

Establishment of Bottlebrush Squirreltail and Siberian Wheatgrass  
with In-Soil Hydrogel Water Reservoirs

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## TABLE OF CONTENTS

INTRODUCTION	2
MATERIALS AND METHODS	9
Glasshouse trials	10
Hydrogel Impact on Six Species	10
Hydrogel Depth	12
Nutrition and Hydrogel Interaction	13
Reduced Seeding Rate	13
Field Trials	15
Field Hydrogel Test	15
Hydrogel Variable Rate Field Trial	15
Statistical Analysis	16
LITERATURE CITED	17
TABLES	19

## INTRODUCTION

The United States Air Force (USAF) maintains the Utah Test and Training Range (UTTR) for war plane practice bombing and gunnery exercises in the desert west of Salt Lake City, UT, USA (United States Air Force, 2016). The UTTR sits on 3,859 km<sup>2</sup> of nearly 6,800 km<sup>2</sup> of land owned by the Department of Defense in northwestern Utah and eastern Nevada. The UTTR is divided into a north and a south range by Interstate 80. Most of the remainder of the land functions as the Dugway Proving Grounds (DPG) for the United States Army. The UTTR supports weapons testing and personnel training for Air Force, Army, Navy, and Marine units from the United States, as well as many foreign countries. Approximately 16,000 sorties for training and 300 sorties for testing are flown each year. The site has been in use since World War II and continues today as an invaluable component of the Department of Defense (United States Air Force, 2016).

Although an asset for training and testing for the military, the UTTR also provides food and limited habitat for a variety of species. It is located within the year-round range of the Puddle Valley Pronghorn antelope (*Antilocapra americana*) herd. Wild horses (*Equus ferus*), mule deer (*Odocoileus hemionus*), black-tailed jackrabbits (*Lepus californicus*), and mountain (*Sylvilagus nuttallii*), desert (*Sylvilagus audubonii*), and pygmy (*Brachylagus idahoensis*) cotton tail rabbits; as well as a variety of birds, rodents, and insects are also found at the site (Utah Department of Environmental Quality, 2013). Additionally, livestock grazing occurs seasonally near the UTTR.

There are numerous native plant species, but the predominate species include: Indian ricegrass (*Achnatherum hymenoides* (Roemer J.A. Schultes) Barkworth), bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey), galleta (*Pleuraphis jamesii* Torr.), scarlet globemallow (*Sphaeralcea coccinea* (Nutt.) Rydb.), shadscale saltbush (*Atriplex confertifolia* (Torr. Frém.) S.

Watson), bud sagebrush (*Picrothamnus desertorum* Nutt.), winterfat (*Krascheninnikovia ceratoides* subspecies *lanata* (Pursh) A. Meeuse Smit), and fourwing saltbush (*Atriplex canescens* (Pursh) Nutt.). Cheatgrass (*Bromus tectorum* L.) and other annual weeds invaded the site when wildfires, both naturally occurring and those resulting from the bombings, damaged and destroyed the native vegetation. Cheatgrass, also known as downy brome, is a winter annual grass inadvertently imported to the United States from Europe, North Africa, and Southwestern Asia in the mid to late 1800s (Zouhar, 2003). In the Intermountain West, it generally germinates in the fall and overwinters as a seedling before continuing growth in the late winter or early spring. However, its germination timing can occur through late spring (Zouhar, 2003). It is profusely productive, creating seed banks that may persist for up to 5 years (Sebastian et al., 2017). For the approximately 6 weeks in the spring that it is green, cheatgrass is good forage for both domesticated livestock and wildlife. However, once it dies in the late spring or early summer it loses most of its nutritional value and increases the fine fuel load—making it a fire hazard (Zouhar, 2003). Perennial species, including a variety of grasses, forbs, and shrubs, are required to provide adequate forage and reduce wildfire potential throughout the summer.

Fluctuations in resources are a key factor in invasibility (Davis et al., 2000). Deep rooted perennial grasses, forbs, and shrubs maintain their dominance in a system by utilizing the available space, water, and nutrients and not leaving enough of an excess to be used by exotic species. Damage by fire, insects, disease, or over grazing frees one or more resource and opens a window for an invasive species to become established (Chambers et al., 2014; Monaco et al., 2016). The early germinating cheatgrass takes advantage of the increase in resources and outcompetes perennial seedlings. This process repeats the following spring and the cheatgrass presence increases.

