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Short Communication

Using hydrogel filled, embedded tubes to sustain grass transplants for arid land restoration

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ABSTRACT

Grass restoration on remote arid rangelands may require irrigation to stimulate establishment. However, irrigation on undeveloped sites is costly. Vertical irrigation tubes that direct applied moisture to subsurface zones where evaporation is reduced, and hydrogels that prevent applied moisture from infiltrating beyond plant root zones can maximize the portion of applied water available for plant uptake. The survival and growth of *Bouteloua eriopoda* (Torr.) Torr. transplants irrigated with either starch- or acrylic-based hydrogels contained in one of three embedded watering tube styles were evaluated in a greenhouse trial. A field trial evaluated differences in transplant survival and cover between treatments consisting of embedded watering tubes with or without acrylic hydrogels. Greenhouse transplants from all treatments grew 146 days on less than 1 L of water. Plants irrigated with starch hydrogels consumed the most water and exhibited the most growth. Variations in tube styles had minor effects on plant growth and water loss from tubes. In the field, heavy growing season precipitation was observed, and transplant survival was high for both treatments. No significant differences in cover were detected. Greenhouse data demonstrate potential for hydrogel filled, embedded tubes to provide adequate moisture for establishment and growth of deep-rooted black grama transplants. Field data indicate deep-rooted black grama transplants establish successfully when adequate moisture is available.

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Reseeding grasses on remote arid sites is expensive and failure prone (Ethridge et al., 1997). Irrigation during germination and establishment phases could improve survival rates, but substantially increases remediation costs. Bainbridge (2007) described watering into buried perforated pipes or clay pots to minimize irrigation water for desert plant establishment. Use of containerized transplants with long root balls and application of hydrogel dips also increases establishment success (Bainbridge, 1995; Miller and Holden, 1993; Rodgers, 1995; Thomas, 2008). The United States Department of Agriculture Natural Resources Conservation Service (USDA-NRCS) has combined the use of 30″ long root systems, embedded watering tubes and a starch-based hydrogel (Soil Moist™ Natural, JRM Chemical, Inc., Cleveland, Ohio) to provide a long-lasting store of soil moisture available for plant uptake with minimal evaporation and percolation losses (Los Lunas Plant Materials Center, 2004). This technique provided for greater than 80% long-term survival of various shrub species and appreciable vegetative growth after eight growing seasons in a semiarid environment experiencing prolonged drought (Dreesen, 2009, personal communication).

Interest in restoring surface disturbances on arid grasslands, combined with high reseeding failure rates prompted interest in evaluating grass transplants for restoration. Transplants of stoloniferous species may establish and reproduce more successfully than plants initiated from seed, but establishment using starch hydrogels could be difficult to manage at the shorter root depths required for grasses. Acrylic gels, which are less fluid and slower to degrade, may offer a more satisfactory solution.

In the greenhouse study, we compared the survival, growth, and development of *Bouteloua eriopoda* (Torr.) Torr. (black grama) irrigated with either starch- or acrylic-based hydrogels encased in various styles of watering tubes embedded to the maximum depth (46 cm) expected for mature black grama root systems (Gibbens and Lenz, 2001).

Irrigation tubes were constructed by cutting 5.08 cm schedule 40 PVC pipe into 50.8 cm (20″) segments. A single line of 13 holes 1.27 cm in diameter placed 3 cm apart, was drilled beginning at the

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bottom of each tube. Type A tubes were capped on both ends. Type B tubes left the bottom opening uncapped, providing increased contact area between soil and hydrogel. Type C tubes included a wire mesh liner to facilitate retention of dessicated acrylic gels, which could be rehydrated if additional irrigation were needed (Fig. 1).

Tubes were filled with JRM Chemical's Soil Moist Natural™ starch polymer, or either 1–2 mm or 2–4 mm crosslinked polyacrylamide (Soil Moist™, JRM Chemical, Inc., Cleveland, Ohio). The fully hydrated starch polymer is fluid, so to prevent seepage loss, a rate of 1 mg starch polymer to 10 mL water was necessary. For consistency across treatments, this rate was also utilized for the acrylic-based products. Because the tube volume was 1.1 L, this rate allowed containment of approximately 1 L of water in each tube.

Ten-week old black grama (cultivar *Nogal*) transplants dipped in a mixture of 4.7 g/L Soil Moist Natural™ in water to reduce transplant shock, were placed in 36 cm deep plastic Treepots™ (Stuewe & Sons, Inc, Tangent, Oregon) containing a single, hydrogel filled irrigation tube. The tube was rotated so that the openings faced the plant roots (Fig. 1). The pots were filled with potting mix and irrigated to saturation at time zero. Pots were placed in a climate controlled greenhouse in Las Cruces, New Mexico which was maintained at 25 ± 5 °C with natural daylight filtered through whitewashed glass panels. Maximum light intensity measured during the study was 820 μmol m^{-2} s^{-1}. After one week, wilted transplants were given an additional 350 mL of tap water to ensure survival. No additional irrigation was provided.

