THE EFFECTS OF AQUASMART POLYMER COATED SAND ON GROWTH AND WATER USE OF ORNAMENTALS, NUTRIENT LEACHING IN GREENHOUSE MEDIA, AND ESTABLISHMENT AND GROWTH OF TURFGRASS

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Abstract: The use of soilless substrates in the greenhouse and nursery industries has increased in recent years. While these substrates provide consistency and initial sterility, they are often hydrophobic, especially if they dry out between irrigations. For the turf industry, water conservation strategies are becoming more important as irrigation water availability is decreasing. Synthetic polyacrylamides, such as AquaSmart, may help with initial water and nutrient absorption in greenhouse substrate and mineral soils, and increase the water holding capacity of those substrates. These studies evaluated the effects of AquaSmart on growth rate, substrate water retention, and days to permanent wilting of ornamental flowers; nutrient leaching and dry-down rates of soilless substrate amended with fertilizer; establishment and growth of newly seeded and sodded bermudagrass, sod establishment under different irrigation regimes, drought tolerance of established bermudagrass. Results indicated some significant effects of AquaSmart on plant growth, irrigation frequency and volume, and days to permanent wilt, although there was also variation within the ornamental species; significant differences in leaching rates of nitrate, ammonium, and phosphorus from the soilless media with phosphorus, ammonium, and nitrate all showing significantly linear responses; significant differences in substrate dry-down rates under three different fertilizer regimes with the no fertilizer treatment taking the longest to dry down; and irrigation regimes in turfgrass sod giving strongly significant results with little strong interaction between AquaSmart rate and turf quality, percent green cover, normalized difference vegetation index, or volumetric water content.

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Chapter I: Literature Review

In some parts of the United States (U.S.), such as California and other western states, drought has become so severe that water use is strictly controlled (Kostyrk, 2015). Decreasing rainfall events during the growing season or prolonged periods of drought are a concern for turfgrass and greenhouse/nursery crop producers, especially as municipal water usage allowances for gardens and turfgrass are becoming tightly regulated (Kostyrk, 2015). While drought is a recurring part of Oklahoma's climate cycle, the last 10 to 15 years have had more extreme and less predictable rainfall and drought events (Arndt, 2003). Additionally, in recent years, the cost of water has increased in many communities due to dwindling groundwater resources and prolonged drought (Niu et al., 2003). The combination of water use restrictions, higher costs for water, and uncertainty over consistent annual rainfall has led many consumers, both commercial and residential, to explore and request more drought-tolerant plant and grass species and water-saving methods and products.

Within the turfgrass industry, there are currently two main strategies for reducing water use. The first is to improve turfgrass drought resistance, and the second is to develop water-saving methods and products during production. Drought resistance is one of the most commonly sought after traits for turfgrasses in the southern and transition zones. Much of the work in developing better drought resistance in turfgrass species is being conducted at research universities across the southern U.S. where established breeding programs exist. As drought resistance is one of the primary traits requested by consumers, selecting for drought resistant turfgrass strains has become common. The second strategy, the development of water-saving methods and products, is directly related to the topic of this thesis.

These strategies also apply in the nursery crop production industry where focusing on water-saving methods and products is the ideal approach for the greatest impact due to the broad swathe of plant varieties used in the nursery industry (Warncke and Krauskopf, 1983). The development of drought-resistant plant varieties is less common in the nursery crop industry as there are often already many varieties of the same species currently under cultivation. However, as consumers in some parts of the country are turning away from turfgrass lawns in favor of more water-wise landscaping and functional turfgrass spaces, the demand for both drought-tolerant plants and water-saving products is increasing.

One of the groups of water-saving products that have come on the market are hydrogels and wetting agents, both of which function as soil and greenhouse substrate amendments. The use of hydrogels and wetting agents in the soil or greenhouse substrate has been shown to increase initial water uptake (Gehring and Lewis, 1980) and has the potential to lower total plant water use without impeding overall growth. Hydrogels may also help with nutrient retention within the soil or potting substrate, thus providing plants with increased access to necessary nutrients. However, the current body of research on the efficacy of these hydrogels, or hydrophilic polymers, on water and nutrient uptake and subsequent release provides mixed results and there is a need for further testing at the product and plant crop levels.

Hydrophilic polymers

Hydrophilic polymers, or hydrogels, have been in use since the 1960's in the greenhouse and agricultural industries. With the capacity to hold many times their weight in water, release it gradually over time, and rehydrate when exposed to water again, hydrogels can potentially provide a great benefit to growers, especially in arid or drought-stricken regions. There are three commonly used types of hydrogels: natural polymers derived from polysaccharides, semi-synthetic polymers (primarily cellulose derivation), and synthetic polymers (Mikkelson, 1994). These synthetic polymers generally consist of polyacrylamides (PAM) and polyvinyl alcohols.

Within the synthetic polyacrylamides, there are two primary classes of polymers: linear and cross-linked polyacrylamides. Both are used within the agricultural and horticultural industries to help combat soil erosion, increase water retention within a soil, and help to slow the leaching of nutrients through the soil (Kay-Shoemake, et. al., 1998). The difference between the two types of polymers lies in their chemical construction: linear polymers are singular polymers while cross-linked polymers are polymers connected together during their construction process through covalent or ionic bonds. Because of this construction difference, linear polymers readily dissolve in water, allowing them to be easily incorporated into a field or along a slope for erosion control. Once in the soil, these polymers appear to irreversibly bond to soil particles and improve clay flocculation, thus helping to stabilize the soil structure (Kay-Shoemake et. al., 1998).

Cross-linked polymers are chemically cross-linked to prevent them from dissolving in solution (Abedi-Koupai and Asadkazemi, 2006). Instead of being applied in tandem with irrigation water, cross-linked polymers tend to be incorporated into the system as part of a substrate mixture for greenhouse and nursery crops or a soil amendment for field crops or turfgrass.

Chemical cross-linking in synthetic polymers binds the segments together to restrict or entirely prevent changes to the physical structure of the polymer. Part of what can make these polymers so effective is their capacity for anionic exchange, cationic exchange, or sometimes both (zwitterions); the most common formation method for both anionic and cationic hydrogels is by polymerizing anionic and cationic monomers (Mikkelson, 1994). These synthetic polymers are formed in chains, and have a large capacity for water absorption due to the polar functional groups along the 'backbone' of the polymer chain and the molecular structure of water (Mikkelson, 1994).

On the other hand, this same capacity for anionic and cationic exchange can also make water uptake more difficult in some hydrogels depending on the salt content and makeup of the hydrating solution being used. Mikkelson (1994) found that divalent cations, such as Ca^{2+}, had a greater adverse effect on hydrogel saturation than monovalent cations, such as NH_4^+. An earlier study by Bowman et al. (1991) hypothesized that the Ca^{2+} ions may be forming ionic bridges between the carboxyl groups along the gel's chain, thereby limiting water absorption by restricting polymer expansion. Mikkelson (1994) also found that the source of the cation had a greater effect than the source of the anion on water uptake capability. This supports findings of Bowman et al (1991) that the valence of the anion had no effect on hydrogel hydration, but that cation valiancy did. Other studies have shown that even tap water, which has an average Ca^{2+} content of only 5 mM across much of the U.S., can reduce the water-holding capacity of polyacrylamide polymers by up to 70%, which could present an additional challenge to growers (Frantz et al., 2005). These findings are important, especially when considering the use of fertilizer treatments in conjunction with hydrogel usage.

Fertilizer use in turfgrass and nursery production is very common, and if hydrogels have the ability to retain nutrients along with water, this could benefit both plants and growers by providing a steady nutrient supply and decreasing fertilizer inputs, respectively. Hydrogels absorb nutrients more effectively when those nutrients are applied in solution, such as through fertigation or through the use of liquid fertilizers (Martin et al., 1993). Once the polymers are fully saturated and have absorbed the nutrients (nitrogen-N, phosphorous-P, and potassium-K are the primary nutrients under consideration), the release of those nutrients back into the soil is facilitated by mass transfer resulting from a concentration gradient (Mikkelson,1994). Previous studies conducted by Magalhaes et al. (1987) compared different concentrations of a vinyl alcohol-acrylic acid copolymer for their effects on N and K leaching. While they found that leachate levels of NH_4 and K were greatly reduced, there was no significant change in the leaching rate of NO_3 across the four polymer treatments. However, a companion study investigating greenhouse-grown radishes (*Raphanus sativus* L.) showed that radish shoot growth and plant uptake of N and P were both significantly increased in the presence of the polymer (Magalhaes et al., 1987). In a study examining Fe (iron) absorption, Mortvedt et al. (1992) noted that the addition of a hydrophilic polymer created a nutrient source in soils that had naturally low Fe content. This greenhouse study showed that some of the polymers, when applied with $FeSO_4$ formed a micro-environment within the root zone that maintained and released $FeSO_4$ in plant-available form as compared to applications of $FeSO_4$ by itself (Mortvedt et al., 1992).

While hydrogels may help with nutrient retention in the soil and allow for a slower release over time, they may also be adversely affected by the chemical content of the fertilizers being used or of the irrigation water, especially when groundwater in high salinity areas is used for irrigation. This can lead to situations where any advantages in water and nutrient retention from using the hydrogels are lost or significantly decreased (Asady et al., 1985). In a study comparing irrigation water and nutrient solutions, Lamont and O'Connell (1987) showed that while the hydrogels absorbed up to 410 times their weights in water when saturated in distilled water, even high-quality tap water with a relatively low conductivity rate reduced absorption by up to 45%. The low fertilizer rate of 0.5 kg m^{-3} Micromax, which is a realistic nutrient level for greenhouse and nursery plant production, further reduced the absorbency rates of the hydrogels (Lamont and O'Connell, 1987; Handreck and Black, 1984).

Additionally, nutrient diffusion from saturated hydrophilic polymers may be complicated by changes in soil moisture, soil pH, and the presence of other ions in the soil (Johnson, 1984b). To help offset these complications, it is important to carefully select the appropriate hydrogel for the area, taking into account soil pH and makeup, baseline irrigation water salt content, and other related factors (Johnson, 1984b). One other consideration for hydrogel use in a field setting is the mechanism for best vertical placement of the product within the soil (Mikkelson, 1994). If used only at the surface, the polymer's water and nutrient retention potential may stimulate shallow, surficial root development of the treated crop, whereas application at too deep of a level may place the polymer at a depth beyond the reach of most plant roots.

The water retention capacity of hydrogels can also vary depending on the type of soil in the field. In general, sandy and sandy loam soils show a greater increase in water-holding capacity with the presence of hydrogels than do loam soils, although both show an improvement over soils not treated with hydrogels (Akhter et al., 2004). In addition to increasing the water holding capacity of soils, hydrogels also reduce the rate of water evaporation from the soil. Akhter et al. (2004) noted that both sandy loam and loam soils treated with hydrogels had longer evaporation release curves than untreated soils, showing a 4 to 5 day delay in the onset of permanent wilting between the treated and untreated plots. They also showed that while the presence of hydrogels did not affect the germination rates of wheat and barley, seedling growth rates were enhanced. Conover and Poole (1979) and Still (1976) both found increases of 10%-30% in time to wilting of several ornamental flower species including chrysanthemums (*Chrysanthemum* x *morifolium* Ramat.). However, other studies such as James and Richards (1986) have shown little or no benefit to incorporating hydrogels into the soil, even at above recommended rates. They also showed that plant wilting response did not closely follow the water-retention trends, although they noted that their study was conducted with young marigold seedlings with small root systems that may not have been able to fully access the additional available water. In line with these results, Johnson (1984a) showed that the tension force, under which absorbed moisture may be held, might be too high for the held water to have an effect on the amount of moisture available to plants.

In a study investigating hydrogel incorporation and its effects in both bark and bark-sand substrate mixes, Fonteno and Bilderback (1993) noted that hydrogels that were initially hydrated in distilled water, allowed to dry, and then rehydrated again in distilled water had greater rehydration rates than hydrogels initially hydrated in either pine bark or a pine bark-sand mixture. Interestingly, they also showed that hydrogels initially hydrated in the pine bark-sand mixture had higher rehydration rates than the hydrogels initially hydrated in the pine bark and they suggest this difference might be due to effects of one or more of the leachable compounds commonly found in pine bark (Fonteno and Bilderback, 1993; DeVleeschauwer et al., 1981). In a study examining the effects of polyacrylamide on water absorption and desorption in a mineral soil, Bakass et al. (2000) showed that higher application rates of the hydrogel corresponded to a soil water retention period. In another component of the same study, looking at corn (*Zea mays* L.) and broad bean (*Vicia faba* L.), they noted that both plants showed a life span increase of 8 to 10 days post-irrigation in the presence of a 1% concentration of the hydrogel as compared to the non-amended soil (Bakass et al., 2000).

While potentially an effective soil amendment for water and nutrient retention purposes, hydrophilic polymers are not a permanent addition to the soil. Once incorporated into the soil or growing substrate, the polymers begin to degrade, averaging 10% degradation per year in ambient soil conditions under the influences of physical, chemical, biological, and phytochemical processes (Tolstikh et al., 1992). Intense ultraviolet radiation has also been shown to increase the rate of polymer breakdown (Bhat et al., 2006). Additionally, Bhat et al. (2006) showed that the five polymers they tested were least effective under variable ambient temperatures, such as are found in a crop field or turfgrass lawn, while the polymers were most effective under greenhouse conditions. Andry et al. (2009) tested two polymers under several temperature and irrigation water quality regimes in sandy soils. They showed that increasing soil temperature and decreasing water quality both adversely affected the absorption potentials of the two polymers, although one of the polymers did have increased water content values at field capacity as the temperature increased (Andry et al., 2009). These results indicate that the polymers released moisture into the surrounding soil as temperatures increased, and that released moisture was either lost through percolation or taken up by plant roots (Andry et al., 2009).

While the synthetic polymers tend to degrade under ambient growing conditions, only a small proportion of the polymer degrades into acrylamide, which is a known toxin (Smith et al., 1997). Interestingly, in other research conducted by Smith et al. (1996) under artificial light and various temperature conditions, the addition of a glyphosate-surfactant herbicide resulted in an increase of acrylamide. The authors suggest that this increase was due to glyphosate promoting the degradation of polyacrylamide to acrylamide. However, under outdoor conditions, Smith et al. (1997) showed that polyacrylamides tend to degrade to acrylamide. They noted that the primary environmental factor of polyacrylamide degradation was exposure to photolytic effects, the energy from the sun that can break chemical bonds. In terms of concentrations of toxic acrylamides in the environment from these polymers, Smith et al. (1997) suggest that either the acrylamide volatilizes into other molecular compounds such as ammonium, or that the polyacrylamide tightly bonds to insoluble particles, preventing its initial degradation into acrylamide.

In conclusion, polyacrylamide polymers, or hydrogels, show promise as useful soil amendments for water and nutrient retention in both greenhouse potting substrate and mineral soils. Due to the variety of chemical structures of these polymers, testing should be done prior to incorporation to ensure that the selected polymer will perform as needed and not react adversely with either the substrate, the fertilizer(s) used, or the available irrigation sources. Some polymers are better suited to greenhouse and nursery crops and potting substrates, while others are better suited to the temperature and humidity variations of mineral soils in the field.