Any mature native plants that survive a disturbance have a chance to recover. Their extensive root systems can secure the water and nutrients necessary for their survival despite cheatgrass competition. However, young perennial seedlings generally emerge too late in the spring to be able to lay claim to the water and nutrients they need to survive the dry summer heat. This occurs because the earlier and faster growing cheatgrass seedlings have already consumed the resources available near the surface. Over time, even established perennial plants suffer from invading cheatgrass.

The continuity of dead, dry plants after cheatgrass completes its life cycle in the early summer increases the likelihood of wildfire. Native perennial species are not adapted to the increased rate of fire and the resulting damage. With limited ability to establish new seedlings, the perennial species can eventually be removed from the landscape and a monoculture of cheatgrass created. The USAF is committed to reasonable restoration of perennial species at the UTTR to reduce their impact on the environment to improving habitat and food sources for the wildlife and reducing wildfire risk.

Reestablishment of perennial species is vital to effectively reduce wildfire frequency and provide wildlife forage and habitat requirements. Perennial grasses, especially, play an invaluable role in controlling and preventing the spread of invasive annuals. Deep roots use resources and prevent invaders from gaining a foothold. Fluctuations in resources can be created that reduce cheatgrass pressure at a site while increasing the probability of success for perennials. Monaco et al. (2016) found that burning (as either wildfires or prescribed burns), herbicides, soil disturbance (disking, tilling or plowing), grazing, mowing, reseeding, and the addition of labile carbon soil amendments to be effective in reducing cheatgrass in the short

term, but only burning, herbicide use, and soil disturbance to be effective in increasing perennial grasses.

Bottlebrush squirreltail is a promising candidate for establishment at cheatgrass infested sites (Zouhar, 2003). A short-lived native perennial bunchgrass that germinates in the early spring, it competes well with cheatgrass. Once established, it plays a key role in assisted succession by competing with invasive species and facilitating the establishment of other grasses, forbs, and shrubs. It maintains a green period during summer months, providing forage for wildlife and livestock and is considered one of the most fire resistant native bunch grasses.

Because introduced species often compete better against invasive species than natives, they are regularly included in rangeland reseeding mixes. Vavilov II Siberian wheatgrass (*Agropyron fragile* (Roth) Candargy), an introduced perennial grass species, was included to compare with bottlebrush squirreltail. A long-lived, drought tolerant, winter hearty bunch grass, it establishes better than native species in areas with low rainfall and competes well with cheatgrass. It is good forage for both livestock and wildlife and is fire resistant. It spreads little by natural seed dispersal and is not considered weedy or invasive (USDA-Natural Resource Conservation Service 2012).

The use of hydrogel (HG) is another potential way to create resource fluctuations in favor of better establishment from seeding of perennials at the UTTR. Hydrogel is a super absorbent, cross linked polyacrylamide or polyacrylamate polymer (Holliman et al., 2005, Varaprasad et al., 2017). Water is a very limiting factor at the UTTR due to an annual precipitation rate of ~25 cm with a typical annual evapotranspiration rate of ~75 cm; along with water infiltration inhibition of the soils dominated by fine particles with low organic matter. (Utah Department of Environmental Quality, 2013). A localized HG soil water reservoir near the roots of an emerging

plant could increase the amount and duration of plant available water during perennial seedling emergence and establishment. When used in conjunction with burning, herbicides, and soil disturbance to reduce cheatgrass presence, HG may allow seeded perennial grasses to establish and outcompete cheatgrass seedlings the next season. Eventually, improved functionality in terms of forage, habitat and wildfire resistance may return.

In addition to limited studies in rangelands, HG has been used as a soil amendment in agriculture to increase infiltration and water holding capacity, improve fertilizer retention, and increase plant longevity (Varaprasad et al., 2017). A similar compound in the form of a water-soluble polyacrylamide is also used in agriculture to increase infiltration, flocculation, and soil aggregation; and can be used to decrease erosion from surface runoff. Both cross-linked and water-soluble forms, as well as other polymers, have been used previously in rangeland applications to prevent soil erosion and crusting and improve vegetation emergence with varying success (Abrol et al., 2013; Ben-Hur, 2006; Darboux et al., 2008; Davidson et al., 2009; Rubio et al., 1992). It has been shown to increase the readily available water capacity for soils (Narjary et al., 2012, El-Asmar et al., 2017, Koupai et al., 2008). Bands of HG prevented or slowed deep percolation of water at irrigation, as well as slowed evaporation of water out of the HG layer in the soil. (Yang et al., 2015). Hydrogels applied as bands at the root zone increase chances for short term survival of seedling transplants (Lucero et al., 2010, Minnick and Alward, 2012, Oliveira et al., 2011). Studies suggest that HGs are capable of absorbing water from precipitation once in the soil (Lucero et al., 2010). Rowe et al. (2005) found that placing dry HG did not affect the mortality of seedling trees. Its water holding potential sharply decreases after 12-18 months, largely due to UV exposure and freeze/thaw cycles (Smagin et al., 2014).