The experiment was set up in a randomized block design using 9 replicated blocks consisting of randomly arranged transplants representing one of each irrigation tube style by hydrogel polymer treatment combination. Gel height within each tube (representing an approximate measure of remaining water content) and plant growth variables were recorded at regular intervals throughout the study. The volume of water lost from the hydrogel over time was estimated using the formula $V = \pi r^2 h$ (V = volume, r = radius of the tube, and h = gel height). The radius of the gel column within the tube was assumed constant. This estimate provided a rough approximation of minimal water loss (Fig. 2). After harvest, leaf area and tissue biomass were measured.

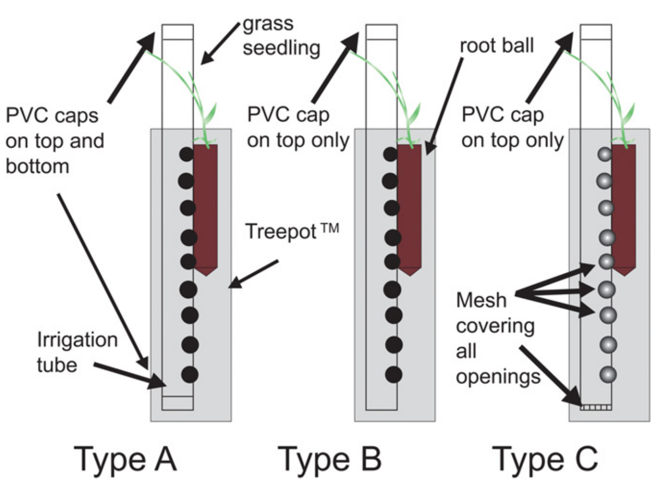

Fig. 1. Irrigation of grass transplants with hydrogel filled irrigation tubes. Type A tubes, left, were capped on the top and bottom to reduce moisture loss. Type B tubes, center, were open on the bottom, allowing for more contact between the hydrated gels and the soil. Type C tubes, right, were identical to type B except that the inside of the tube was lined with stainless steel mesh to ensure retention of desiccated gel particles. All irrigation tubes contained a single row of openings to direct water toward the transplant root. PVC tubes were placed in Treepot™ containers next to transplants, such that holes exposing hydrogel were aligned with the original, cone shaped rootball of the transplant.

A field study examining establishment success was conducted in a 5.5 × 7 m plot within an existing exclosure on the Jornada Experimental Range. This site lies within the Jornada Basin, in the northern Chihuahuan Desert at 32° 36.906′ North latitude and 106° 44.731 West longitude. The location is characteristic of a Sandy Ecological Site (ID # R042XBO12NM) as delineated by the Natural Resource Conservation Service's Ecological Site Information System (ESIS). Average precipitation is 245 mm/year. Mean maximum summer temperature is 36 °C.

Ten-week old, greenhouse cultivated black grama plants with 14 cm root balls were transplanted into eight randomized blocks. The Soil Moist Natural™ aqueous dip described above was applied to reduce transplant shock. Each experimental block contained two groups of 4 transplants, 1 of which was irrigated by tubes filled with 1–2 mm crosslinked polyacrylamide, hydrated as above. The second group utilized empty irrigation tubes as controls. Transplant survival and basal cover were determined after 15 weeks, using actual counts and a grid-point intercept method, respectively.

Statistical analyses were executed using SAS version 9.1.3 software (SAS Institute Inc., 2004). Greenhouse data were analyzed as a randomized complete block with a 3 × 3 treatment structure defined by the variables tube type (A, B, or C) and hydrogel (large acrylic, small acrylic, and starch) and, for some variables, with repeated measures.

Continuous response variables were analyzed with SAS PROC MIXED software using models that included fixed effects for tube type, hydrogel, date, and all interactions of these factors. Blocking was accounted for with random effects for both block and block × date. Correlations among repeated observations from the same unit were accounted for with a REPEATED statement specifying date as the repeated factor, the individual experimental unit as the subject and an unstructured covariance. The Kenward-Roger denominator degree of freedom option was specified.

2. Results

Gel heights within starch filled irrigation tubes were consistently lower (representing greater water loss) than for either acrylic-based hydrogel. At the end of the study, the remaining volume of gels suggested water losses of approximately 455 mL from starch gels and 115 mL from the acrylic gels (Fig. 2). Tube styles also influenced the rate of water loss from acrylic gels, such that the end of the study, large and small hydrogels in tube type C (mean heights of 35.2 and 35.6 cm, SEM = 1.422) had lost more water, as measured by gel height, than either large or small hydrogels in tube types A (mean heights of 42.2 and 42.9 cm) or B (mean heights of 40.5 and 40.1 cm).

