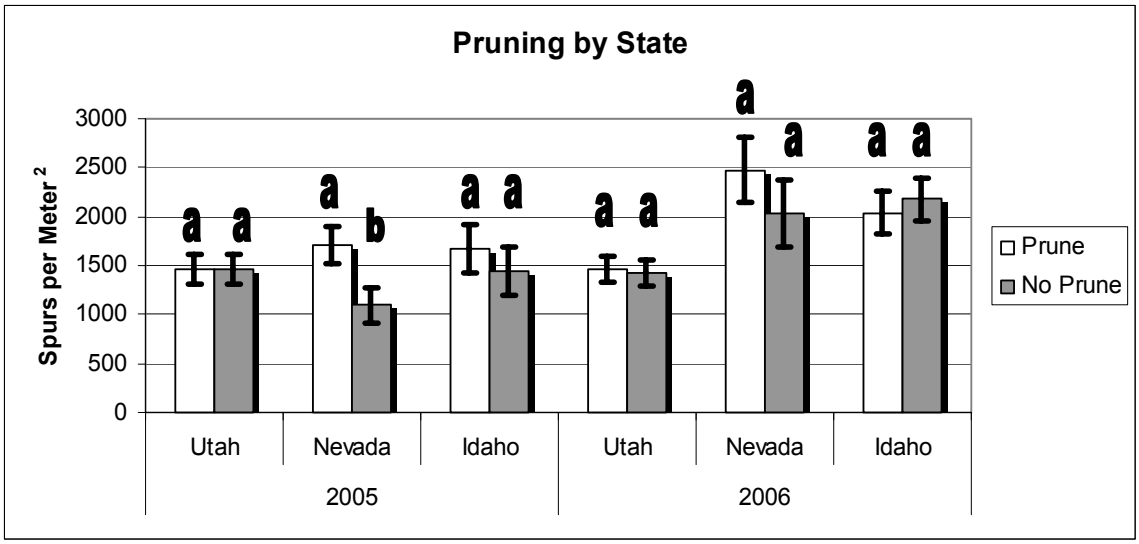

Figure 6: Pruning by state. Statistical significance is specific to state and year i.e. Utah 2005 to Utah 2005. Only the 2005 Nevada site showed a significant positive response (p = .01) to the pruning treatment.

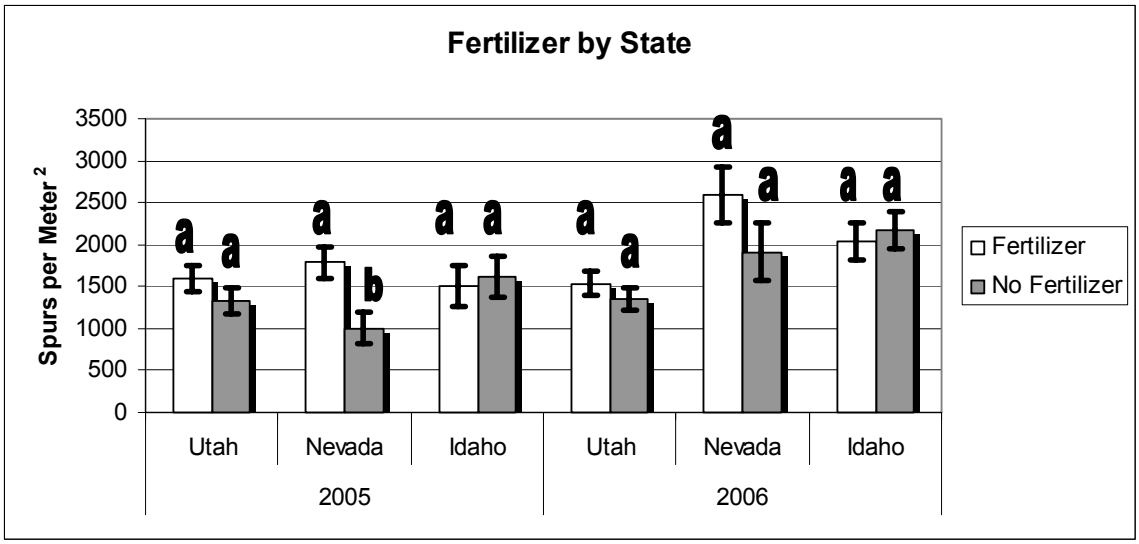

Figure 7: Fertilizer by state. Statistical significance is specific to state i.e. Utah 2005 to Utah 2005. Only the 2005 Nevada site showed a significant positive response ($p < .01$) to the fertilizer treatment.

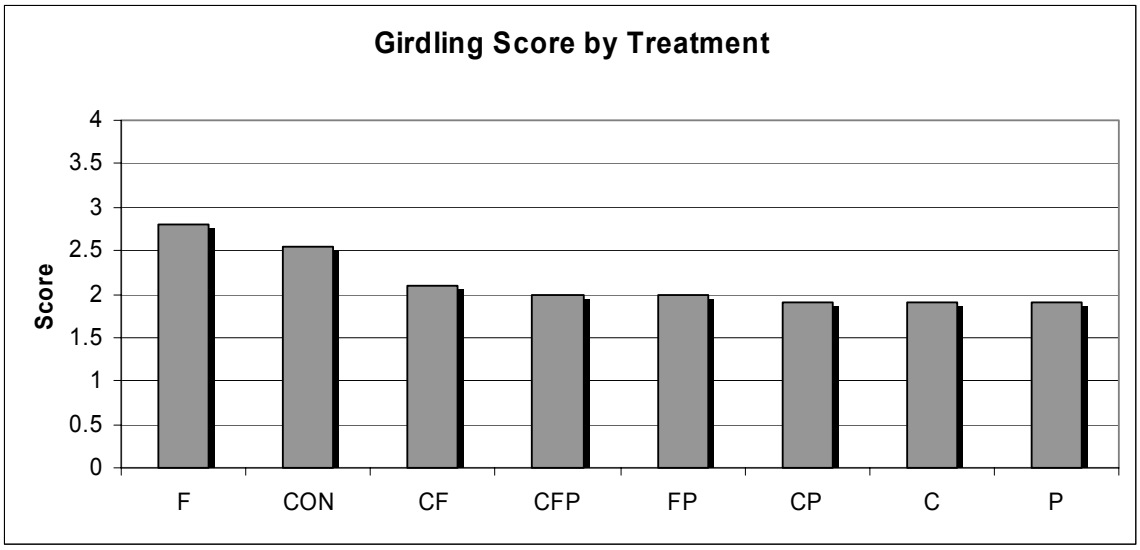

Figure 8: Amount of girdling by treatment at the Nevada site in 2006, no other sites received girdling in the two years of this study. Fertilizer and Control shrubs received the highest girdling scores. Girdling Scores: 4-extreme, 3-severe, 2-moderate, 1-minor, 0-none. C: Competition Removal, F: Fertilizer, P: Prune, CON: Control

		Total Seed Production	Total Seed Collected	Percent of Total Seed Production Collected
2006	Beat	133.9	105.4	78.72%
	Handstrip	55	15.9	28.91%
2005	Beat	281.7	194.4	69.01%
	Handstrip	239.9	124.5	51.90%

Table 2: Experiment one seed collection totals. Data is for the Idaho site only, no other site produced seed for comparison in 2006. Seed from all replications was combined and all seed weights are in grams. Beating seed from plants collects more of the total seed produced over the handstripping treatment.