Questions have been raised about its effectiveness in land restoration because of the loss of water holding capacity over time (Holliman et al., 2005). However, the degradation of HG may encourage roots to spread in search of deeper water, stabilizing the plant and making it more resilient. El-Asmar et al. (2017) concluded that HG did improve plant growth, survival, and water use efficiency when banded in the soil, but the amounts of HG required made it technologically and financially impractical to use in agricultural applications.

As in agriculture, germination and establishment of range species are greatly affected by temperature, precipitation, and consumption of seed. However, range restoration differs considerably from agriculture in several aspects. The cost of the seed for a range reseeding project in the Great Basin ranges from about \$185 to \$865 ha<sup>-1</sup> (\$75-\$350/acre) with the average being \$370-\$500 ha<sup>-1</sup> (\$150-\$200/acre) (Josh Buck, Granite Seed, Lehi, UT, USA; personal communication). Establishment rates less than 10% are normal—often with complete failures. These limited successes greatly elevate the relative cost of each surviving plant. Typically, range restoration seeding projects are large—easily running in the tens of thousands of hectares. Often, they are in locations not easily accessed by surface equipment. When terrain, slope, area, and project timing allow, range drills are used in reseeding to improve the seed bed and seed to soil contact as well as keep costs down. If those parameters do not allow drilling, seed is often broadcast by plane. Due to a reduction in the accuracy of seed placement and seed to soil contact, seeding rates are typically doubled when seed is broadcast.

Restoration at the UTTR should be viewed as a hybrid between agriculture production and range restoration with the added boost of a military improvement budget. The area to be seeded is only 162 ha annually—the size of a very small farm. As with most restoration projects, the seed is expensive, and the temperature, precipitation and seed consumption are not



controllable. The small area, with nearly flat ground with minimal rock outcroppings, makes drilling of seed a possibility in most areas. This increases the emergence potential due to better seed to soil contact than aerial broadcasting. In contrast to most range improvement projects, the Air Force has a budget that allows for the option of trying new treatments to improve seeding success. Just over \$233,600 have been spent at the UTTR on seed alone since November 2013, for an average cost of \$46,700 per year. Unfortunately, this has resulted in less than 10% establishment success rate. In some cases, the success rate is as low as 0-4% (Steve Petersen, Brigham Young University, Provo, UT, USA; personal communication). There is always a cost associated with soil improvements. Farmers count the cost of fertilizer and irrigation as a necessary part of doing competitive business. The use of alternative methods, such as HG, in restoration should be of interest to the Air Force to better meet their goal of reducing their impact on the environment at the UTTR.

Priced between \$5.00 kg<sup>-1</sup> (\$2.27 lb<sup>-1</sup>) and \$6.18 kg<sup>-1</sup> (\$2.80 lb<sup>-1</sup>), the cost per kg of HG is less than most range seed (Ken Aguilar, Global Plastic Sheeting, San Diego, CA, USA; personal communication; Scott Mecom, Creasorb, Omaha, NE, USA; personal communication). To increase the likelihood of seeing a response, HG was used in these initial proof-of-concept studies at rates of 1500, 3000, and 6000 kg ha<sup>-1</sup>. Even at the relatively low cost of HG, the cost for those rates will run \$7500- \$37,000 per ha. There are several mitigating financial factors to consider, however. It may be possible to apply the HG at much lower rates successfully, as well as to obtain HG at a lower price if purchasing in very large quantities. Having the ability to reabsorb water during multiple precipitation events, the amount of HG needed to increase establishment may be less than the rates studied here. If used in a band, the HG must be buried in the ground, presumably with an attachment to a range drill, and thus may only be used with

species and in areas with terrain and slope that permit that method of seeding. Improved establishment rates could reduce the amount of seed, and thus the cost, needed each year, as well as the need to reseed the same area multiple times. Rather than being used on the entire reseeding area, HG could be used facilitate assisted succession. Bio-islands or green firebreaks of established perennial grasses could provide a free seed source, invasive species control, fire protection, and erosion reduction for the larger landscape, allowing other species to establish. Invasive weed and fire suppression provided by perennial grasses could also help reduce the overall restoration costs for the site by reducing the amount of money spent to manually, chemically or mechanically do the same. Before any cost savings can be realized, confirmation that HG will increase establishment must be obtained. Once effectiveness is demonstrated, future studies should be done to find alternate seeding, species, and HG rates that would provide an improved establishment rate while lowering the costs.