Greenhouse/Ornamentals

Greenhouse and nursery production operations primarily rely on soilless substrates for growing their plants (Warncke and Krauskopf, 1983). The incorporation of hydrogels into these substrates can facilitate increased initial water uptake, thus allowing for quicker substrate saturation (Fonteno and Bilderback, 1993). However, other studies have shown that the water retention capacity of hydrogels is significantly affected by the chemical and ionic makeup of the irrigation water (Asady et al., 1985), especially when water salinity is high. Additionally, hydrogels often show the greatest efficacy when used in coarse, or sandy, soils where water retention potential is very low as noted in Johnson (1984a). For greenhouse and nursery production, more than in turfgrass, drying and rehydrating of substrate is relatively common depending on the irrigation scheme for the facility. While hydrogels have been shown to increase water holding capacity initially, some begin to lose their efficacy with constant drying and rewetting (Frantz et al., 2005). Given the high cost of incorporating hydrogels into the substrate mix (up to 15% of total costs), relying on hydrogels for initial germination and establishment of plants is most cost-effective (Frantz et al., 2005).

Other studies have compared different types of hydrogels in soilless substrate with and without amendments. Length of time and amount of water needed to initially bring the polymers to full saturation within the substrate differed, and there were differences in rehydration depending on the soil amendments used (Wang and Gregg, 1990). Wang and Gregg (1990) showed that for the polyacrylamide materials, most effects of soil amendments on water uptake were reversed when polymers were soaked in distilled water. Unfortunately, using distilled water as the irrigation source for a greenhouse or nursery would be cost-prohibitive to any growing operation, regardless of size. As discussed above, to offset the adverse effects of irrigation water conductivity and soluble salt levels, growers must carefully choose the hydrogel for their operation to ensure the greatest return on their investment (Johnson, 1984b).

In a greenhouse study investigating bell pepper (*Capsicum annuum* L.) growth and fruit production in three different types of media, del Amor and Gomez-Lopez (2009) showed that peppers grown in rice hulls amended with a synthetic polymer (Hydrocell) were smaller plants that produced less fruit compared to bell peppers grown in coconut coir dust or urea formaldehyde foam. Bell pepper plants are a drought-sensitive crop, and the addition of a hydrophilic polymer did not counteract the low water holding capacity of rice hulls compared to the other two growing substrates (del Amor and Gomez-Lopez, 2009). In a separate greenhouse study involving pansies (*Viola tricolor* DC.), and new guinea impatiens (*Impatiens hawker* W. Bull) grown with different rates of a polyacrylamide hydrogel, Frantz et al. (2005) noted few significant differences, and concluded that the primary benefits of the polyacrylamide was a lower irrigation requirement early in plant establishment, that could provide a benefit such as larger, higher quality plants or faster plant growth to greenhouse and nursery growers.

Woodhouse and Johnson (1990) compared early establishment (the first 16 days) of lettuce (*Lactuca sativa* cv. 'Webb's Wonderful' L.) and barley (*Hordeum vulgare* cv. 'Tasman' L.) plants grown with three polymers. They measured dry weight of plants, days to wilting after saturation, and the water use efficiency (grams of dry matter produced per kg of water supplied). Water use efficiency improved with all three polymers, regardless of the plant species tested, and root aggregation around gel fragments within the potting substrate was clearly visible for both species. Root aggregation is important because it results in maximum root contact with the hydrogel and the moisture source within the soil and likely facilitates greater water use efficiency (Woodhouse and Johnson, 1990). Previous research with greenhouse-grown plants resulted in similar results in establishment for seedlings, including establishment increases near 100% (Azzam, 1983) and improved growth in tomatoes, a drought-sensitive species, following the incorporation of polymers into their growing substrate (Pill and Jacono, 1984).

Greenhouse and nursery growers, because they primarily use soilless substrate in their operations, rely on fertilizer application to supply plants with required nutrients. Fertigation, or an irrigation system that provides water and nutrients in the same solution, is a common practice among operators of facilities with NO_3-N – one of the primary necessary nutrients (McAvoy et al., 1992). Due to the way greenhouse irrigation and fertigation systems are set up, water often overflows and flushes nutrients through the media to the floor, where it can become a potential source of significant nitrate contamination to the underlying soil and surrounding area (McAvoy et al., 1992). Aside from the potential environmental concerns of nitrate contamination, the overflow of fertilizer also represents an economic cost to growers as they are required to add more fertilizer than necessary to account for leaching rates. Polyacrylamide polymers have the potential to mitigate this problem by holding and releasing nutrients as well as water.

Hydrophilic polymers also can be used in landscape beds with annual ornamentals. In a field study, Boatright at al. (1997) showed that petunias (*Petunia parviflora* cv. Lilac Madness) planted in soils amended with hydrophilic polymers had more flowers and greater growth rates of both roots and shoots (measured by dry weight) than petunias planted in unamended soils. This same study noted no difference in flower production or root and shoot growth rates of marigolds and vinca between polymer amendment rates. However, petunias are less drought tolerant than either marigolds (*Tagetes micrantha* Cav. cv. Safari Orange) or vinca (*Catharanthus roseus* G. Don cv. Tropicana Bright Eye), which might explain the difference in plant growth performance with different polymer treatments. Additionally, in a similar study Bearce and McCollum (1977) reported similar increases in plant height, dry weights, and number of flowers in potted chrysanthemums grown in soil amended with hydrophilic polymers.

Research results on the effectiveness of hydrogels as a water-reducing and cost-savings amendment to greenhouse potting substrate is mixed. Some studies show increases in seedling germination and initial growth (Woodhouse and Johnson, 1990; Azzam, 1983), but whether the plant benefits outweigh the additional cost of the hydrogel depends on a variety of factors including potting substrate, plant species, and fertilizers used. Even with demonstrated moisture-retention properties (Woodhouse and Johnson, 1990), the binding tension under which the water is held may be too great for the plant roots to break, leaving the moisture within the soil inaccessible to plants. In light of the current body of research on hydrogels, polymer selection is perhaps the most important factor for determining water-retention, plant growth increases, and resulting success.

Turf

In the United States, the turfgrass industry is a stable and important part of agriculture. Aside from commercial sod and seed production for turfgrasses, the industry also includes lawn care and equipment, golf courses and sports fields, and turfgrass maintenance. According to the 2012 Census of Agriculture conducted by the United States Department of Agriculture (USDA), in 2012 there were 321,309 acres in the United States being managed for commercial sod production, down from 408,440 acres from 2007, for a total revenue of $1.01 billion in 2012, down from $1.35 billion in total revenue from 2007 (USDA 2012 Ag Census). In 2002 the United States turfgrass industry as a whole brought in some $57.9 billion in revenue (Haydu et. al., 2008). Also in 2002, over 163,000 km^2 of land area was being managed for turfgrass, about 128,000 km^2 of that managed as home lawns, an area 3 times larger than any irrigated crop grown in the U.S. (Milesi et. al. 2005).

In the turfgrass industry, turf quality is very important, especially for sports complexes and golf courses (Guerrero et al., 2007). Maintaining high turf quality is a water-intensive operation, especially in regions with lower rainfall, arid soils, warmer temperatures, or a combination of those factors. In the past 15 to 20 years weather patterns have provided more intensive drought, higher temperatures, and less predictable and more severe storms than previously, all of which impact the management and quality of turfgrass areas. As public awareness of water use increases, turf managers are looking for ways to decrease water consumption while maintaining turf quality. Hydrogels may help increase soil water retention and reduce irrigation frequency.

In a study testing the hydrogel marketed as *fytofoam*, Guerrero et al. (2007) showed that water retention increased between 9.2% and 14.2 % at a soil depth of 15 cm which could potentially allow for as much as a 50% reduction in irrigation volume. While they found only a slight increase in germination rates of *Agrostis stolonifera* L. and *Cynodon dactylon* L. (Pers) with the *fytofoam*, their results indicated that root growth and root development were faster with the treatments. MacPhail et al. (1980) found that Viterra 2 Hydrogel had little effect on seedling establishment and root growth in Kentucky bluegrass sod, although they did see some increase in sod transplanting success with a post-installation application of the hydrogel. Hadam (2010) investigated germination and establishment rates of red fescue (*Festuca rubra* L.), sheep fescue (*Festuca ovina* L.), and perennial ryegrass (*Lolium perenne* L.) with manufacturer-recommended rates of application of BASF. While results varied regarding drought tolerance of the three species, the results suggested positive longer-term effects on drought tolerance under infrequent irrigation conditions for all three species (Hadam, 2010).

Agaba et al. (2011) investigated the effects of *Luquasorb* hydrogel on biomass development, water infiltration through different sand layers, and in water use during growth of *Agrostis stolonifera*, a cool-season grass commonly used on golf greens and lawns. Using rates of 0% (control), 0.2%, and 0.4% by weight (0 kg, 2 kg, and 4 kg/1000 kg sand), the water use efficiency and irrigation frequency were measured with a water potential meter. Agaba et al. (2011) showed that water use efficiency of *Agrostis stolonifera* increased by nearly 8 times at 0.4% hydrogel compared to the control. Over the 69-day study, the control plot required 24 L of water compared to 18 L for the 0.2% hydrogel and 8.4 liters for the 0.4% hydrogel. Root and shoot biomasses both increased with the 0.4% hydrogel treatment.

These results are consistent with Dorraji et al's (2010) study on hydrophilic polymers and their effects on corn growth, which noted that rates of 0.6% in loamy-sandy soils and 0.2% in sandy clay loams resulted in the greatest root and shoot biomass. However, this study also showed that higher rates of hydophilic polymer amendments in sandy clay loams sometimes resulted in reduced biomass production compared to the lower rates. They concluded that for soils that already have a high water retention capacity, such as clay loams, higher rates of the hydrogels result in too much water being stored, negatively impacting root development and growth and overall plant growth.

In general, whether hydrogels are beneficial for turfgrass establishment and growth and reduce irrigation depends on the application method. For established turfgrass, applying the hydrogels in the root zone can be difficult, whereas, in establishment by seed, hydrogels become problematic as, by their water absorption in subsequent increase in size, may prevent the seeds from contact with the soil and may hold the water too tightly for the initial turfgrass roots to access.

AquaSmart

One of the more recent polyacrylamide hydrogels on the market is *Ready Play Field Magic*, a polymer-coated sand product manufactured by AquaSmart Enterprises, LLC. Marketing information for AquaSmart polymer-coated sand states that this product can hold up to 12 times its weight in water, and, apart from enhancing water holding capacity, will improve aeration, prevent soil erosion, enhance top growth, and lower the frequency of watering and irrigation. The product is applied to turfgrass in a similar fashion to topdressing sand, and can be incorporated into greenhouse and nursery substrate during the mixing or potting process. This study aimed to test this marketing information through: 1) a turfgrass study focused on new seed and sod establishment, drought resistance in established sod, and overall water use and turf quality and 2) in a greenhouse study that examined water use, irrigation frequency, and plant growth in greenhouse-grown ornamentals, as well as nutrient leaching and water evaporation in amended soilless substrate.

The objectives of this research were to:

1. Evaluate the effects of AquaSmart on water usage, plant growth via dry shoot weight and dry root weight, and time to permanent wilting in greenhouse ornamentals.

2. Evaluate the effects of AquaSmart on nutrient leaching and dry-down rates of greenhouse media.

3. Evaluate the effects of AquaSmart on establishment, germination, root growth, and soil moisture in newly sodded and newly seeded bermudagrass.

4. Evaluate the effects of AquaSmart on well-established bermudagrass under drought conditions.

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CHAPTER II

THE EFFECTS OF AQUASMART POLYMER COATED SAND ON GROWTH AND WATER USE OF GREENHOUSE GROWN ORNAMENTAL PLANTS

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Additional index words: hydrogel, verbena, marigold, petunia, salvia, lobelia, pansy, rose moss

Abstract: The use of soilless substrates in the greenhouse and nursery industries has increased in recent years. While these substrates provide consistency and initial sterility, they are often hydrophobic, especially if they dry out between irrigations. Synthetic polyacrylamides, such as AquaSmart, may help with initial water absorption and increase the water holding capacity of the substrates. These studies were conducted to determine the effect of different concentrations of AquaSmart polymer coated sand on growth rates (as measured by dry biomass), water retained within the substrate, and days to permanent wilting of ornamental flowers after irrigation has been terminated. Results indicated that while there were some significant effects of AquaSmart on plant growth, irrigation frequency and volume, and days to permanent wilting point, there was strong variation between the flower species in the study, both in their physiological requirements and in their performance with different concentrations of AquaSmart.

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Introduction

Soilless substrate is commonly used in the greenhouse and nursery industry (Warncke and Krauskopf, 1983). Soilless substrate has advantages including a lower risk of contamination (as compared to mineral soils), consistency within each substrate mixture, and reliable moisture holding and aeration properties (Warncke and Krauskopf, 1983). However, although soilless substrates have reliable moisture retention, once they dry, rehydrating can become difficult as the component materials are often strongly hydrophobic. Polyacrylamide polymers, or hydrogels, are super-absorbent hydrophilic gels that could potentially alleviate some of the initial and rehydration problems of soilless substrates.

In a study investigating lettuce (*Lactuca sativa* L.), cotton (*Gossypium hirsutum* L.), and tomato (*Solanum lycopersicum* L.) seed germination and emergence, Williams and Wallace (1986) noted that emergence was earlier when seeds were grown with hydrogel, both dry and in solution. They also showed that lettuce seedling emergence was quicker and seedling dry weights were greater when the lettuce seedlings were grown in a greenhouse under the same treatment concentrations of hydrogel (Williams and Wallace, 1986). Their results are reinforced by those of Frantz et al. (2005) who showed that hydrogels might be primarily effective during the initial establishment and germination phases of greenhouse grown plants, when water needs are high and plants are not yet well-established. Woodhouse and Johnson (1991) also noted significant results in an establishment study incorporating hydrogels. Their study investigated barley (*Hordeum vulgare* L.) and lettuce, and they found strong evidence of root aggregation around the hydrogel fragments within the potting substrate (Woodhouse and Johnson, 1991). This aggregation is important as it provides plant roots with maximum exposure to available moisture in the soil.

Boatright et al. (1997) noted that three ornamental flower species grown in garden beds in hydrogel-amended soil had an increased number of flowers per plant and greater plant growth as determined by plant dry weight. Of the three species in this study, petunia (*Petunia x hybrid* Juss.), vinca (*Catharanthus roseus* L.), and marigold (*Tagetes patula* L.), the results for petunia were the most significant, followed by vinca, and then marigold. This trend slightly mirrors the drought tolerance levels of the three species, with petunia being the least drought tolerant of the three and vinca being the most drought tolerant (Boatright et al., 1997).

AquaSmart is a polyacrylamide hydrogel being marketed as having the potential to absorb up to 12 times its weight in water. Unlike other, similar, hydrogels on the market, AquaSmart's product is bonded onto sand grains for ease of incorporation into substrate mixes and field soils. However, research of AquaSmart's products is limited. This study investigates the effects the water retention capacity of AquaSmart has on the growth and water use of ornamental flower species.

The objectives of this research were to:

1. Determine the effect of different application concentrations of AquaSmart on the growth of six ornamental flower species.

2. Determine the effect of different application concentrations of AquaSmart on the frequency of irrigation required by six ornamental flower species.

3. Determine the effect of different application concentrations of AquaSmart on the time to permanent wilt under drought conditions for six ornamental flower species.

We hypothesize that:

1. Growth of plants, as measured by root and shoot dry biomass weights, will be greater under higher concentrations of AquaSmart.

2. Water use and frequency of irrigation will be lower for plants grown with higher concentrations of AquaSmart.

Materials and Methods

This research was conducted at the Oklahoma State University Research Greenhouse in Stillwater, OK. The study was conducted from 4 April 2014 to 17 June 2014 and then repeated from 7 April 2015 to 29 May 2015 and was carried out in a fiberglass-sided greenhouse with a corrugated polycarbonate roof, which was temperature-controlled through a forced-air heating unit and a evaporative cooling system. Average greenhouse low temperature was 20^{O} C and average high temperature was 30^{O} C. No supplemental light sources were used during this study, so ornamentals received only natural light.