Plant height (Fig. 3A) differed with hydrogel type. There was no evidence of hydrogel or tube type effects upon root biomass. However, there was a significant hydrogel effect upon the leaf biomass (Fig. 3B), and total leaf area (Fig. 3C).

Above ground, non-leaf biomass, including seedheads, stems, and stolons, comprised 92% of the total biomass and are identified in Fig. 3D as "other" biomass. For other biomass, tube and hydrogel main effects were significant ($p = 0.0232$, <0.0001). Tube types A and B produced higher mean other biomass than tube type C (estimated other biomass = 0.85, 0.79, 0.63, respectively, SEM = 0.067) and starch produced more other biomass than either acrylic hydrogel (Fig. 3D).

Field transplant survival was high (94%) for both gel-treated and control groups. Basal cover by black grama transplants ranged from 1.1 to 2.4%, with neither date nor gel treatment significantly affecting basal cover.

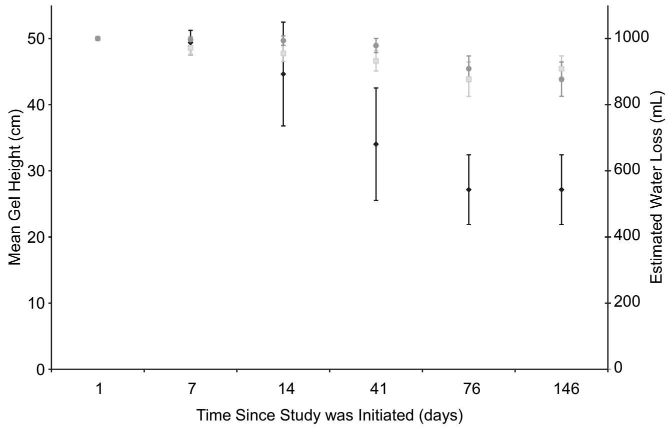

Fig. 2. Gel height in cm decreased over time for all treatments. Heights for each treatment are shown with symbols for starch (diamonds), small acrylic (squares), and large acrylic (circles) hydrogels. Regression lines modeling loss over time are shown with 95% confidence intervals.

3. Discussion

Greenhouse results indicated more rapid water loss and faster plant growth from the starch than from the acrylic hydrogels. These values should be interpreted with caution, since all of the plants irrigated with starch hydrogels (and none of the plants associated with acrylic hydrogels) received 350 mL water additions in the first week after planting. This suggests transplants may have initially accessed more water from the acrylic gels (in which wilting was not observed), and improved growth of the starch hydrogel treatments may simply reflect the benefit of this added free water.

The water holding efficacy of hydrogels is influenced by various factors. The base polymer, water pH, salinity and ionic composition can all have significant effects on maximum water absorption capability (Johnson, 1984). When polyacrylamide gels are mixed with sandy soils the maximum water absorption is substantially reduced compared with the gel alone; the swelling of the gel is limited by confinement by the soil matrix (Bhardwaj et al., 2007). Larger gel granules are also able to absorb more water (Bhardwaj et al., 2007). The use of irrigation tubes to hold the gel might allow increased sorption of water if the gel is rehydrated because gel granules would not be confined by the soil matrix. Reported water holding capacities of Soil Moist™ products in particular vary among vendors, but JRM chemical reports both acrylic and starch-based products can hold 200 times their weight in water. Hence, the gels used in this study were far below maximum water holding capacity.

Plants irrigated with starch-based hydrogels produced more leaf area and total biomass than plants irrigated with the acrylic gels. This is likely due to the higher fluidity of the gel, the receipt of additional water (applied to the soil) at the end of week one, the more rapid loss of water from the starch-based gel (Fig. 2), and the greater bioavailability of the starch, which may have provided additional organic carbon to beneficial microbes.

Low overall counts of seedheads and plantlets (not shown), reduced biomass, and lower heights and leaf areas among plants irrigated with acrylic gels suggests that water was limiting reproductive capacity. Rowe et al. (2005) indicated crosslinked polyacrylamide gels hydrated to a 1:10 polymer to water ratio have a water potential of about −0.4 MPa; at ratios of 1:100 or less, water potentials of approximately −0.1 MPa were reported. A polymer to water ratio of 1:200 would have increased both the bioavailability and the rate of consumption of the polymer-bound water, more adequately ensuring sufficient moisture for growth and reproduction. Increasing the water bound to the starch gel would have had a less positive impact, since this would have resulted in excess seepage, making added water unavailable to the relatively shallow grass roots.