The objective of this project is to determine the effect of banded HG as an in-soil water reservoir on the establishment from seed of various perennial species. It is part of a larger project commissioned by the USAF for reasonable restoration at the UTTR to reduce their impact on the environment by improving habitat and food sources for wildlife and reducing wildfire risk. It is hypothesized that the HG will collect and store water from rain and melting snow during the late fall, winter, and spring then extend its availability to seedlings of desired species as the weather warms and the soil dries through the summer.

## MATERIALS AND METHODS

A HG (Stockosorb 660 micro; Evonik Industries AG; Essen, Federal Republic of Germany) was evaluated for impact on soil moisture and resultant impacts on emergence and

survival of various range species. The manufacturer states that it can be blended with or placed in a band in the soil with a recommended depth for banding at 10 cm.

### *Glasshouse trials*

Effects of HG application under drought conditions were evaluated in five glasshouse experiments at Brigham Young University (BYU), Provo, Utah, USA (40.2454, -111.6415, 40° 14' 43.33" N, 111° 38' 29.4" W, elevation 1391 m). Seedlings were grown under natural light. Greenhouse temperatures fluctuated to match naturally occurring day and night cycles. Daytime temperatures ranged from 21-28° C and night temperatures from 13-19° C. The pots were only watered once in these studies to determine the water holding capacity of HG over time. Since water couldn't be added to see if dry or wilted seedlings would revive or were truly dead, a seedling was considered dead if it snapped in two when the blade was bent and pinched at the base.

The soil used was collected from Murray's Mesa at the UTTR (41° 2' 27.5136" N, 112° 58' 56.9064" W; elevation 1392 m) unless otherwise stated. The Natural Resources Conservation Service (NRCS) map unit of this site is Tooele Fine Sandy Loam with the rating as coarse-loamy, mixed (calcareous), mesic Typic Torriorthents (Soil Survey Staff, USDA, NRCS). The site is in a disturbed condition due to wildfire followed by cheatgrass invasion.

### *Hydrogel Impact on Six Species*

The effect of HG was evaluated on six range species over 82 d from 28 Sep 2016 to 19 Dec 2016. The species included: bottlebrush squirreltail (*Elymus elymoides* (Raf.) Swezey), Lewis flax (*Linum lewisii* Pursh), forage kochia (*Kochia prostrata* (L.) Schrad.), Wyoming big sagebrush (*Artemisia tridentata* Nuttall ssp. *wyomingensis* Beetle Young), yellow sweet clover (*Melilotus officinalis*), and crested wheatgrass (*Agropyron cristatum* (L.)).

A 300 cm long wood grow box was divided into nine compartments—each 30 cm long by 43 cm wide by 15 cm height. Each compartment was filled with soil having a simulated 4 cm deep planting furrow. At the bottom of the furrow (valley) the soil was 10 cm deep. This furrow was created in the middle of each compartment along the 43 cm length. The soil on the sides of each compartment sloped upward with peaks 14 cm deep at both edges.

Dry HG was placed in a band running the length of the valley at a depth of 7.5 cm below the surface of the valley. Treatments were arranged in a complete randomized block design with HG of 0, 1500, or 3000 kg ha<sup>-1</sup>. The soil in each section was watered once to saturation with 8 l of water poured through paper towels covering the soil surface to prevent erosion. Holes in the bottom of each compartment allowed for gravitational water to escape—with the soils reaching field capacity at about 1 d after saturation. Each species was planted in the order listed above in evenly spaced rows perpendicular to the valley from one peak to the other at a rate of 0.3 g m<sup>-1</sup>. Sagebrush, kochia, Lewis flax, and yellow sweet clover seed were pressed into the soil surface and bottlebrush squirreltail and crested wheatgrass were seeded at 1 cm depth in each compartment.