All pots (3.79L) were filled with a soilless substrate mixture of coarse pine bark and sand (4:1 by volume) amended with an 18N-2.6P-9.9K controlled release fertilizer (18N-6P_2O_5-12K_2O Osmocote The Scotts Company, Marysville, OH), at a rate of 3.85 kg/yd^3 and Micromax (The Scotts Company, Marysville, OH), a granular micronutrient fertilizer, at 0.45 kg/yd^3. Three application concentrations of the hydrogel were tested along with one control treatment containing no hydrogel. To account for the weight of the hydrogel-coated sand and to ensure that pot weights were the same across all treatments, untreated sand was mixed with the hydrogel so that each treatment mixture had a total of 9.07 kg/yd^3 of sand, hydrogel, or hydrogel and sand. Treatment concentrations were 100% (9.07 kg/yd^3) sand; 25% (2.27 kg/yd^3) hydrogel and 75% (6.8 kg/yd^3) sand; 50% (4.53 kg/yd^3 hydrogel and 50% (4.53 kg/yd^3) sand; and 100% (9.07 kg/yd^3) hydrogel. The substrate was mixed in a 0.06 m^3 capacity rotary mixer (Powr Kraft, Montgomery Ward, Monroe, WI), and for each treatment, the sand and hydrogel was incorporated at this mixing.

All pots were filled to the same dry weight (g), and then pots were saturated to container capacity. Initial pot weight and container capacity weight were then used to calculate the weight at 60% of container capacity (1835g), which became the target container weight at or below which plants were irrigated. Commercially produced plugs (Kemmer's Greenhouse, Mayport, PA) of annual bedding plants were used for the study. In 2014, the species used were pansy (*Viola tricolor* DC.), petunia, rose moss (*Portulaca grandiflora*, Hook.), salvia (*Salvia splendens* Sellow), verbena (*Verbena officinalis* Meisn.), and lobelia (*Lobelia siphilitica* L.). In 2015, the same species were used except that pansy was replaced by marigold because in 2014 many of the pansies did not survive the study.

Pots were weighed daily and the weights were recorded. Irrigation was applied when the pot weights were at 60% container capacity. The volume of water added increased over the course of the study as plant growth increased, from 200 mL to 400 mL. Pots were irrigated with enough water to provide a 10% leaching fraction. Leachate was collected in a saucer under each pot, measured, and discarded.

The studies were terminated each year when plant root growth had reached the bottom of the pots, but before the plants became root-bound. Root growth was checked periodically by carefully sliding a plant partway out of the pot, checking root growth, and sliding the plant back into the pot. At this time, irrigation was stopped. Plants were inspected each morning after irrigation ended and the number of days to permanent wilting point was determined. Plant shoots and clean roots (free of substrate) were placed in paper bags and dried for 7 days at 43^{O}C. Root and shoot dry weights were recorded and analyzed within species and across treatments. Irrigation frequency, time to permanent wilt from last irrigation, and root and shoot dry weights were analyzed using SAS statistical software (SAS 9.4, SAS Institute, Cary, NC).

The experimental design for this study was a randomized complete block with five replications of the four hydrogel treatments and six plant species. A general linear model (GLM) test with trend analysis was used to test for significance between hydrogel treatments and within plant species for shoot and root dry weights (biomass measurement), total amount of irrigation received and total volume of water retained by the substrate, frequency of irrigation over the course of the study, and days from the end of irrigation to permanent wilting point.

Results and Discussion

2014 Results: Shoot dry weight decreased linearly as hydrogel concentrations increased for rose moss (Table 2.1). No trends between shoot dry weight and hydrogel concentration occurred for any other species. Root dry weight increased linearly for salvia and lobelia but curvilinearly for verbena (Table 2.2). No trend between root dry weight and hydrogel concentration existed for rose moss, pansy, and petunia (data not presented).

A curvilinear relationship existed between the numbers of days to permanent wilt and hydrogel concentration for verbena and petunia (Table 2.3). A curvilinear relationship existed between irrigation frequency and hydrogel concentration for rose moss and salvia, but irrigation frequency increased linearly as hydrogel concentration increased in verbena (Table 2.4) suggesting that higher concentrations of hydrogel resulted in more frequent irrigations required by the plants than lower concentrations.

The amount of water retained by the substrate was measured as the difference between the volume of water added during each irrigation and the volume of leachate collected. Curvilinear relationships occurred between volume of water retained and hydrogel concentrations for rose moss and verbena (Table 2.5). During the course of the study, containers with rose moss plants frequently retained very little of the water. This might be explained by the plant anatomy of rose moss providing mechanisms for low water use including very thick, small leaves, which results in small surface area for transpiration.

2015 Results: Shoot dry weight of salvia increased as hydrogel concentration increased (Table 2.6). No trends between dry weight and hydrogel concentration existed for any other species (data not presented) Root dry weights increased curvilinearly for rose moss, but linearly for salvia, and verbena as hydrogel concentrations increased (Table 2.7).

A curvilinear relationship existed between days to permanent wilt and hydrogel concentration for rose moss (Table 2.8), unlike 2014 where both petunia and verbena showed significant results with mixed benefit to the plants. A curvilinear relationship existed between frequency of irrigation and hydrogel concentration for lobelia and rose moss, but irrigation frequency increased linearly as hydrogel concentration increased for salvia and verbena (Table 2.9). The mL of water retained by the substrate increased linearly with hydrogel concentration (Table 2.10).

Early establishment of greenhouse-grown plants is where many of the benefits of hydrogel applications are seen. Woodhouse and Johnson (1991) showed that water use efficiency (here determined by grams of dry matter produced per kg of water applied) improved with the use of all three hydrogels tested, regardless of the plant species being grown. Pill and Jacono (1984) support these results with their research on tomatoes, which showed improved growth after the incorporation of a hydrogel into their growing substrate as well as improved substrate aeration potentially caused by the swelling hydrogel fragments. Although this study was conducted with plugs rather than mature plants, analyses were done only on the mature plants after two months of growth, thus providing results that are not directly comparable to the above studies. However, the irrigation volume added and frequency of irrigation analyses show few significant results, indicating that there was little hydrogel benefit during the establishment period.

Petunias were grown during both years of the ornamental study, and in neither year were plant growth rates, as measured by root and shoot dry weights, significantly affected by the application of the hydrogel. These results differ from those of Boatright et al. (1997)'s study that examined the effects of a hydrogel on the growth rates and flower number of petunias, vinca, and marigolds. Boatright et al. (1997) showed that petunia growth rates (by dry biomass) were significant at the 0.05% level for all five application concentrations of the hydrogel. For our study, petunia only showed significance for days to permanent wilt during the 2014 study, but there were no significant effects on shoot or root dry weight for petunia in either year. However, both studies found similar results of no significant differences in the response of marigolds grown with a hydrogel. In the comparison of these two studies, it is important to note that Boatright et al. (1997)'s study was conducted in a field setting, although the substrate was still a pine bark: sand mixture.

Frantz et al. (2005) noted that pansies grown in substrate amended with hydrogel produced slightly larger plants that had more canopy coverage as compared to pansies grown in nonamended substrate. These results suggest that pansies grow more quickly in the presence of a hydrogel, thus providing the benefit of more rapid growth, which could result in economic benefits from less fertilizer and irrigation requirements over the shorter growing period (Frantz et al., 2005). These results are in contrast with those observed in our study where no significant results were found in pansies for either irrigation or plant growth. However, pansies are a heat-sensitive plant, more commonly used during the late fall and early spring in Oklahoma, and half of the pansies grown in the 2014 study season died from heat stress, which may have skewed the sample pool.

Another determining factor in determining the potential and actual effects of hydrogels on growth rates and water usage in greenhouse-grown plants is the type and amount of fertilizer used in the greenhouse. Fertilizer salts can react with the hydrogels, changing how much water may be absorbed initially and retained throughout (Johnson, 1984b). Additionally, individual plant water use requirements and drought tolerances will affect hydrogel efficacy for seedling establishment and plant growth. While results for hydrogel use in the greenhouse and nursery industry are promising, hydrogel and plant species selection, along with substrate composition, are important factors to consider prior to selecting a hydrogel.

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Table 2.1: Shoot dry weights (SDW) for herbaceous species treated with four concentrations of hydrogel during the 2014 study season. n=5.

Species	Rate (kg/yd^3)	Mean SDW
Rose Moss	0	1.08
	2.27	1.06
	4.54	0.90
	9.07	0.86
	Linear	*
	Quadratic	NS
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at $P\leq 0.05$, 0.01, or 0.001 respectively.

Table 2.2: Root dry weights (RDW) for herbaceous species treated with four concentrations of hydrogel during the 2014 study season. n=5.

Species	Rate (kg/yd^3)	Mean RDW
Salvia	0	3.32
	2.27	2.94
	4.54	3.3
	9.07	5.16
	Linear	*
	Quadratic	NS
	Cubic	NS
Lobelia	0	0.62
	2.27	0.60
	4.54	0.90
	9.07	1.18
	Linear	*
	Quadratic	NS
	Cubic	NS
Verbena	0	2.98
	2.27	2.06
	4.54	1.98
	9.07	6.06
	Linear	**
	Quadratic	*
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

Table 2.3: Days to permanent wilt (DTW) for herbaceous species treated with four concentrations of hydrogel during the 2014 study season. n=5.

Species	Rate (kg/yd^3)	Mean DTW
Petunia	0	11.2
	2.27	12.5
	4.54	10.0
	9.07	10.4
	Linear	NS
	Quadratic	NS
	Cubic	*
Verbena	0	6.4
	2.27	8.0
	4.54	7.4
	9.07	6.0
	Linear	NS
	Quadratic	*
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

Table 2.4: Frequency of irrigation for herbaceous species treated with four concentrations of hydrogel during the 2014 study season. n=5.

Species	Rate (kg/yd^3)	Mean Irrigation Frequency (Number of Irrigations)
Rose Moss	0	17.2
	2.27	21.4
	4.54	18.8
	9.07	13.6
	Linear	***
	Quadratic	***
	Cubic	*
Salvia	0	20
	2.27	24.4
	4.54	22.6
	9.07	22.4
	Linear	NS
	Quadratic	*
	Cubic	*
Verbena	0	24
	2.27	24
	4.54	22.2
	9.07	31
	Linear	*
	Quadratic	NS
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

Table 2.5: Water retention (mL) for herbaceous species treated with four concentrations of hydrogel during the 2014 study season. n=5.

Species	Rate (kg/yd^3)	Mean mL Water Retained
Rose Moss	0	5527.0
	2.27	6096.0
	4.54	5395.2
	9.07	4039.6
	Linear	***
	Quadratic	**
	Cubic	*
Verbena	0	8263.6
	2.27	7321.6
	4.54	7263.4
	9.07	9603.6
	Linear	*
	Quadratic	*
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

Table 2.6: Shoot dry weights (SDW) for herbaceous species treated with four concentrations of hydrogel during the 2015 study season. n=5.

Species	Rate (kg/yd^3)	Mean SDW
Salvia	0	7.84
	2.27	7.48
	4.54	9.8
	9.07	11.64
	Linear	**
	Quadratic	NS
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at P≤ 0.05, 0.01, or 0.001 respectively.

Table 2.7: Root dry weights (RDW) for herbaceous species treated with four concentrations of hydrogel during the 201% study season. n=5.

Species	Rate (kg/yd^3)	Mean RDW
Rose Moss	0	0.6
	2.27	0.6
	4.54	0.56
	9.07	0.94
	Linear	NS
	Quadratic	*
	Cubic	NS
Salvia	0	1.28
	2.27	1.32
	4.54	1.46
	9.07	2.42
	Linear	**
	Quadratic	NS
	Cubic	NS
Verbena	0	0.1
	2.27	0.18
	4.54	0.2
	9.07	0.24
	Linear	*
	Quadratic	NS
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

Table 2.8: Days to permanent wilt (DTW) for herbaceous species treated with four concentrations of hydrogel during the 2015 study season. n=5.

Species	Rate (kg/yd^3)	Mean DTW
Rose Moss	0	30.4
	2.27	26.6
	4.54	27.6
	9.07	30.2
	Linear	NS
	Quadratic	*
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at P≤ 0.05, 0.01, or 0.001 respectively.

Table 2.9: Frequency of irrigation for herbaceous species treated with four concentrations of hydrogel during the 2015 study season. n=5.

Species	Rate (kg/yd^3)	Mean Frequency of Irrigation (Number of Irrigations)
Lobelia	0	17.0
	2.27	15.2
	4.54	20.0
	9.07	16.8
	Linear	NS
	Quadratic	NS
	Cubic	*
Rose Moss	0	18.4
	2.27	19.4
	4.54	21.4
	9.07	19.4
	Linear	NS
	Quadratic	*
	Cubic	NS
Salvia	0	16.2
	2.27	15.6
	4.54	13.8
	9.07	18.8
	Linear	**
	Quadratic	NS
	Cubic	NS
Verbena	0	11.6
	2.27	15.6
	4.54	13.8
	9.07	18.8
	Linear	*
	Quadratic	NS
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at P≤ 0.05, 0.01, or 0.001 respectively.

Table 2.10: Water retention (mL) for herbaceous species treated with four concentrations of hydrogel during the 2015 study season. n=5.

Species	Rate (kg/yd^3)	Mean mL Water Retained
Salvia	0	4182
	2.27	4255.6
	4.54	5878.4
	9.07	6629.8
	Linear	**
	Quadratic	NS
	Cubic	NS
Verbena	0	2883.2
	2.27	3672.4
	4.54	2874.6
	9.07	4787.2
	Linear	*
	Quadratic	NS
	Cubic	NS

NS, *, **, *** Nonsignificant or significant at $p \leq 0.05$, 0.01, or 0.001 respectively.

Chapter III

The Effects of AquaSmart Polymer Coated Sand on Nutrient Leaching and Water Retention in Soilless Greenhouse Substrate

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Abstract: The use of soilless substrates in the greenhouse and nursery industries has increased in recent years. While these substrates provide consistency and initial sterility, they are often hydrophobic and may lack the ability to retain nutrients. Synthetic polyacrylamides, such as AquaSmart, may help with both water and nutrient retention within the substrate. However, these polymers have also been shown to be adversely affected by fertilizer salts within substrate and irrigation solution, so nutrient and water retention capabilities may be equally affected. These studies were conducted in order to determine the effects of AquaSmart polymer coated sand on leaching rates of potassium, nitrate, and ammonium in a pine bark-sand soilless substrate and the evaporation rates of the same substrate under five AquaSmart concentrations and three fertilizer regimes. Results indicate that there was a significant difference in the leaching rates of potassium and ammonium, with lower leaching rates corresponding to higher concentrations of AquaSmart. Nitrate results were more mixed, potentially because of the anionic nature of nitrate. Dry-down results indicate that a liquid fertilizer negates nearly all of the water retention potential of the AquaSmart, while a granular slow-release fertilizer did show a longer evaporation time under higher concentrations of AquaSmart although the untreated control was not significantly different from those higher concentrations.