Of the three tube styles used, type B provided the most surface contact between hydrogels and soils. However, tube style did not significantly influence plant height, root biomass, leaf biomass, or leaf area, suggesting tube styles were not appreciably influencing plant water availablility.

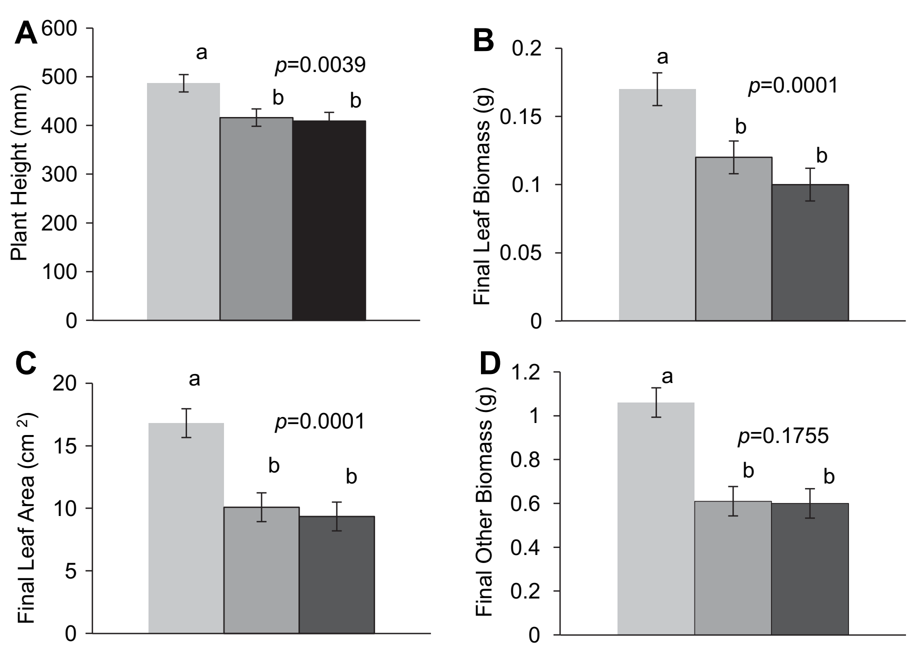

Fig. 3. Selected variables illustrate differences among *Bouteloua eriopoda* greenhouse transplants irrigated with starch (light grey), large acrylic (dark grey), or small acrylic (black) hydrogels. Error bars represent SEM. Treatments with different letters are statistically different according to an F-protected LSD ($p < 0.05$).

Differences in field transplant growth that could be attributed to the presence of hydrogel filled embedded irrigation tubes were not seen. This is probably due to above-average precipitation (216 mm in 15 weeks) observed during the study. Transplant survival was identical for both treatments (94%). This value is high compared to a recent field study in which only 38% of black grama transplants survived through the end of the season (Lucero et al., 2008). The high survival rate could be attributed to the use of deeper rooted transplants, the starch gel dip utilized at planting, and the timely arrival of precipitation. Tubes examined at the end of the study were still completely filled with hydrogel, suggesting that high moisture levels in the surrounding soil either reduced water loss from the tubes or that the tubes captured runoff from precipitation, permitting the gels to rehydrate.

4. Implications

Deep-rooted grass transplants receiving adequate moisture exhibited high survival rates on arid rangelands. Starch-based hydrogels in embedded irrigation tubes described here provided moisture sufficient to ensure plant growth and reproduction beyond a single growing season. However, the amount of polymer required to retain the gel within tubes is high, making the starch gels expensive to utilize. Acrylic gels also supported plant growth, but the hydration ratio of 1 part hydrogel to 10 parts water applied in this study limited growth and reproduction. Ratios of 1:200 (hydrogel:water) should provide initial water potentials near −0.05 mPa (Rowe et al., 2005), which would significantly improve plant performance. For this reason, transplants irrigated with fully hydrated acrylic gels are expected to produce the best restoration outcomes at the lowest cost. Additional field studies should be implemented to assess these expectations. Plant growth differences between large and small acrylic particle sizes were insignificant. Minor differences in plant growth and water consumption suggested small tradeoffs for various tube styles. Larger openings may increase water availability for the transplant, but may also increase water available to surrounding weeds. Although reproduction via stolons and seeds was only observed for large particle hydrogels in tubes with maximum exposed hydrogel surface area (tube style B), a lower ratio of hydrogel to water within the other tube styles would increase the moisture available to transplants without augmenting risk of increased weed competition. Placement of tube openings in direct contact with the transplant roots is recommended.

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