Volumetric water content was measured at the peak, slope, and valley for each species in each compartment daily until the last seedling died. These measurements were made using a Theta probe and data logger (MLS Moisture Meter with HH2 logger, Delta-T Devices; Cambridge, England). Seedlings were counted daily to determine emergence and survival.

After all seedlings died, the soil and HG in each compartment were resaturated with 8 l of water and allowed to dry completely to observe HG efficacy in the soil over time. This process occurred twice during 2017—13 Jan through 21 March and 1 June through 11 July. As there were no seeds planted either time, the moisture readings were taken at the peak, slope, and valley

only in the front, middle, and back of each section daily from January to March and on days 8, 16, 28, and 41 after rewetting in June and July.

This trial was repeated beginning in April 2018 and is expected to last through January 2019. In this trial, all conditions were the same with a few exceptions. Each compartment was filled by mass instead of volume of soil, with each receiving 16 kg dry soil. The six species were planted at rates of 8 kg pure live seed (PLS) ha<sup>-1</sup> (bottlebrush squirreltail), 6 kg PLS ha<sup>-1</sup> (crested wheatgrass), 4 kg PLS ha<sup>-1</sup> (Lewis flax and yellow sweet clover), and 0.625 kg PLS ha<sup>-1</sup> (sagebrush and kochia) to provide the equivalent of approximately 83 PLS m<sup>-1</sup>. Seedling count, longevity, and soil moisture content were monitored 3 times per week.

#### *Hydrogel Depth*

Hydrogel was evaluated at various depths over 118 d between 13 Feb through 1 June 2017 to determine the effect on seedling survival. Treatments were randomized and replicated four times with rates of 0, 1500, and 3000 kg ha<sup>-1</sup> placed at depths of 0, 2.5, 7.5, or 15 cm below the soil surface, or mixed throughout the soil. These were added to 10 cm square pots 23 cm deep filled to within 6 cm from the top. Based on the results of the previous trial, bottlebrush squirreltail was heavily seeded at a rate of 27 kg ha<sup>-1</sup> seeds per pot at a depth of 1 cm below the soil surface. All pots were immersed once partially in water until capillary action saturated the soil. Seedlings were thinned to three plants on day 15 and to one healthy, vigorous plant per pot on day 30. Soil moisture content was measured gravimetrically three times per week. Seedling emergence was evaluated on day 9. Seedling longevity was monitored on days 26, 30, 71, 73, 82, 85, 87, 106, 108. Shoot lengths were measured and number of blades counted on day 77. After all seedlings had died, the roots were cleaned by spraying with water and filtering through a screen. Lengths were measured of those that were recovered.

### *Nutrition and Hydrogel Interaction*

The impact of fertilizer was evaluated beginning 14 Nov 2017 to determine its effectiveness at stimulating root growth to increase survival of seedlings under drought conditions. The study is expected to continue through June 2018.

Soil was added to a depth of 15 cm into 10 cm square pots 23 cm deep. Treatments were applied to two species grown separately. These treatments included six replicates of all combinations of HG at 0 or 3000 kg ha<sup>-1</sup> with or without fertilizer. The fertilizer was applied at (kg ha<sup>-1</sup>) 4 N, 17 P<sub>2</sub>O<sub>5</sub>, 17 K<sub>2</sub>O, 0.6 S, 0.6 Fe, 0.1 Zn, 0.1 Mn, 0.1 Cu, 0.1 B [the micronutrients were all applied as the chelated form with ethylene diamine tetracetic acid (EDTA) at a 1:1 ratio] applied to the soil surface or 7.5 cm below the soil surface. The HG was applied at 7.5 cm below the soil surface. Prior to planting, the pots were soaked in distilled water for two weeks to encourage germination of seed already in the soil and to allow the soil and HG to become completely saturated. Bottlebrush squirreltail or Siberian wheatgrass were seeded at rates of 8 kg ha<sup>-1</sup> and 7 kg ha<sup>-1</sup> respectively at 1 cm depth. The seedlings were not thinned.

Soil moisture content was measured gravimetrically three times per week. Seedling emergence, length, blade count, and longevity were monitored every 7 d. After all seedlings had died, the soil and HG in the pots were resaturated through capillary action. the Soil water content was again measured gravimetrically three times per week and seedling emergence, length, blade count, and longevity were evaluated every 7 d until all seedlings died.