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Introduction:

In greenhouse and nursery operations, the trend for growing substrate has been away from soil and towards peat or bark-based mixes that may also contain other components such as vermiculite (Warncke and Krauskopf, 1983). Growers purchasing these substrates can determine the exact proportions of mixture components, something that may be more difficult when working with mineral soils that tend to vary more widely. Additionally, soilless substrate mixes are sterile, which can help reduce risk of contamination and spread of disease within a greenhouse operation. Many of these mixes, while they may have good water retention capability and aeration properties, tend to be strongly hydrophobic, which can make initial saturation difficult. Also, because of the nature of these mixes, nutrient retention potential can be low, requiring greenhouse operations to pay close attention to fertility management (Warncke and Krauskopf, 1983). For many greenhouse and nursery operations, fertigation systems, or combined fertilizer and irrigation systems, are the primary means of providing water and nutrients to the plants. While soilless substrates may retain moisture when initially saturated, their lack of nutrient retention requires continual fertilizer applications.

With these limitations of soilless substrate mixes, hydrogels, or hydrophilic polymers, may help increase initial moisture uptake of substrate, improve nutrient retention within the substrate, and contribute to slower dry-down rates between irrigations. Hydrogels function by expanding to absorb water and nutrients through ionic bonding, and then slowly release both water and nutrients over time (Mikkelson, 1994). There are three commonly used types of hydrogels: natural polymers derived from polysaccharides, semi-synthetic polymers (primarily cellulose derivation), and synthetic polymers (Mikkelson, 1994). Hydrogels used as a substrate amendment may help release water and nutrients consistently through the crop cycle. This might allow growers to apply smaller amounts of water and nutrients during crop production. Synthetic polyacrylamides are currently the most commonly used hydrogels within the greenhouse industry, and previous research has shown varied positive effects with the incorporation of hydrogels into the substrate mixes (Kay-Shoemake, et al., 1998).

Previous research has indicated that some hydrogels lose water and nutrient uptake efficacy depending on the salt content of the fertilizers being used (Mikkelson, 1994). For some hydrogels, even the salt content of tap water can severely impede water and nutrient absorption, which should be a consideration for greenhouse growers in areas where tap water has a high mineral content (Asady et al., 1985; Frantz et al., 2005). Some research suggests that components of soilless substrate may affect water and nutrient retention and release from hydrogels. Release depends on the structural makeup of the specific hydrogel, and could potentially also depend on the mode of fertilizer application, whether granular or applied in solution (Martin et al., 1993). Because greenhouse crops are rarely grown without fertilizers and other soil amendments, research is needed to determine the efficacy of these products when used in conjunction with fertilizers. Research may show that their retention capabilities are sufficient to counteract the effects of ionic bonding.

AquaSmart (hereafter referred to as 'hydrogel') is a polyacrylamide hydrogel that is being marketed as having the potential to absorb up to 12 times its weight in water, with additional potential for nutrient uptake, retention, and release back into the soil. Unlike other, similar hydrogels, AquaSmart's product is bonded onto sand grains for ease of incorporation into substrate mixes and field soils. However, research of AquaSmart's products is limited. This study investigates nutrient retention/release capabilities of AquaSmart in the presence of slow-release fertilizer in a soilless substrate. Additionally, this study investigates water-retention and evaporation rates of AquaSmart combined with the same slow-release fertilizer, a liquid fertilizer, or no fertilizer to determine the effects of fertilizer salts on the initial water uptake and retention over time.

The objectives of this research were to:

1. Determine the effect of AquaSmart concentrations on NH_4 leaching from a pine bark-sand soilless substrate mixture.

2. Determine the effect of AquaSmart concentrations on NO_3 leaching from a pine bark-sand soilless substrate mixture.

3. Determine the effect of AquaSmart concentrations on P leaching from a pine bark-sand soilless substrate mixture.

4. Determine the effect of liquid fertilizer and granular slow release fertilizer on water evaporation rate from pine-bark and sand substrate amended with AquaSmart.

We hypothesize that:

1. Leaching rates of NH_4, NO_3, and P will be reduced with higher concentrations of AquaSmart.

2. Higher concentrations of AquaSmart will decrease the rate of water evaporation from pine-bark and sand substrate with different fertilizer treatments.

Materials and Methods

This research was conducted at the Oklahoma State University Research Greenhouse in Stillwater, OK. The nutrient release study occurred from 15 October 2014 to 29 May 2015, with 1291 leachate samples collected and analyzed for P, NO_3-N, and NH_4-N concentration. The entire nutrient study was carried out in a fiberglass-sided greenhouse with a corrugated polycarbonate roof, which was temperature-controlled through a forced-air heating unit. Average greenhouse low temperature was 11^0C and average high temperature was 25.5^0C, while soil temperatures were an average of 32.8^0C.

Pots (3.79 L) were filled with a soilless media consisting of coarse pine bark and sand (4:1 by volume) amended with a 14N-6P-11.6K (14N-14P_2O_5-14K_2O, Osmocote, The Scotts Co., Marysville, OH) controlled release fertilizer, at 3.85 kg/yd^3 and Micromax (The Scotts Co., Marysville, OH) a granular micronutrient fertilizer, at 0.45 kg/yd^3. Three application rates of AquaSmart were tested along with one control treatment containing no AquaSmart. To account for the weight of the AquaSmart-coated sand and to ensure that pot weights were the same across all treatments, sand was mixed with the AquaSmart so that each treatment mixture had a total of 9.07 kg/yd^3 of sand, AquaSmart, or sand and AquaSmart. Treatment rates were 100% (9.07 kg/yd^3) sand; 25%

(2.27 kg/yd^3) AquaSmart and 75% (6.8 kg/yd^3) sand; 50% (4.53 kg/yd^3) AquaSmart and 50% (4.53 kg/yd^3) sand; and 100 % (9.07 kg/yd^3) AquaSmart. The substrate was mixed in a 0.06 m^3 capacity rotary mixer (Powr Kraft, Montgomery Ward, Monroe, WI), and for each treatment, the sand and hydrogel was incorporated at this mixing.

All pots were filled to the same dry weight (2300 g) and then pots were saturated to container capacity. Initial pot weight and container capacity weight were then used to calculate the weight at 80% of container capacity (1835 g), which became the target container weight for determining when to irrigate for the duration of the study. We selected 80% container capacity as the target weight to ensure that adequate nutrient samples would be collected for analysis. To prevent the nutrient leaching results from being skewed by plant uptake of nutrients, this study was conducted with substrate only.

The experiment was conducted using a randomized complete block design with five replications of four treatments. To help maintain constant substrate temperatures, as this study was conducted over the course of the winter, the filled pots were arranged in insulated containers constructed from 2.54 cm thick Styrofoam insulation panels and placed on heated propagation mats. This ensured that pot media remained between 29^{0}C and 38^{0}C. Thermometers were placed in six of the pots to track media temperature compared to the ambient temperature within the greenhouse, which was measured by a digital thermometer (Acurite, Indoor Temperature and Humidity Monitor, Chaney Instrument Co., Lake Geneva, WI) placed below the greenhouse bench.

Pots were weighed daily and weights were recorded. Irrigation was applied when pot weights were less than 80% of container capacity. A volume of 325 mL of water was added to each underweight pot. The resulting leachate was collected, measured, recorded, and sent to the Oklahoma State University Soils and Water Lab (SWAFL) for analysis for P, NO_3-N and NH_4-N. P was measured using an Inductively Coupled Plasma (SpectroCiros, Kleve, Germany). This tests for the concentration of total P by measuring the wavelength of elemental P. Both NO_3 and NH_4 were measured using the Lachet flow injection analyzer (Loveland, CO), which uses a colormetric system to determine nutrient concentration. From these data, concentrations of elemental P, NO_3, and NH_4 were determined for all samples (Pers. comm. Michael Kress, 2016).

The evaporation studies were conducted from 15 October 2014 to 30 April 2015, although each study lasted for a different period of time depending on how quickly the substrate dried down under ambient greenhouse conditions (average highs and lows here). For this component of the study, the container capacity and water retention rates of the hydrogel were tested using three fertilizer regimes to determine changes in water and nutrient absorption and retention of the hydrogel. Five hydrogel concentrations were used. The soilless substrate described above was also used in this study. To ensure that all pots were starting at the same weight, each of the different treatment levels incorporated sand and hydrogel, sand, or hydrogel, to equal an application rate of 27.22 kg/yd^3. Treatment rates were 100% (27.22 kg/yd^3) sand, 8% (2.27 kg/yd^3) hydrogel and 92% (24.9 kg/yd^3) sand, 16% (4.54 kg/yd^3) hydrogel and 84% (22.68 kg/yd^3) sand, 33% (9.07 kg/yd^3) hydrogel and 66% (18.14 kg/yd^3) sand, and 100% (27.22 kg/yd^3) hydrogel. The substrate was mixed in a 0.06 m^3 capacity rotary mixer, and for each treatment, the sand and hydrogel was incorporated at this mixing.

The three fertilizer regimes were a 14N-6P-11.6K granular controlled release fertilizer (Osmocote 14N-14P_2O_5-14K_2O, The Scotts Co., Marysville, OH) at 3.9 kg/yd^3, an 18N-7.9P-17.4K liquid fertilizer (MiracleGro Tomato Fertilizer 18N-18P_2O_5-21K_2O, The Scotts Co., Marysville, OH) at 500 mL/pot, and a non-fertilized control. The controlled released fertilizer was incorporated into the substrate during mixing, the liquid fertilizer was applied during the initial saturation to container capacity, and the control pots were saturated to container capacity with tap water. Once container capacity was reached for each of the treatments, the pots were placed in the greenhouse at ambient temperature (ambient day/night temps on average) and allowed to dry down naturally. Pots were weighed daily until they were within 100 g of their initial (dry) weights.

All analyses were conducted with SAS Version 9.4 (SAS Institute, Cary, NC). For the drying data, a one-way analysis of variance was conducted for each experiment to assess the effect of treatments on the response. Areas under the growth curve were calculated for each 30-day interval and for each experimental unit. One-way analyses of variance were conducted for each 30-day interval to assess treatment effects. Protected least significant difference procedures were conducted and means and standard errors are reported.

Results and Discussion

Nutrient Leaching. Similar trends occurred for total phosphorus (P) and ammonium (NH_4) nutrient leaching amounts across hydrogel treatments (Table 3.1 and Table 3.2). The control treatment of no hydrogel yielded the greatest P and NH_4 while the 9.07 kg/yd^3 of hydrogel, the highest treatment rate, yielded the lowest amounts of P and NH_4. For P, the control, 2.27 kg/yd^3, and 4.54 kg/yd^3 concentrations of hydrogel did not differ from one another, but all three differed from the 9.07 kg/yd^3 concentration of hydrogel. For NH_4 leaching, the control concentration differed from all other concentration rates, while 2.27 kg/yd^3 and 4.54 kg/yd^3 hydrogel did not differ from each other, but both differed from the 9.07 kg/yd^3 concentration. Similar results were obtained by Magalhaes et a. (1987) who showed greatly reduced leaching rates of NH_4 in the presence of a hydrogel.

Greater variability in NO_3 leaching compared to P or NH_4 leaching occurred throughout the study with different hydrogel concentrations (Table 3.3). The 0 kg/yd^3 concentration had greater NO_3 leaching than the 2.27 kg/yd^3 or 9.07 kg/yd^3 concentrations, but did not differ from 4.54 kg/yd^3. Magalhaes et al. (1987) also showed differences between NO_3 and NH_4 leaching in the presence of a hydrogel.

When the P leachate averages are separated into 30-day increments (Table 3.4), similar trends occurred for each 30-day period. These data suggest that hydrogel application at 9.07 kg/yd^3 reduces P leaching whereas application concentrations less than or equal to 4.54 kg/yd^3 of the hydrogel do not affect P leaching. Likewise, NH_4 leached less from substrate containing greater concentrations of hydrogel (Table 3.5). Differences between the three hydrogel concentrations and the untreated control increased as the study progressed. One difference between P and NH_4 results is that starting in the 91 to 120 day period, greater variation occurred in the NH_4 cumulative averages. In contrast, nitrate (NO_3) leaching was greater with the 0 kg/yd^3 or 4.54 kg/yd^3 than with the 2.27 kg/yd^3 or 9.07 kg/yd^3 concentrations of the hydrogel (Table 3.6). These results differed from those of Magalhaes et al. (1987) who found no difference in leaching rates of NO_3 regardless of hydrogel treatment. A linear trend analysis was run on the 30-day increments for nutrient leaching (Figure 3.1, Figure 3.2, Figure 3.3) and shown separated by nutrient.

Dry-Down Studies: To determine the effects of fertilizer salts on the efficacy of the hydrogel, three evaporation studies were conducted to test a liquid fertilizer, a slow-release granular fertilizer, and no fertilizer on evaporation times with five hydrogel concentrations. When no fertilizer was present, higher concentrations of the hydrogel resulted in a greater number of days for the substrate to dry down to within 100 g of starting weight (Table 3.7). In contrast, in the presence of liquid fertilizer, no differences in evaporation occurred regardless of hydrogel concentration (Table 3.8), suggesting that all water retention benefits of the hydrogel were negated by the use of the fertilizer. With slow-release granular fertilizer treatment results (Table 3.9), a significant difference in evaporation occurred between the paired application rates of 2.27 kg/yd^3 and 10 lb/yd^3 and of 9.07 kg/yd^3 and 27.22 kg/yd^3. However, no difference existed between the 9.07 kg/yd^3 and 27.22 kg/yd^3 concentrations and the control, suggesting again that any benefit of the hydrogel in water absorption and retention is negated in the presence of the fertilizer.

The nutrient study yielded interesting results, both in the average total amounts of nutrients released and in the 30-day cumulative increments. For all three nutrients tested, trends were significant for the total amounts released during the study. These trends of significance held when the data were analyzed in 30-day increments, with results staying strongly significant. One hypothesis for the difference seen between P and NH_4 and NO_3 is that for the nutrient tests run in this study, both P and NH_4 are cations, whereas NO_3 is an anion. Previous research by Magalhaes et al. (1987) noted that leachate levels of NH_4

and K were greatly reduced in the presence of a hydrogel while NO_3 did not differ in leaching. However, Magalhaes et al. (1987) also showed increased radish root growth and plant uptake of N and P in the presence of a hydrogel, which could result in larger, healthier plants. Magalhaes et al. (1987) also noted that the effect of the hydrogel on nutrient retention increased when the soil was dried prior to the execution of their nutrient study. In a study investigating iron (Fe) absorption, Mortvedt et al. (1992) noted that the addition of a hydrogel created a nutrient source in soils where natural Fe content was low. The study showed that some of the hydrogels, when applied with $FeSO_4$, formed micro-environments within the root zone that maintained and released $FeSO_4$ in plant-available form when compared with $FeSO_4$ applied by itself (Mortvedt et al., 1992).

Hydrogel absorption and release of nutrients may also be impacted by changes in soil and substrate pH, moisture and other ions in the soil or substrate (Johnson, 1984b). These factors can economically outweigh potential benefits from plant-available nutrients and nutrient retention within the substrate. Additionally, nutrients absorbed onto the hydrogel may be prevented from leaching, but may not be accessible by plant roots, depending on how tightly the nutrients are bonded to the hydrogel.

Our dry-down studies showed some significance in time to complete dry-down between application rates, although only the study without fertilizer showed a significant trend of a longer time to complete dry-down with a higher concentration rate of the hydrogel. While differences existed with the granular slow-release fertilizer, the higher concentration rates of the hydrogel: 9.07 kg/yd^3 and 27.22 kg/yd^3 did not differ from the untreated control for days to complete dry-down. The liquid fertilizer showed no significant differences between the untreated control and any of the concentration rates of the hydrogel for days to complete dry-down.