### *Reduced Seeding Rate*

A trial was begun in May 2018 to observe the effect of reduced seeding rate with HG use on seedling emergence and longevity. Treatments were randomized and replicated four times

with HG rates of 0, 1500, and 3000 kg ha<sup>-1</sup> placed at 7.5 cm depth and bottlebrush squirreltail seeded at rates of 4, 8, and 16 kg ha<sup>-1</sup> at 1 cm depth. These were added to 10 cm square pots 23 cm deep filled with soil to within 6 cm from the top. Seeds were planted after the pots were soaked once from below for 2 weeks to allow germination of any weed seed. Moisture content was measured gravimetrically and emergence and longevity monitored three times a week. Seedling length was measured and the number of blades counted weekly until all seedlings snapped when bent at the base of the plant. This trial is anticipated to run through Sept 2018

#### *Hydrogel Depth and Root Growth*

A trial was conducted to observe the effect of HG banding and depth on root growth beginning in May 2018 and is anticipated to run through September 2018. Manufactured quartz sand (Unimin Corp., Emmett, ID, USA) was used due to previous difficulty in extracting the correct, intact roots from the UTTR soil in previous studies. Treatments were randomized and replicated four times with HG rates of 0, 1500, and 3000 kg ha<sup>-1</sup> placed at depths of 0, 2.5, 7.5, below the soil surface, or mixed throughout the soil. These were added to 176 cm<sup>2</sup> clear containers 18 cm deep filled to within 6 cm from the top. All pots were partially immersed in water until capillary action saturated the soil and HG. Bottlebrush squirreltail was seeded at 1 cm depth a rate of 8 kg ha<sup>-1</sup> around the edge of the container. The sides of the containers were covered with black paper so as not to disrupt normal root growth. Seedling emergence and longevity were monitored three times per week. Soil moisture readings were measured gravimetrically and at 5 and 10 cm depth with a Theta probe through the sides of the containers for the same duration. Shoot length, blade count, and root lengths observable through the container were measured once per week. Upon senescence, the soil was sprayed with water from

the roots and all lengths were measured. This study is anticipated to run through September 2018.

### *Field Trials*

Effects of HG application in range conditions were evaluated in three field trials that took place at the UTTR (41° 2' 27.5136" N, 112° 58' 56.9064" W; elevation 1392 m) and Rush Valley, UT near Lookout Point (40° 7' 52" N, 112° 30' 45" W; elevation 1888m).

### *Field Hydrogel Test*

To test the concept of HG as a water reservoir to aid in seedling survival in a range setting, a study was installed at the UTTR 2 May 2017. Treatments were randomized and replicated 24 times with dry HG rates of 0 or 3000 kg ha<sup>-1</sup> and bottlebrush squirreltail at 8 kg ha<sup>-1</sup> or Siberian wheatgrass seeded at a rate of 7 kg ha<sup>-1</sup>. The HG was placed 7.5 cm below the soil surface in 13 cm diameter holes spaced one m apart in a randomized block design and was charged with 200 ml of water before being covered with soil. Seeds were planted at a depth of 1 cm. The surface soil was wet with 200 ml water at planting and again on 2, 9, and 22 d after planting, as well as natural precipitation at 17 d after planting. No water, other than naturally occurring precipitation was given after day 22. Emergence, seedling length, number of blades, and senescence were monitored at 22, 24, 32, 36, 38, 43, 51, 53, 59, 70, 81, 107, 151, and 193 d after planting. The plots will be monitored for emergence and seedling longevity once a month during the spring of 2018 to observe any new germination or seedling survival from 2017.

### *Hydrogel Variable Rate Field Trial*

Variable rate HG field studies were installed in 2017 to test the efficacy of HG in the field. Bands of dry HG at rates of 0, 1500, 3000, and 6000 kg ha<sup>-1</sup> were placed 7.5 cm below the



soil surface directly below the seeds in 1.5 m rows with Siberian wheatgrass, bottlebrush squirreltail, and antelope bitterbrush (*Purshia tridentate* (Pursh) DC). The bottlebrush squirreltail and Siberian wheatgrass were planted at UTTR on 9 Nov and Rush Valley on 17 Nov at 1 cm depth at 8 and 7 kg ha<sup>-1</sup> respectively. Treatments were arranged in a complete randomized block design and replicated seven times. The antelope bitterbrush was planted in clusters of four seed at a depth of 5 cm every 0.5 m in each row on 1 Dec 2017 at Rush Valley and in blocks 1, 3, and 5 only on 16 Jan 2018 at the UTTR. Soil moisture and temperature were monitored via matric potential and temperature sensors (Teros 21; Decagon MPS-6 sensors; METER Group, Inc., Pullman, Washington, USA). Seedling germination, length, and longevity were monitored monthly beginning in March 2018.