Previous studies have investigated hydrogel initial water absorption and time to full hydration. Ghebru et al. (2007) investigated two hydrogels at various concentrations for time required to reach full saturation, and noted that the hydrogels took far less time to reach saturation in distilled water than when in the growing substrate. These results suggest that hydrogels may be unable to extract water effectively when mixed in unsaturated substrate, requiring near field capacity conditions to extract ample water for full hydration (Ghebru et al., 2007). In a study by Johnson (1984b), the question was raised as to whether water absorbed by the hydrogels was accessible by the plants, or if hydrogels bonded too tightly to the water molecules for plants to break the bonds, although this question was not examined or answered in the study.

In conclusion, while there were some significant differences in how the hydrogel affected nutrient leaching and dry-down rates within soilless greenhouse substrate, the results presented here are not conclusive enough to state whether or not this hydrogel is economically effective in helping with nutrient and moisture retention except in the absence of any fertilizer.

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Table 3.1: Area under the curve analysis for average total phosphorus leached from greenhouse substrate with four concentrations of hydrogel. n=5.

Hydrogel Concentration	Mean Total P	P-value
0.00 kg/yd^3	62609.42a^z	0.0034
2.27 kg/yd^3	55835.07a	
4.54 kg/yd^3	58508.99a	
9.07 kg/yd^3	48440.40b	

^{z}Means followed by the same letter are not significantly different.

Table 3.2: Area under the curve analysis for average total ammonium leached from greenhouse substrate with four concentrations of hydrogel. n=5.

Hydrogel Concentration	Mean Total P	P-value
0.00 kg/yd^3	68803.24a[z]	0.0003
2.27 kg/yd^3	55432.75b	
4.54 kg/yd^3	59858.34b	
9.07 kg/yd^3	47668.93c	

[z]Means followed by the same letter are not significantly different.

Table 3.3: Area under the curve analysis for average total nitrate leached from greenhouse substrate with four concentrations of hydrogel. n=5.

Hydrogel Concentration	Mean Total NO_3	P-value
0.00 kg/yd^3	60743.76a[z]	0.0071
2.27 kg/yd^3	47988.43b	
4.54 kg/yd^3	56457.16a	
9.07 kg/yd^3	47467.97b	

[z]Means followed by the same letter are not significantly different.

Table 3.4: Area under the curve analysis for average total phosphorus leached from greenhouse substrate with four concentrations of hydrogel. n=5.

Interval	Hydrogel Concentration	Mean Total P	P-value
0-30 Days	0 lb/kg3	1029.92a[z]	0.0198
0-30 Days	2.27 kg/yd3	858.28a	
0-30 Days	4.54 kg/yd3	869.34a	
0-30 Days	9.07 kg/yd3	538.34b	
31-60 Days	0 lb/kg3	4523.59a	0.0129
31-60 Days	2.27 kg/yd3	4183.37a	
31-60 Days	4.54 kg/yd3	4360.46a	
31-60 Days	9.07 kg/yd3	3096.92b	
61-90 Days	0 lb/kg3	5553.51a	0.0107
61-90 Days	2.27 kg/yd3	5041.65a	
61-90 Days	4.54 kg/yd3	5229.66a	
61-90 Days	9.07 kg/yd3	3635.25b	
91-120 Days	0 lb/kg3	12766.09a	0.0365
91-120 Days	2.27 kg/yd3	11462.47ab	
91-120 Days	4.54 kg/yd3	11932.16a	
91-120 Days	9.07 kg/yd3	9396.81b	
121-150 Days	0 lb/kg3	22047.20a	0.0097
121-150 Days	2.27 kg/yd3	19701.61a	
121-150 Days	4.54 kg/yd3	20394.99a	
121-150 Days	9.07 kg/yd3	16513.69b	
151-180 Days	0 lb/kg3	32464.92a	0.0064
151-180 Days	2.27 kg/yd3	29088.99a	
151-180 Days	4.54 kg/yd3	30459.91a	
151-180 Days	9.07 kg/yd3	24339.45b	
181-210 Days	0 lb/kg3	43685.94a	0.0043
181-210 Days	2.27 kg/yd3	39234.31a	
181-210 Days	4.54 kg/yd3	41164.05a	
181-210 Days	9.07 kg/yd3	33383.17b	

[z]Means followed by the same letter within interval are not significantly different.

Table 3.5: Area under the curve analysis for average total ammonium leached from greenhouse substrate with four concentrations of hydrogel. n=5.

Interval	Hydrogel Concentration	Mean Total NH_4	P-value
0-30 Days	0 lb/kg3	1182.26a[z]	0.0104
0-30 Days	2.27 kg/yd3	1029.01a	
0-30 Days	4.54 kg/yd3	1059.51a	
0-30 Days	9.07 kg/yd3	623.32b	
31-60 Days	0 lb/kg3	4655.67a	0.007
31-60 Days	2.27 kg/yd3	4007.84a	
31-60 Days	4.54 kg/yd3	4250.74a	
31-60 Days	9.07 kg/yd3	2902.39b	
61-90 Days	0 lb/kg3	5837.92a	0.0057
61-90 Days	2.27 kg/yd3	5036.86a	
61-90 Days	4.54 kg/yd3	5310.25a	
61-90 Days	9.07 kg/yd3	3525.71b	
91-120 Days	0 lb/kg3	13708.85a	0.0135
91-120 Days	2.27 kg/yd3	11339.82ab	
91-120 Days	4.54 kg/yd3	12142.47a	
91-120 Days	9.07 kg/yd3	9240.87b	
121-150 Days	0 lb/kg3	24032.65a	0.0017
121-150 Days	2.27 kg/yd3	19433.88bc	
121-150 Days	4.54 kg/yd3	20953.32ab	
121-150 Days	9.07 kg/yd3	16384.55c	
151-180 Days	0 lb/kg3	35683.97a	0.0009
151-180 Days	2.27 kg/yd3	28740.76bc	
151-180 Days	4.54 kg/yd3	31499.04ab	
151-180 Days	9.07 kg/yd3	24233.46c	
181-210 Days	0 lb/kg3	48211.41a	0.0004
181-210 Days	2.27 kg/yd3	38982.55b	
181-210 Days	4.54 kg/yd3	42549.94ab	
181-210 Days	9.07 kg/yd3	33213.10c	

[z]Means followed by the same letter within interval are not significantly different.

Table 3.6: Area under the curve analysis for average total ammonium leached from greenhouse substrate with four concentrations of hydrogel. n=5.

Interval	Hydrogel Concentration	Mean Total NO3	P-value
0-30 Days	0 lb/kg3	1077.13a[z]	0.0112
0-30 Days	2.27 kg/yd3	843.13a	
0-30 Days	4.54 kg/yd3	925.69a	
0-30 Days	9.07 kg/yd3	531.22b	
31-60 Days	0 lb/kg3	4337.15a	0.0054
31-60 Days	2.27 kg/yd3	3410.35bc	
31-60 Days	4.54 kg/yd3	3888.66ab	
31-60 Days	9.07 kg/yd3	2694c	
61-90 Days	0 lb/kg3	5414.29a	0.0047
61-90 Days	2.27 kg/yd3	4253.49bc	
61-90 Days	4.54 kg/yd3	4814.35ab	
61-90 Days	9.07 kg/yd3	3225.81c	
91-120 Days	0 lb/kg3	12369.21a	0.0124
91-120 Days	2.27 kg/yd3	9598.75bc	
91-120 Days	4.54 kg/yd3	10785.44ab	
91-120 Days	9.07 kg/yd3	8339.34c	
121-150 Days	0 lb/kg3	21435.51a	0.0032
121-150 Days	2.27 kg/yd3	16596.27bc	
121-150 Days	4.54 kg/yd3	18549.93ab	
121-150 Days	9.07 kg/yd3	14882.68c	
151-180 Days	0 lb/kg3	31501.08a	0.0026
151-180 Days	2.27 kg/yd3	24570.06bc	
151-180 Days	4.54 kg/yd3	28119.49ab	
151-180 Days	9.07 kg/yd3	22349.01c	
181-210 Days	0 lb/kg3	42223.3a	0.0033
181-210 Days	2.27 kg/yd3	33289.50bc	
181-210 Days	4.54 kg/yd3	38658.81ab	
181-210 Days	9.07 kg/yd3	31435.04c	

[z]Means followed by the same letter within interval are not significantly different.

Table 3.7: Area under the curve analysis for pine-bark and sand substrate dry-down across four concentrations of hydrogel with no fertilizer amendment. n=5.

Hydrogel Concentration	Mean Days to Dry-Down	P-value
0 lb/kg3	59.4c[z]	<0.0001
2.27 kg/yd3	61.0c	
4.54 kg/yd3	69.8b	
9.07 kg/yd3	80.8a	
27.22 kg/yd3	82.4a	

[z]Means followed by the same letter are not significantly different.

Table 3.8: Area under the curve analysis for pine-bark and sand substrate dry-down across four concentrations of hydrogel with liquid fertilizer. n=5

Hydrogel Concentration	Mean Days to Dry-Down	P-value
0 lb/kg3	52.5a[z]	0.2026
2.27 kg/yd3	56.0a	
4.54 kg/yd3	54.0a	
9.07 kg/yd3	60.6a	
27.22 kg/yd3	46.8a	

[z]Means followed by the same letter are not significantly different.

Table 3.9: Area under the curve analysis for pine-bark and sand substrate dry-down across four concentrations of hydrogel with granular slow-release fertilizer. n=5

Hydrogel Concentration	Mean Days to Dry-Down	P-value
0 lb/kg3	68.0a[z]	<0.0001
2.27 kg/yd3	58.2b	
4.54 kg/yd3	55.17b	
9.07 kg/yd3	68.4a	
27.22 kg/yd3	67.2a	

[z]Means followed by the same letter are not significantly different.

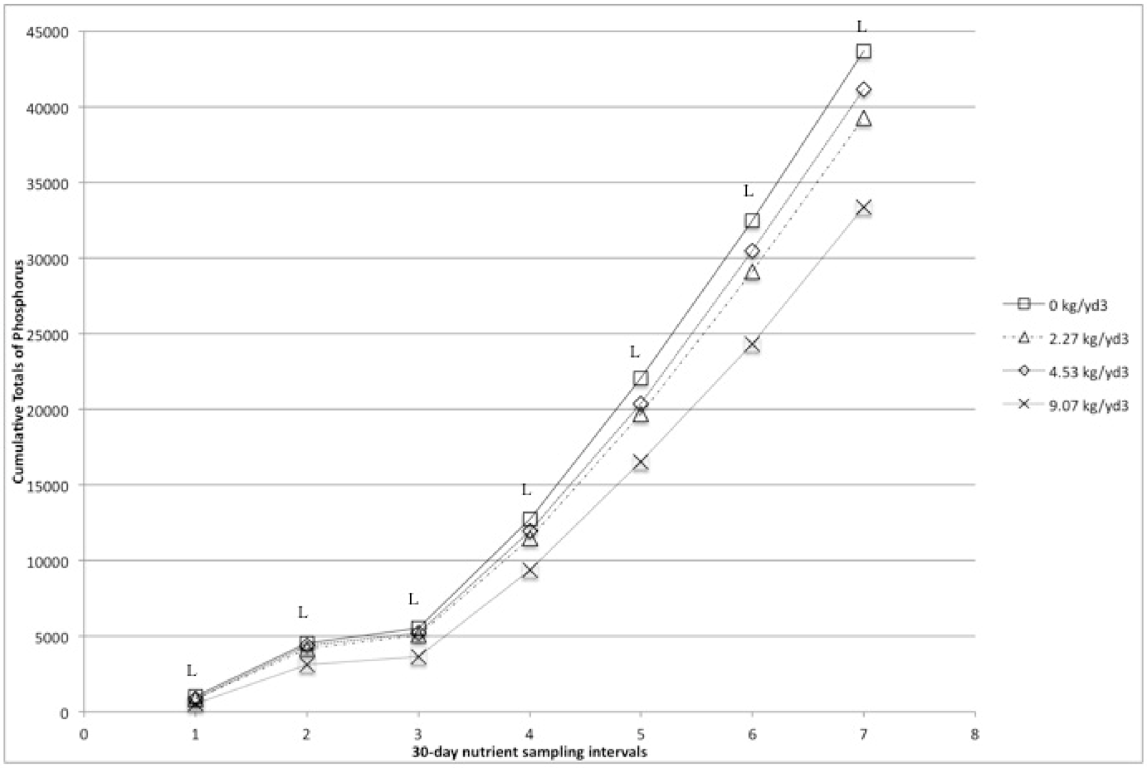

Fig 3.1: Area under the curve analysis for phosphorus in 30-day cumulative increments. Linear trend analysis significance indicated by "L" above intervals with p-value ≤0.05.

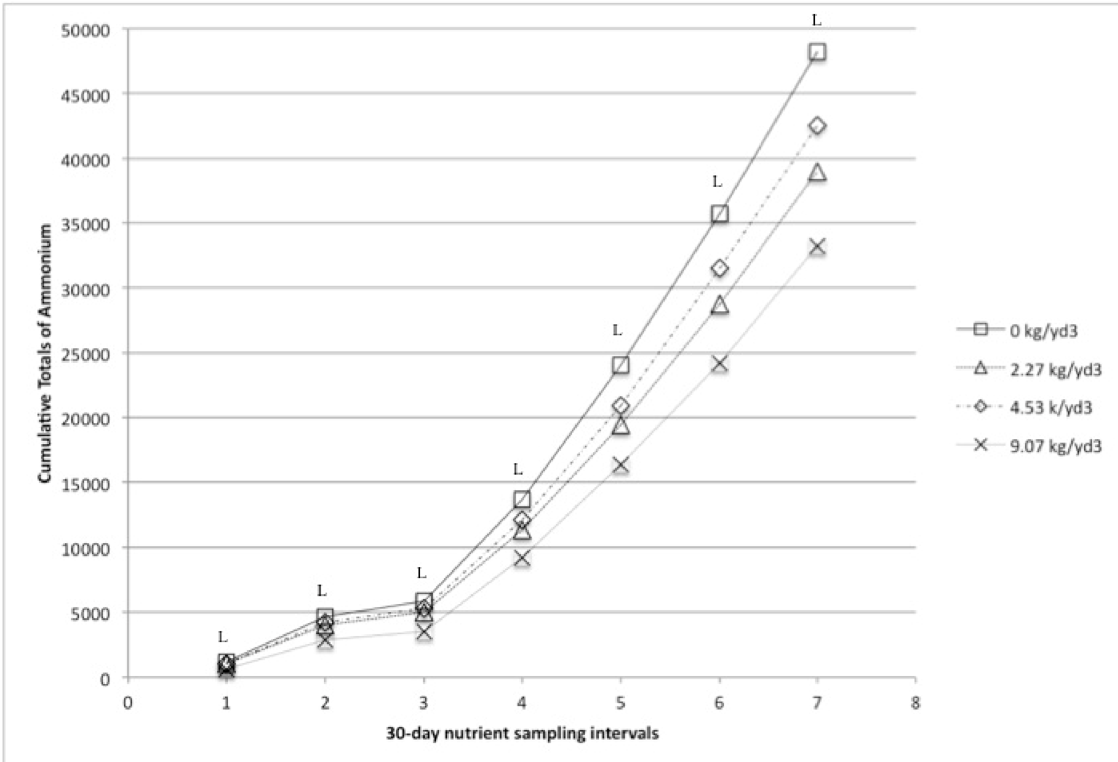

Fig 3.2: Area under the curve analysis for ammonium in 30-day cumulative increments. Linear trend analysis significance indicated by "L" above intervals with p-value ≤ 0.05.

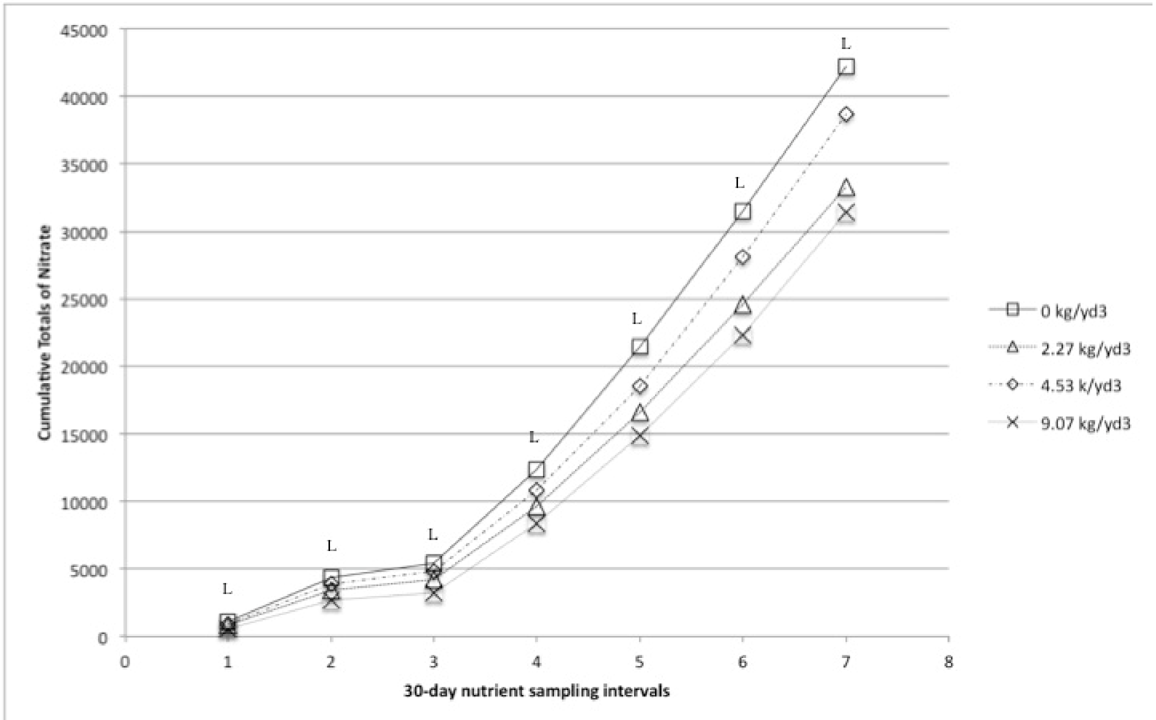

Fig 3.3: Area under the curve analysis for nitrate in 30-day cumulative increments. Linear trend analysis significance indicated by “L” above intervals with p-value ≤0.05.

Chapter IV

The Effects of AquaSmart Polymer Coated Sand on Turfgrass Establishment and Growth

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Abstract: The United States turfgrass industry is one of the fastest growing segments of U.S. agriculture, and one of the challenges facing the industry today is the limited availability of water for irrigation. Two important water conservation strategies used in the turfgrass industry are to develop water-saving methods and products and to improve turfgrass drought resistance. Synthetic polyacrylamides, such as AquaSmart, may help with water retention within the soil and require fewer irrigation inputs while still resulting in a quality turfgrass. This study was conducted to determine the effects of different application rates of AquaSmart polymer coated sand and different irrigation regimes on establishment in bermudagrass seed and sod, and drought resistance in established bermudagrass sod. Results indicated that while irrigation regime had a strongly significant effect on establishment and quality in bermudagrass sod, AquaSmart concentration had few consistent effects on seed or sod establishment. The drought tolerance studies also showed no significant differences between application rates of AquaSmart.

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Introduction

In addition to commercial sod and seed production for turfgrass, the U.S. turfgrass industry also includes lawn care and equipment, golf courses and sports fields, and turfgrass maintenance. According to the 2012 Census of Agriculture conducted by the United States Department of Agriculture (USDA), in 2012 there were 321,309 acres in the United States being managed for commercial sod production, helping to make the turfgrass industry an important part of domestic agriculture (USDA 2012 Ag Census). As of 2002, the U.S. turfgrass industry brought in $57.9 billion in revenue (Haydu et al., 2008). That same year, over 163,000 km^2 of land was being managed for turfgrass, with about 128,000 km^2 of that as home lawns, which gives managed turfgrass an area three times larger than any other irrigated crop grown in the U.S. (Milesi et al., 2005).

While turf quality is very important, especially for golf courses and sports complexes, maintaining high turf quality is a water-intensive operation, especially for regions with lower rainfall or warmer temperatures (Guerrero et al., 2007). Weather patterns of more intensive drought, higher temperatures, and less predictable and more severe storms have occurred in the last 20 years. All of these conditions impact management and quality of turfgrass areas. As water use consciousness increases, turf managers are looking for ways to decrease water consumption while maintaining turf quality. Super-absorbent polyacrylamide polymers, or hydrogels, have the potential to help increase water retention in the soil and reduce irrigation frequency. Hydrogels absorb water and nutrients, helping to hold both within the soil, and then can release both back into the soil increasing plant access (Kay-Shoemake et al., 1998).

MacPhail et al. (1980) showed that hydrogels had little to no effect on seedling establishment and root growth in Kentucky bluegrass (*Poa pratensis* L.) sod, although they noted some increase in sod transplant success with a post-installation application of the hydrogel. Guerrero et al. (2007) noted that while germination rates of creeping bentgrass (*Agrostis stolonifera* L.) and common bermudagrass (*Cynodon dactylon* L. Pers) were only slightly increased when grown with a hydrogel, root growth and development were faster, and soil water retention increased between 9.2% and 14.2% at a depth of 15 cm. This increase could potentially allow for up to a 50% reduction in required irrigation volume. And Hadam (2010) noted that while germination and establishment results varied for red fescue (*Festuca rubra* L.), sheep fescue (*Festuca ovina* L.), and perennial ryegrass (*Lolium perenne* L.) when grown under manufacturer-recommended hydrogel rates, the results did suggest positive long-term effects on drought tolerance under infrequent irrigation conditions. In a study focused on creeping bentgrass, Agaba et al. (2011) investigated the effects of various hydrogel concentrations on biomass development and water use during growth and on water infiltration through soil and sand layers. Their results noted that higher application concentrations of hydrogel increased the water use efficiency of the grass along with increased root and shoot biomass.

Even with results that suggest increased water use efficiency and increased establishment and growth with hydrogel use, the incorporation of hydrogels into common practice is still not well established (Hadam et al., 2011). One primary reason is that effectiveness of hydrogels depends greatly on both the composition of the hydrogel and the specific water use requirements and drought tolerance of each species (Williams and

Wallace, 1986; Akhter et al., 2004). Further research at the species and individual hydrogel levels is needed.

AquaSmart is a cross-linked polyacrylamide hydrogel being marketed as having the potential to absorb up to 12 times its weight in water. Unlike other, similar, hydrogels on the market, AquaSmart's product is bonded onto sand grains for ease of incorporation into substrate mixes and field soils. However, research of AquaSmart's products is limited. This study investigates the effects the water retention capacity that AquaSmart has on the establishment and growth of newly seeded and sodded bermudagrass and on the drought tolerance of established bermudagrass.

The objectives of this research were to determine effects of different application rates of AquaSmart:

1. On the establishment and growth quality of seeded bermudagrass.

2. On the establishment and growth quality of bermudagrass sod.

3. On drought tolerance in established bermudagrass sod.

We hypothesize that:

1. Bermudagrass seed and sod established with higher application rates of AquaSmart will have higher turf quality and maintain higher soil volumetric water content.

2. Established bermudagrass sod with higher application rates of AquaSmart will take longer to exhibit signs of drought stress, including leaf firing, brown cover, and soil volumetric water content.

Materials and Methods

All of the turfgrass studies were conducted at the Oklahoma State University Turfgrass Research Facility in Stillwater, OK (36º 07' 06.76" N and 97º 06' 11.60" W). Prior to the start of the seed and sod establishment study an irrigation audit was conducted to determine spread and coverage of the in-ground automatic sprinkler system (0.51 cm/5 minutes with a coefficient of uniformity of 74.73%). Soil tests were also conducted for the establishment plots in 2014 (NO_3-N at 23.1 kg/A) and 2015 (NO_3-N at 6.35 kg/A). For the establishment studies in 2014 and 2015, the plot was sprayed with glyphosate (Roundup, Monsanto Company, Marysville, OH) according to label directions for herbaceous weeds, tilled, and rolled prior to the beginning of the study. AquaSmart (hereafter referred to as hydrogel) was procured from a local distributor.

For all the turfgrass studies, the following data were collected weekly: turf quality visual ratings on a scale of 1 to 9, with 1 being poor and 9 being high quality; Normalized difference vegetation index (NDVI) ratings taken using a handheld GreenSeeker sensor (N Tech Industries Inc., Ukian, CA) on a scale from zero to one, with a number closer to one indicating a greener plot; soil moisture readings taken at a depth of 5.08 cm using a Steven's POGO portable soil sensor (Stevens, Portland, OR); and percent green cover analyzed using digital photographs taken using a galvanized metal light box (constructed by OSU turfgrass research staff, Stillwater, OK) and SigmaScan Pro 5.0 software (Systat Software, Chicago, IL).

2014 Seed and Sod Establishment Study: On 3 July 2014, the seed and sod establishment study began. Six treatments were tested for both seed and new sod: untreated control and topdressing sand at 18.14 kg/92.9 m^2 as well as hydrogel at 4.54, 9.07, 18.14, and 27.22 kg/92.9 m^2. Plots were 1.52 m x 1.52 m and the study design was a randomized complete block with 4 replications of the 6 treatments. For all seed plots, 'Riviera' seed was spread at a rate of 0.454 kg/92.9 m^2, while for all sod plots, 'Latitude 36' sod was laid. Seed and sod plots were fertilized with urea (46N-0P-0K) at a rate of 0.454 kg/92.9 m^2 and irrigated, and the seed plots were covered with seed cloth. Fertilization occurred only at the beginning of the study and mowing was conducted using a push rotary mower at a height of 3.81 cm.

Irrigation was conducted via in-ground, rotating sprinkler heads three times/day for seven minutes each time during the first week post-installation. In the following weeks of the study, as the seed sprouted, irrigation event timing and frequency was reduced. Irrigation event length was based on the turfgrass evapotranspiration (ET) ratio provided by the Oklahoma Mesonet and was intended to replace the amount of moisture lost through ET (Table 4.1). The nearest Mesonet station was 0.4 km from the Turfgrass Research Center facility in Stillwater. Sod data collection began on 10 July 2014, one week post-installation, and seed data collection began on 27 July 2014, three weeks post-seeding after the seed cloth had been removed. Data collection continued until 2 October 2014, when the experiments were terminated. Mowing was conducted at a height of 3.81 cm using a push rotary mower. Results were analyzed using SAS statistical software

(SAS 9.4, SAS Institute, Cary, NC) using Fisher's Protected LSD test at a 0.05 confidence level.

2014 Drought Study on Established Sod: The goal of the established sod study was to determine the effects of the hydrogel on drought survival of an established bermudagrass plot. The research plot used for this study was an established 'Riviera' bermudagrass plot grown on a native soil (clay loam). Six treatments were tested in the established sod drought study: untreated control and topdressing sand at 18.14 kg/92.9 m^2 as well as hydrogel at 4.54, 9.07, 18.14, and 27.22 kg/92.9 m^2. The experimental design was a randomized complete block containing 1.23 m x 1.23 m plots with four replications. Prior to plot establishment, the sod was aerated and the cores were removed from the plots. Hydrogel and sand treatments were then applied and brushed to the soil surface and into the aeration holes. Sod was then irrigated using an in-ground sprinkler system (0.63 cm/5 minutes with a coefficient of uniformity of 81.34%).

Irrigation occurred for seven minutes every evening for two weeks post treatment application, and then stopped. To exclude water from rain events, a sod cutter was used to cut a trench around the treatment area to prevent water seepage. A waterproof tarp measuring 15.24 m x 15.24 m was staked along the north side of the plot trench, and completely covered the plot when pulled flat. To ensure full rain exclusion, two smaller tarps (9.14 m x 9.14 m) were staked along the east and west sides of the plot trench, and were pulled to the middle, over the large tarp. Where the tarps overlapped in the center of the plot, both layers were held down by cinder blocks to prevent rainwater from seeping or being blown beneath the tarp. Both the trench and the tarps were arranged to provide at least a 3.04 m buffer zone between the edge of the block and the treated research plots.

The plots were covered before rain events and were left covered overnight when there was a chance of nighttime rain showers. During overcast, but rainless, days, the plots were not covered. Mowing was conducted using a riding reel mower at a height of 5 cm.

The scheduled point was when all plots rated at a 3 or lower on the turf quality and leaf firing ratings, although soil moisture measurements were expected to be at drought level prior to the turfgrass showing severe drought distress. The drought study was ended on 18 September 2014, prior to complete leaf firing of the turfgrass, due to heavy rains. Final data were collected and analyzed using SAS statistical software (SAS 9.4, SAS Institute, Cary, NC) using Fischer's Protected LSD test at a 0.05 confidence level.

2015 Sod Establishment Study: The sod establishment study was repeated with some modifications during the 2015 growing season. Three application rates of hydrogel were tested against one untreated control, and all rates were tested under three different irrigation regimes. Hydrogel rates were 9.07, 18.14, and 36.29 kg/92.9m^2, and the irrigation regimes were an industry standard, a reduced, and no irrigation. The industry standard irrigation schedule was as follows: twice per day for 15 minutes the first week post-installation, once per day for 15 minutes the second week, every other day for 15 minutes the third week, and then irrigation as needed in subsequent weeks. The reduced irrigation schedule was as follows: once per day for 15 minutes the first week post-installation, every other day for 15 minutes the second week, and irrigation as needed in subsequent weeks. The no irrigation treatment received irrigation on the day of installation, and then only received irrigation via rainfall. 'Latitude 36' sod was installed on 13 July 2015 and that same day plots were fertilized with urea (46N-0P-0K) at a rate of 0.454 kg/92.9 m^2. On 28 August 2015 the plots were again fertilized with 15N-0.87P-12.4K (15N-2P_2O_5-15K_2O granular fertilizer, Plant Science Inc., Gormley, Ontario, CAN).

The experimental design for this study was a split-plot with irrigation as the main plot and hydrogel treatment as the subplot. The main plot was not randomized, while the subplot was a randomized complete block design. Analysis was conducted using PROC MIXED in SAS 9.4 statistical software (SAS Institute, Cary, NC), and tested irrigation across subplots, hydrogel rate across subplots, and hydrogel rate against irrigation for main plots and subplots.

All manual irrigation was applied using a hose with a flow meter attachment (c700 flow meter, Elster AMCO Water, Ocala, FL) to accurately record irrigation volumes (Table 4.2). Rainfall event totals were taken from the Oklahoma Mesonet website, with readings from the Mesonet station located 0.4km away from the research station. The "as needed" determinant for irrigation was based on the visual ratings. When over half of the plots within one of the three irrigation schedule plots were rated 5 or less in visual quality, the entire irrigation plot was irrigated. Sod data collection began on 19 July 2015, one week post-installation and continued until 18 October 2015. Mowing was conducted with a push rotary mower at a height of 5 cm, and took place infrequently due to scalping injury on parts of the sod.

Results and Discussion

2014 Seed and Sod Establishment Study: Results shown below are based on days after treatment, with the seed study measurements beginning 21 days after treatment and the sod study measurements beginning 7 days after treatment.