An additional small trial was installed at the UTTR on 9 Nov 2017. Three replications of HG at the same rates and seed of the same species used in the UTTR field trial installed the same day were mixed together and placed at 2.5 cm below the soil surface.

These trials will be repeated in 2019-20 with, depending on the findings in the previously described experiments, reduced rates of seeding and/or HG.

### *Statistical Analysis*

The data from each trial were analyzed by analysis of variance with mean separation by the Tukey Kramer test.

## LITERATURE CITED

- Abrol, V., Shainberg, I., Lado, M., Ben-Hur, M., 2013. Efficacy of dry granular anionic polyacrylamide (PAM) on infiltration, runoff and erosion. *European Journal of Soil Science* 64, 699-705. doi:10.1111/ejss.12076
- Ben-Hur, M., 2006. Using synthetic polymers as soil conditioners to control runoff and soil loss in arid and semi-arid regions—a review. *Australian Journal of Soil Research* 44, 191-204. doi:10.1071/SR05175
- Chambers, J. C., Miller, R. F., Board, D. I., Pyke, D. A., Roundy, B. A., Grace, J. B., Schupp W., Tausch, R. J., 2014. Resilience and resistance of sagebrush ecosystems: Implications for state and transition models and management treatments. *Rangeland Ecology Management* 67, 440-454. doi:10.2111/REM-D-13-00074.1
- Darboux, F., Robin, J. G., Fox, D., 2008. Evaluation of two soil conditioners for limiting post-fire erosion as part of a soil conservation strategy. *Soil use and Management* 24, 366-372. doi:10.1111/j.1475-2743.2008.00175.x
- Davidson, R. A., Davidson, C. F., Roa-Espinosa, A., 2009. Linear anionic polyacrylamide as an effective post-fire soil treatment: Understanding the chemistry and physical science. *Journal of Soil and Water Conservation* 64, 243-252. doi:10.2489/jswc.64.4.243
- Davis, M. A., Grime, J. P., Thompson, K., 2000. Fluctuating resources in plant communities: A general theory of invasibility. *Journal of Ecology* 88, 528-534. doi:10.1046/j.1365-2745.2000.00473.x
- El-Asmar, J., Jaafar, H., Bashour, I., Farran, M. T., Saoud, I. P., 2017. Hydrogel banding improves plant growth, survival, and water use efficiency in two calcareous soils. *CLEAN – Soil, Air, Water* 45. doi:10.1002/clen.201700251
- Holliman, P. J., Clark, J. A., Williamson, J. C., Jones, D. L., 2005. Model and field studies of the degradation of cross-linked polyacrylamide gels used during the revegetation of slate waste. *Science of the Total Environment* 336, 13-24. doi:10.1016/j.scitotenv.2004.06.006
- Koupai, J. A., Eslamian, S. S., Kazemi, J. A., 2008. Enhancing the available water content in unsaturated soil zone using hydrogel, to improve plant growth indices. *Ecohydrology Hydrobiology* 8, 67-75. doi:10.2478/v10104-009-0005-0
- Lucero, M. E., Dreesen, D. R., VanLeeuwen, D. M., 2010. Using hydrogel filled, embedded tubes to sustain grass transplants for arid land restoration. *Journal of Arid Environments* 74, 987-990.
- Minnick, T. J., Alward, R. D., 2012. Soil moisture enhancement techniques aid shrub transplant success in an arid shrubland restoration. *Rangeland Ecology Management* 65, 232-240. doi:10.2111/REM-D-10-00133.1
- Monaco, T. A., Mangold, J. M., Meador, B. A., Meador, R. D., Brown, C. S., 2016. Downy brome control and impacts on perennial grass abundance: A systematic review spanning 64 years. *Rangeland Ecology Management* 70, 396. doi:10.1016/j.rama.2016.09.008