2014 Seed: No differences existed between hydrogel concentrations for germination rate, percent green cover, or visual turf quality ratings. Normalized difference vegetation index (Table 4.3) and volumetric water content (Table 4.4) differed among hydrogel application rates on some dates. Normalized difference vegetation index (NDVI) measurements for seeded plots showed significant differences as follows: for 21 days after treatment (P=0.044), the control plots had the highest mean NDVI at 0.365 while the 9.07 kg/92.9 m^2 and 27.22 kg/92.9 m^2 application rates had the lowest mean NDVI measurements at 0.315 and 0.328 respectively. At 84 days after treatment (P=0.0093), the 9.07 kg/92.9 m^2 application rate had the highest mean NDVI measurements at 0.697, while the control plots and the 27.22 kg/92.9 m^2 application rate had the lowest mean NDVI at 0.657 and 0.667 respectively. For 91 days after treatment (P=0.0194), the 9.07 kg/92.9 m^2 concentration again had the highest mean NDVI measurements at 0.73, while the control again had the lowest mean NDVI measurements at 0.685.

Differences occurred in volumetric water content as follows: 21 days after treatment ($P<0.0001$), the 27.22 kg/92.9 m^2 concentration had the highest mean volumetric water content at 26.92% while the 9.07 kg/92.9 m^2 concentration had the lowest mean volumetric water content at 21.73%. For 35 days after treatment (P=0.0048), the 9.07 kg/92.9 m^2 application rate had a lower mean volumetric water (28.2%) content than the other application rates. At 63 days after treatment (P=0.0015), sand and hydrogel at 4.54 kg/92.9 m^2 were significantly higher than the other application rates at 35.12% and 35.02% respectively. At 70 days after treatment (P=0.0057), the control had a lower volumetric water content (30.79%) than any other treatments. For 84 days after treatment (P=0.0031), the 4.54 kg/92.9 m^2 application rate had a higher mean volumetric water content (38.34%) than the other treatments except at 27.22 kg/92.9 m^2 (25.83%), while the control had the lowest mean volumetric water content (22.78%).

2014 Sod: No differences existed between hydrogel application rates for percent green cover or visual turf quality ratings. Normalized difference vegetation index (Table 4.5) and volumetric water content (Table 4.6) did show some significant results. Normalized difference vegetation index measurements for sod establishment showed significant results as follows: 28 days after treatment (P=0.0464), sand and the 9.07 kg/92.9 m^2 and 27.22 kg/92.9 m^2 application rates showed significantly higher mean NDVI measurements (0.811, 0.82, and 0.811 respectively) than the control and the 4.54 kg/92.9 m^2 application rate (0.781 and 0.803 respectively). At 77 days after treatment (P=0.0497), the 27.22 kg/92.9 m^2 application rate showed significantly higher mean NDVI readings (0.705) and 9.07 kg/92.9 m^2 showed significantly lower mean NDVI measurements (0.67).

Volumetric water content showed significant differences as follows: 7 days after treatment (P<0.0001), the 4.54 kg/92.9 m^2 application rate gave the highest mean volumetric water content (25.03%), while the control gave the lowest mean percentage (20.99%). At 14 days after treatment (P=0.0005), the 9.07 kg/92.9 m^2 application rate gave the highest mean volumetric water content (30.71%), while the 4.54 kg/92.9 m^2 application rate gave the lowest mean volumetric water content (27.88%). AT 77 days after treatment (P=0.0415), the 27.22 kg/92.9 m^2 application rate gave the highest mean volumetric water content (34%), while sand gave the lowest mean volumetric water content (31.06%). At 91days after treatment (P=0.0027), 27.22 kg/92.9 m^2 application rate again gave the highest mean volumetric water content (28.54%), while the 9.07 kg/92.9 m^2 and 18.14 kg/92.9 m^2 application rates gave the lowest mean volumetric water content measurements (23.94% and 24.61% respectively).

2014 Established Sod Drought Study: Analyses indicated no significant differences between hydrogel concentrations for percent green cover, visual turf quality ratings, or NDVI. During the enforced drought portion of the study, there were no significant differences observed for leaf firing or percent brown cover between hydrogel concentrations. Volumetric water content (Table 4.7) did show some significant results. At 7 days after treatment (P<0.0001), the 9.07 kg/92.9 m^2 concentration showed the highest mean volumetric water content (40.85%), while the 27.22 kg/92.9 m^2 concentration showed the lowest mean volumetric water content (40.26%). At 14 days after treatment (P<0.0001), the 9.07 kg/92.9 m^2 concentration again showed the highest mean volumetric water content (36.17%), while the 27.22 kg/92.9 m^2 concentration again showed the lowest mean volumetric water content (32.3%).

The following results are from after the drought conditions were imposed on the study plots. At 42 days after treatment (P<0.0001), the 27.22 kg/92.9 m^2 application rate showed the highest mean volumetric water content (14.5%) with no differences noted between the other treatments. For 49 days after treatment ($P \leq 0.0008$), the 4.54 kg/92.9 m^2

application rate showed the highest mean volumetric water content (13.9%), while the 9.07 kg/92.9m^2 and 18.14 kg/92.9 m^2 application rates showed the lowest mean volumetric water content (6.1% and 6.9% respectively). At 56 days after treatment, the 27.22 kg/92.9 m^2 application rate again showed the highest mean volumetric water content (14.8%), while the 9.07 kg/92.9 m^2 and 18.14 kg/92.9 m^2 application rates showed the lowest mean volumetric water content (8.4% and 8.5% respectively).

2015 Sod Establishment Study: Analysis of volumetric water content (Table 4.8) showed no significant differences between hydrogel application rates or hydrogel application rates tested against irrigation schedules. There was a significant difference between the three irrigation schedules (industry standard, reduced, and none), which was expected. For some of the weeks, there was no difference seen between the three irrigation schedules. Much of this variation can be attributed to heavy rainfall events as none of the plots were covered during rain. Figure 4.1 shows the mean volumetric water content for each irrigation schedule over time with rainfall events indicated. As can be seen in the figure, the data collection dates where the mean volumetric water content measurements are most similar directly follows these rain events. Analysis of NDVI (Table 4.9) also showed no significant differences between hydrogel application rates or hydrogel application rates tested against irrigation schedules. Analysis of NDVI did show a significant difference between the three irrigation schedules, and again, that was expected and was not a result of hydrogel application rate.

Analyses of both the visual turf quality (Table 4.10) and green cover from digital photo analysis (Table 4.11) showed a significant result for either hydrogel application rate or hydrogel application rate tested against irrigation schedule several sampling days.

However, because all three irrigation blocks were open to rainfall, it could not be conclusively determined whether the significant effects were a result of the hydrogel or of outside environmental factors such as rainfall. Additionally, the significant results were periodic rather than consistent from week to week, indicating that rainfall is a more likely causal factor than the effects of hydrogel application rates.

Previous research on the effects of hydrogels on turfgrass establishment and germination are mixed. Some studies, such as Guerrero et al. (2007) have shown that root growth and development rates and soil water retention levels were increased with applications of hydrogel at a depth of 15 cm. However, MacPhail et al. (1980) noted that hydrogels had little to no effect on seedling establishment and root growth in Kentucky bluegrass sod when hydrogel was applied prior to sod installation. One of the issues MacPhail et al. (1980) noted was that the hydrogel, when saturated, formed a barrier between the sod and the soil surface, preventing the roots from penetrating the soil. This did not appear to be an issue in our bermudagrass studies, even though application rates were comparable for the two hydrogels used. In a companion study that involved hydrogel application post sod-installation, they found some significant differences between hydrogel application rates, which might suggest an economic benefit to post-installation hydrogel applications (MacPhail et al., 1980). Our 2014 drought study on established bermudagrass showed no significant differences at all between treatments, although the water requirements and drought tolerances of Kentucky bluegrass and bermudagrass are different, which may help explain the differences in results.

Meanwhile, Agaba et al. (2011) showed that higher application concentrations of hydrogel increased the water use efficiency and root and shoot biomass of *Agrostis* *stolonifera* L. Agaba et al. (2011) study involved seed sown in hydrogel-amended sand (mixed to a depth of 25 cm), which allowed the *Agrostis stolonifera* L. seeds ready access to the water held by the hydrogel. For our bermudagrass seeded study, we only incorporated the hydrogel into the top 1-2 cm of the soil, so the water-retention potential was primarily at the soil's surface and not in the root zone. These differences in the experimental setup may help account for the differences between results, even taking into consideration the water requirement and drought tolerance differences between bermudagrass and *Agrostis stolonifera* L. Sheikhmoradi et al. (2012) also found significant differences between hydrogel application rates for seeded turfgrass including shoot height and chlorophyll levels. The other performance and turfgrass health factors they investigated only showed significance between irrigation schedules, not hydrogel application rates (Sheikhmoradi et al., 2012). These significant differences between irrigation schedules align with our similar results from the 2015 sod establishment studies. As we did not test grass blade chlorophyll levels, no comparisons can be made with those data.

These results suggest that some benefits to hydrogel usage may be obtained in the turfgrass industry, both for seed and sod. However, because the effectiveness of hydrogels depends both on the chemical composition of the hydrogel and on the water use requirements and drought tolerance of individual turfgrass species, more research is needed to pinpoint which hydrogels applied in what manner are most beneficial economically and physiologically to turfgrass establishment and growth.

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Table 4.1: Monthly average air temperature (°C), precipitation (mm), and reference evapotranspiration (ET_o, mm) for the Oklahoma State University Turfgrass Research Facility in Stillwater, OK, during the research period (July-October 2014, July-October 2015)

	July	Aug.	Sept.	Oct.
Air Temperature (°C)				
2014	25.4	27.6	22.8	18.1
2015	28.0	26.1	24.4	16.6
Precipitation (mm)				
2014	101.0	51.0	106.4	55.4
2015	97.3	85.0	89.9	94.7
ET_o (mm)				
2014	5.7	4.2	4.8	2.1
2015	5.8	5.0	4.6	2.8

Table 4.2: Applied irrigation volume (L) for standard and reduced irrigation plots for 2015 sodded bermudagrass establishment study.

Days After Treatment	Standard Irrigation (L)	Reduced Irrigation (L)
1	159	83.3
2	151.4	75.7
3	136.3	68.1
4	121.1	60.6
5	121.1	60.6
6	121.1	60.6
7	60.6	0
9	60.6	0
10	60.6	60.6
11	60.6	0
12	60.6	60.6
13	60.6	0
14	60.6	60.6
16	60.6	0
18	60.6	0
20	18.9	18.9
23	18.9	45.4
25	18.9	18.9
26	18.9	18.9
30	18.9	45.4
32	75.7	75.7
33	75.7	75.7
39	26.5	22.7
45	30.3	26.5
48	37.9	37.9
50	22.7	15.1
53	15.1	22.7
55	37.9	45.4
66	30.2	22.7
73	18.9	18.9
76	68.1	60.6
90	37.9	37.9
94	18.9	18.9
96	11.4	15.1

Table 4.3: Normalized difference vegetation index (NDVI) for 2014 seeded bermudagrass plots under four application rates of hydrogel. n=4.

Days After Treatment	Application Rate (kg/92.9m^2	Mean NDVI (0-1)
21	0	0.365a^z
	Sand	0.337ab
	4.54	0.346ab
	9.07	0.315b
	18.14	0.324ab
	27.22	0.328b
28	0	0.661a
	Sand	0.618a
	4.54	0.616a
	9.07	0.578a
	18.14	0.63a
	27.22	0.616a
35	0	0.741a
	Sand	0.688a
	4.54	0.743a
	9.07	0.698a
	18.14	0.738a
	27.22	0.748a
42	0	0.736ab
	Sand	0.727b
	4.54	0.765ab
	9.07	0.77a
	18.14	0.753ab
	27.22	0.765ab
49	0	0.675b
	Sand	0.682b
	4.54	0.695ab
	9.07	0.728a
	18.14	0.703ab
	27.22	0.692b
56	0	0.712ab
	Sand	0.71ab
	4.54	0.697b
	9.07	0.723a
	18.14	0.715ab
	27.22	0.718a
63	0	0.675b
	Sand	0.691ab
	4.54	0.693ab

	9.07	0.708a
	18.14	0.675b
	27.22	0.688ab
70	0	0.766b
	Sand	0.771b
	4.54	0.77b
	9.07	0.783a
	18.14	0.772ab
	27.22	0.773ab
77	0	0.681b
	Sand	0.697ab
	4.54	0.701ab
	9.07	0.692ab
	18.14	0.705a
	27.22	0.692ab
84	0	0.657c
	Sand	0.693ab
	4.54	0.68abc
	9.07	0.697a
	18.14	0.671c
	27.22	0.667c
91	0	0.685c
	Sand	0.711ab
	4.54	0.712ab
	9.07	0.73a
	18.14	0.712ab
	27.22	0.705bc

[z]Numbers followed by the same letter are not statistically significant from one another

Table 4.4: Volumetric water content (VWC) for 2014 seeded bermudagrass plots under four application rates of hydrogel. n=4.

Days After Treatment	Application Rate (kg/92.9m^2	Mean VWC (%)
21	0	24.33b[z]
	Sand	20.81cd
	4.54	19.81d
	9.07	21.73c
	18.14	24.73b
	27.22	26.92a
28	0	37.38a
	Sand	38.34a
	4.54	38.39a
	9.07	37.32a
	18.14	37.81a
	27.22	38.09a
35	0	32.19a
	Sand	31.17a
	4.54	31.87a
	9.07	28.2b
	18.14	30.97a
	27.22	31.08a
42	0	24.77a
	Sand	23.34a
	4.54	23.52a
	9.07	24.46a
	18.14	23.75a
	27.22	24.85a
49	0	11.03a
	Sand	10.19a
	4.54	10.68a
	9.07	10.40a
	18.14	10.34a
	27.22	9.67a
56	0	12.52a
	Sand	13.15a
	4.54	12.11a
	9.07	13.57a
	18.14	12.35a
	27.22	12.4a
63	0	32.79b
	Sand	35.12a
	4.54	35.02a

	9.07	33.27b
	18.14	33.53b
	27.22	33.39b
70	0	30.79b
	Sand	33.03a
	4.54	33.73a
	9.07	32.58a
	18.14	32.99a
	27.22	33.15a
77	0	31.28ab
	Sand	31.14ab
	4.54	32.6a
	9.07	31.79ab
	18.14	30.77b
	27.22	31.81ab
84	0	22.78c
	Sand	34.37bc
	4.54	38.34a
	9.07	25.18bc
	18.14	24.97bc
	27.22	25.83ab
91	0	20.16b
	Sand	20.56ab
	4.54	22.15ab
	9.07	20.38ab
	18.14	22.95a
	27.22	21.51ab

[z]Numbers followed by the same letter are not statistically significant from one another.

Table 4.5: Normalized difference vegetation index (NDVI) for 2014 seeded bermudagrass plots under four application rates of hydrogel. n=4.

Days After Treatment	Application Rate (kg/92.9m^2	Mean NDVI (0-1)
7	0	0.71ab[z]
	Sand	0.67b
	4.54	0.725a
	9.07	0.678ab
	18.14	0.673ab
	27.22	0.72ab
14	0	0.798a
	Sand	0.803a
	4.54	0.814a
	9.07	0.818a
	18.14	0.8a
	27.22	0.816a
21	0	0.799b
	Sand	0.825a
	4.54	0.824a
	9.07	0.815a
	18.14	0.829a
	27.22	0.816a
28	0	0.781b
	Sand	0.811a
	4.54	0.803b
	9.07	0.82a
	18.14	0.804ab
	27.22	0.811a
35	0	0.799a
	Sand	0.823a
	4.54	0.819a
	9.07	0.819a
	18.14	0.816a
	27.22	0.825a
42	0	0.83a
	Sand	0.836a
	4.54	0.834a
	9.07	0.845a
	18.14	0.84a
	27.22	0.841a
49	0	0.725a
	Sand	0.732a
	4.54	0.713a

	9.07	0.705a
	18.14	0.704a
	27.22	0,726a
56	0	0.709a
	Sand	0.716a
	4.54	0.709a
	9.07	0.705a
	18.14	0.706a
	27.22	0.719a
63	0	0.718a
	Sand	0.73a
	4.54	0.718a
	9.07	0.709a
	18.14	0.713a
	27.22	0.721a
70	0	0.774a
	Sand	0.77a
	4.54	0.778a
	9.07	0.776a
	18.14	0.778a
	27.22	0.784a
77	0	0.69abc
	Sand	0.685abc
	4.54	0.68bc
	9.07	0.67c
	18.14	0.694ab
	27.22	0.705a
84	0	0.669a
	Sand	0654b
	4.54	0.669a
	9.07	0.66ab
	18.14	0.655b
	27.22	0.665ab
91	0	0.674a
	Sand	0.678a
	4.54	0.678a
	9.07	0.673a
	18.14	0.679a
	27.22	0.631a

[z]Numbers followed by the same letter are not statistically significant from one another.

Table 4.6: Volumetric water content (VWC) for 2014 seeded bermudagrass plots under four application rates of hydrogel. n=4.

Days After Treatment	Application Rate (kg/92.9m^2	Mean VWC (%)
7	0	20.99d^z
	Sand	21.55cd
	4.54	25.03a
	9.07	23.84ab
	18.14	22.7bc
	27.22	22.83bc
14	0	28.58c
	Sand	28.92c
	4.54	27.88c
	9.07	30.71a
	18.14	28.63bc
	27.22	29.78ab
21	0	32.3a
	Sand	32.03a
	4.54	32.47a
	9.07	32.51a
	18.14	32.18a
	27.22	32.27a
28	0	39.31a
	Sand	39.02a
	4.54	39.41a
	9.07	39.31a
	18.14	39.3a
	27.22	39.59a
35	0	32.71a
	Sand	31.97a
	4.54	33.45a
	9.07	32.76a
	18.14	32.6a
	27.22	32.81a
42	0	29.46b
	Sand	30.92ab
	4.54	31.0ab
	9.07	32.58a
	18.14	30.79ab
	27.22	30.69ab
49	0	12.41a
	Sand	13.13a
	4.54	13.33a

	9.07	13.33a
	18.14	12.0a
	27.22	12.96a
56	0	14.57a
	Sand	14.58a
	4.54	14.71a
	9.07	15.11a
	18.14	15.69a
	27.22	14.18a
63	0	35.43a
	Sand	35.93a
	4.54	36.08a
	9.07	36.39a
	18.14	36.33a
	27.22	35.84a
70	0	36.17b
	Sand	36.24b
	4.54	36.24b
	9.07	37.25a
	18.14	36.56ab
	27.22	36.95ab
77	0	32.23c
	Sand	31.06c
	4.54	32.66abc
	9.07	33.08ab
	18.14	32.45abc
	27.22	34.0a
84	0	28.5a
	Sand	28.64a
	4.54	30.35a
	9.07	29.08a
	18.14	29.43a
	27.22	30.73a
91	0	26.19bc
	Sand	25.04bc
	4.54	27.03ab
	9.07	23.94c
	18.14	24.61c
	27.22	28.54a

[z]Numbers followed by the same letter are not statistically significant from one another.

Table 4.7: Volumetric water content (VWC) for 2014 established bermudagrass sod drought plots under four application rates of hydrogel. n=4.

Days After Treatment	Application Rate (kg/92.9m^2	Mean VWC (%)
7	0	40.56b[z]
	Sand	40.7ab
	4.54	40.58b
	9.07	40.83a
	18.14	40.69ab
	27.22	40.26c
14	0	35.0ab
	Sand	35.58ab
	4.54	34.75ab
	9.07	36.17a
	18.14	34.62b
	27.22	32.3c
21	0	21.08a
	Sand	20.33a
	4.54	22.18a
	9.07	20.61a
	18.14	19.94a
	27.22	19.83a
28	0	9.7a
	Sand	8.6ab
	4.54	9.3ab
	9.07	8.4ab
	18.14	9.5ab
	27.22	7.5b
35	0	10.9ab
	Sand	10.8ab
	4.54	9.3b
	9.07	9.9ab
	18.14	11.2a
	27.22	9.2b
42	0	8.4b
	Sand	8.5b
	4.54	7.5b
	9.07	8.5b
	18.14	7.5b
	27.22	14.5a
49	0	11.4ab
	Sand	9.6bc
	4.54	13.9a

	9.07	6.1c
	18.14	6.9c
	27.22	12.1ab
56	0	12.2bc
	Sand	10.6cd
	4.54	14.2ab
	9.07	8.4d
	18.14	8.5d
	27.22	14.8a

[z]Numbers followed by the same letter are not statistically significant from one another.

Table 4.8: Volumetric water content (VWC) for 2015 sodded bermudagrass plots under four application rates of hydrogel and three irrigation schedules. n=5.

Days After Treatment	Irrigation Schedule	Mean VWC (%)
6	NONE	5.02a[z]
	REDUCED	21.09b
	STANDARD	24.9c
14	NONE	4.49a
	REDUCED	16.49b
	STANDARD	21.47c
20	NONE	7.07a
	REDUCED	7.08a
	STANDARD	19.6b
27	NONE	1.33a
	REDUCED	12.48b
	STANDARD	5.67c
33	NONE	0.37a
	REDUCED	22.3b
	STANDARD	18.52c
41	NONE	16.15a
	REDUCED	18.28b
	STANDARD	17.74b
47	NONE	8.8a
	REDUCED	10.64ab
	STANDARD	15.31b
56	NONE	1.27a
	REDUCED	17.27b
	STANDARD	15.63b
61	NONE	18.49a
	REDUCED	17.9a
	STANDARD	17.84a
70	NONE	16.69a
	REDUCED	17.82b
	STANDARD	16.55a
76	NONE	3.98a
	REDUCED	3.97a
	STANDARD	3.59a
82	NONE	15.43a

	REDUCED	16.71a
	STANDARD	16.47a
90	NONE	10.66a
	REDUCED	9.09a
	STANDARD	9.32a
97	NONE	1.80a
	REDUCED	8.54b
	STANDARD	11.34b

[z]Numbers followed by the same letter are not statistically significant from one another.

Table 4.9: Normalized difference vegetation index (NDVI) for 2015 sodded bermudagrass plots under four application rates of hydrogel and three irrigation schedules. n=5.

Days After Treatment	Irrigation Schedule	Mean NDVI (0-1)
6	NONE	0.41a[z]
	REDUCED	0.63b
	STANDARD	0.62b
14	NONE	0.41a
	REDUCED	0.70b
	STANDARD	0.69b
20	NONE	0.38a
	REDUCED	0.69b
	STANDARD	0.70b
27	NONE	0.27a
	REDUCED	0.67b
	STANDARD	0.69b
33	NONE	0.25a
	REDUCED	0.64b
	STANDARD	0.60b
41	NONE	0.23a
	REDUCED	0.62b
	STANDARD	0.57b
47	NONE	0.32a
	REDUCED	0.65b
	STANDARD	0.61b
56	NONE	0.39a
	REDUCED	0.71b
	STANDARD	0.70b
61	NONE	0.50a
	REDUCED	0.75b
	STANDARD	0.74b
70	NONE	0.65a
	REDUCED	0.77b
	STANDARD	0.76b
76	NONE	0.59a
	REDUCED	0.75b
	STANDARD	0.74b

82	NONE	0.60a
	REDUCED	0.76b
	STANDARD	0.75b
90	NONE	0.62a
	REDUCED	0.73b
	STANDARD	0.70b
97	NONE	0.61a
	REDUCED	0.75b
	STANDARD	0.72b

[z]Numbers followed by the same letter are not statistically significant from one another.

Table 4.10: Turf quality for 2015 sodded bermudagrass plots under four application rates of hydrogel and three irrigation schedules. n=5.

Days After Treatment	Irrigation Schedule	Mean Turf Quality Rating (1-9)
6	NONE	2.6a[z]
	REDUCED	6.7bb
	STANDARD	7.0b
14	NONE	3.0a
	REDUCED	7.9b
	STANDARD	7.6b
20	NONE	2.2a
	REDUCED	6.9b
	STANDARD	6.6b
27	NONE	1.3a
	REDUCED	6.4b
	STANDARD	6.9b
33	NONE	1.1a
	REDUCED	4.9b
	STANDARD	4.9b
41	NONE	1.6a
	REDUCED	5.6b
	STANDARD	5.4b
47	NONE	1.8a
	REDUCED	5.8b
	STANDARD	5.0b
56	NONE	2.3a
	REDUCED	6.7b
	STANDARD	7.0b
61	NONE	3.4a
	REDUCED	7.4b
	STANDARD	7.4b
70	NONE	3.6a
	REDUCED	6.9b
	STANDARD	6.4b
76	NONE	3.6a
	REDUCED	5.4b
	STANDARD	6.4b

82	NONE	3.5a
	REDUCED	6.1b
	STANDARD	5.9b
90	NONE	4.1a
	REDUCED	5.7b
	STANDARD	5.0c
97	NONE	3.8a
	REDUCED	6.0b
	STANDARD	5.5b

[z]Numbers followed by the same letter are not statistically significant from one another.

Table 4.11: Percent green cover for 2015 sodded bermudagrass plots under four application rates of hydrogel and three irrigation schedules. n=5.

Days After Treatment	Irrigation Schedule	Mean Percent Green Cover (1-100%)
6	NONE	31.81a[z]
	REDUCED	30.82a
	STANDARD	36.79a
14	NONE	5.38a
	REDUCED	26.38b
	STANDARD	42.6c
20	NONE	5.65a
	REDUCED	53.34b
	STANDARD	65.8c
27	NONE	8.66a
	REDUCED	48.86b
	STANDARD	59.03c
33	NONE	16.98a
	REDUCED	29.72b
	STANDARD	28.42ab
41	NONE	12.68a
	REDUCED	51.2b
	STANDARD	43.17b
47	NONE	9.11a
	REDUCED	47.9b
	STANDARD	46.7b
56	NONE	27.13a
	REDUCED	54.87b
	STANDARD	56.77b
61	NONE	13.67a
	REDUCED	56.01b
	STANDARD	59.79b
70	NONE	17.8a
	REDUCED	59.44b
	STANDARD	59.77b
76	NONE	24.15a
	REDUCED	52.89b
	STANDARD	59.77b

82	NONE	29.6a
	REDUCED	80.74b
	STANDARD	76.72b
90	NONE	38.2a
	REDUCED	63.35b
	STANDARD	78.86c
97	NONE	33.9a
	REDUCED	69.74b
	STANDARD	70.1b

[z]Numbers followed by the same letter are not statistically significant from one another.

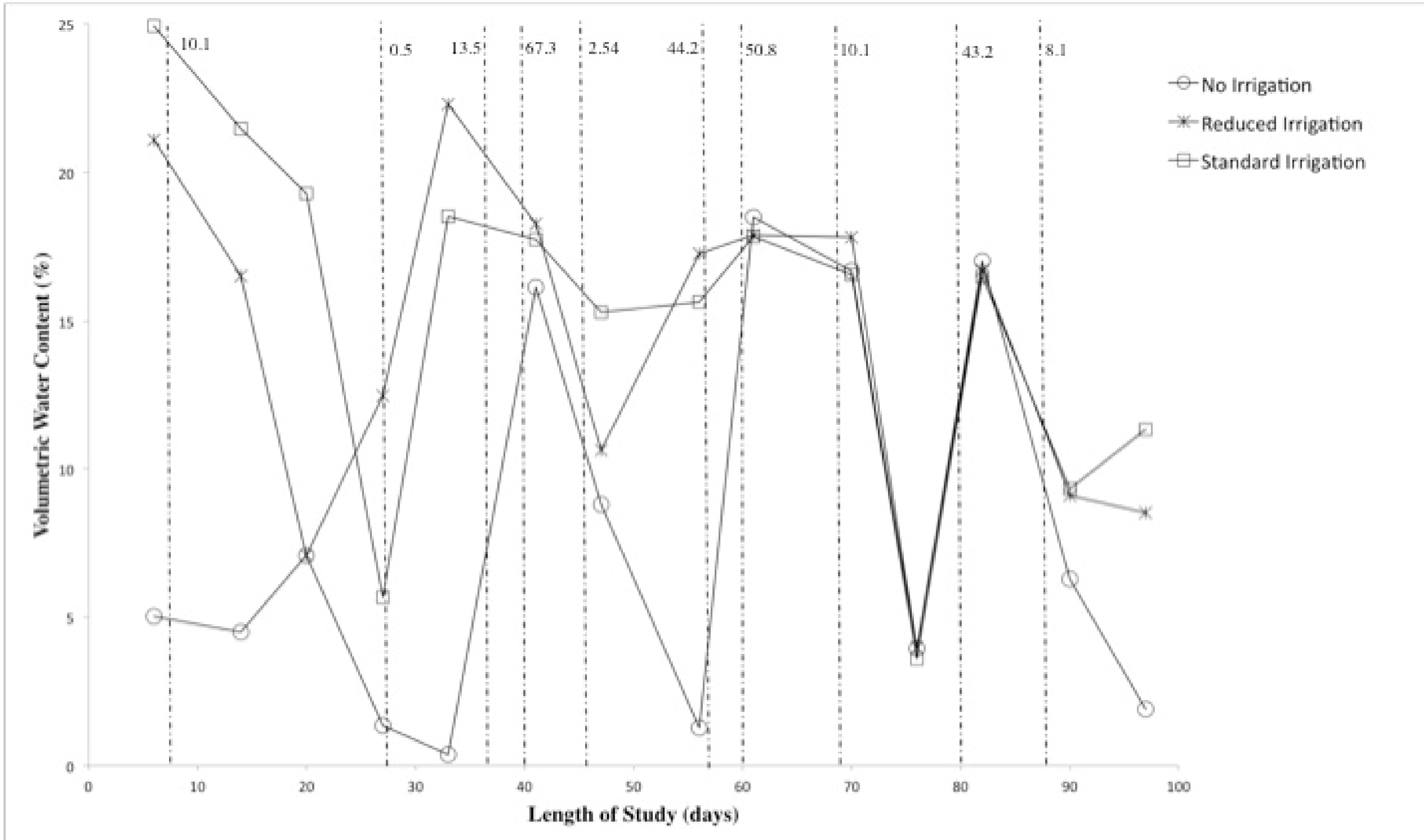

Figure 4.1: Average volumetric water content for 2015 sod plots under three irrigation schedules. Vertical dashed lines indicate rainfall events, with precipitation totals given at the tops of vertical lines.

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VITA

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Master of Science

Thesis: THE EFFECTS OF AQUASMART POLYMER COATED SAND ON GROWTH AND WATER USE OF ORNAMENTALS, NUTRIENT LEACHING IN GREENHOUSE MEDIA, AND ESTABLISHMENT AND GROWTH OF TURFGRASS

Major Field: Horticulture

Education:

Completed the requirements for the Master of Science in Horticulture at Oklahoma State University, Stillwater, Oklahoma in May, 2016.

Completed the requirements for the Master of Science in Environmental Studies at Antioch University New England, Keene, New Hampshire in May, 2010.

Completed the requirements for the Bachelor of Arts in Russian Language and Literature at Smith College, Northampton, Massachusetts in 2005.