- Narjary, B., Aggarwal, P., Singh, A., Chakraborty, D., Singh, R., 2012. Water availability in different soils in relation to hydrogel application. *Geoderma* 187-188 (Supplement C), 94-101. doi:10.1016/j.geoderma.2012.03.002
- Oliveira, G., Nunes, A., Clemente, A., Correia, O., 2011. Effect of substrate treatments on survival and growth of Mediterranean shrubs in a revegetated quarry: An eight-year study. *Ecological Engineering* 37, 255-259. doi://doi.org/10.1016/j.ecoleng.2010.11.015
- Plumb H. R., 2010. Plant guide bottlebrush squirreltail & big squirreltail. May, NRCS USDA.
- Rowe, E. C., Williamson, J. C., Jones, D. L., Holliman, P., Healey, J. R., 2005. Initial tree establishment on blocky quarry waste ameliorated with hydrogel or slate processing fines. *Journal of Environmental Quality* 34, 994. doi:10.2134/jeq2004.0287
- Rubio, H. O., Wood, M. K., Cardenas, M., Buchanan, B. A., 1992. The effect of polyacrylamide on grass emergence in south-central New Mexico. *Journal of Range Management* 45, 296-300. doi:10.2307/4002981
- Sebastian, D. J., Nissen, S. J., Sebastian, J. R., Beck, K. G., 2017. Seed bank depletion: The key to long-term downy brome (*Bromus tectorum* L.) management. *Rangeland Ecology Management* 70, 477-483. doi:10.1016/j.rama.2016.12.003
- Smagin, A., Sadovnikova, N., Smagina, M., 2014. Biodestruction of strongly swelling polymer hydrogels and its effect on the water retention capacity of soils. *Eurasian Soil Science* 47, 591-597. doi:10.1134/S1064229314060088
- Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web soil survey. Retrieved from <https://websoilsurvey.sc.egov.usda.gov/>
- United States Air Force., 2016. Utah test and training range -hill air force base-about us-fact sheets. Retrieved from <http://www.hill.af.mil/About-Us/Fact-Sheets/Display/Article/672497/utah-test-and-training-range/>
- USDA-Natural Resource Conservation Service. 2012. Release brochure for Vavilov II Siberian wheatgrass (*Agropyron fragile*). Dec; Aberdeen, ID: USDA NRCS.
- Utah Department of Environmental Quality, 2013. Utah test and training range attachment 1-facility description and location. Aug. 8. 1-19.
- Varaprasad, K., Raghavendra, G. M., Jayaramudu, T., Yallapu, M. M., Sadiku, R., 2017. A mini review on hydrogels classification and recent developments in miscellaneous applications.79(Supplement C), 958-971. Retrieved from <http://www.sciencedirect.com.erl.lib.byu.edu/science/article/pii/S0928493116315223>
- Yang, L., Han, Y., Yang, P., Wang, C., Yang, S., Kuang, S., Yuan, H., Xiao, C., 2015. Effects of superabsorbent polymers on infiltration and evaporation of soil moisture under point source drip irrigation. *Irrigation and Drainage* 64, 275-282. doi:10.1002/ird.1883
- Zouhar, K., 2003. *Bromus tectorum*. Retrieved from <https://www.fs.fed.us/database/feis/plants/graminoid/brotec/all.html>

## TABLES

Table 1. Properties of Stockosorb HG used in this study.

<b>Physical Properties</b>	<b>660 Medium, 660 Micro</b>
Basis	Polyacrylic acid – Potassium salt, crosslinked
Appearance	Free flowing white granules
Particle Size Distribution [mm]	660 Medium 0.8 - 2.0 660 Micro 0.2 - 0.8
Solubility	Insoluble in water and organic solutions; swells to a gel upon contact with aqueous fluids
pH-Value (1g/l H <sub>2</sub> O)	7.0 - 8.0
Maximum Absorption (Free swelling conditions)	
1) 0.125% NPK 14-12-14 2MgO	> 150 mL/g
2) Tap Water (hardness grade 4)	> 100 mL/g
3) Synth. soil solution	> 60 mL/g
Absorption Against Soil Pressure (Use conditions in soil at 20 cm depth)	
1) 0.125% NPK 14-12-14 2MgO	> 80 g/g
2) Tap Water (hardness grade 4)	> 30 g/g
3) Synth. soil solution	> 20 g/g
Water available for plants	> 95 %
Toxicology / Ecology	Nontoxic for plants, soil organism and ground water according to OECD – Test Ecology
Residual Monomers [mg/kg] Acrylic acid	< 600

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Stockosorb 660 Technical Data Sheet (Stockosorb); Stockosorb 660 Technical Data Sheet. Evonik, Stockhausen GmbH, CREASORB, Bäckerpfad 25, 47805 Krefeld, Germany. (+49) 2151-38 1314. creaservice@evonik.com; www.creasorb.com, www.evonik.com.