

Applications of Hydrogels in the Nursery and During Outplanting

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Abstract: Hydrogels have a variety of potential uses including application to plants in the nursery and at the time of outplanting. Absorptive capacity of these gels is influenced by their chemical and physical composition as well as the ion concentration of the liquid being absorbed. The most common uses for hydrogels in nurseries or during outplanting are incorporation or root dips. Research results are mixed regarding hydrogel influences on plant water uptake and vary by product and environmental conditions. It is recommended that growers or planters conduct small trials to determine whether there are benefits to using hydrogels under their specific conditions.

Keywords: Polymer gels, plant moisture stress, root dips

What are Hydrogels?

Hydrophilic gels, or “hydrogels”, which are commonly known as superabsorbents, are crosslinked polymers that can absorb 400 to 1500 times their dry weight in water (Figure 1A). Most of the early hydrophilic polymers were destined for non-agricultural uses, most notably baby diapers, but have also found uses in such diverse applications as oil recovery, food processing, water purification, and wound dressings (Peterson 2002).

Hydrophilic polymers can be categorized into three classes, but can be chemically manipulated to produce products with different characteristics in each class (Mikkelsen 1994):

1. Naturally occurring polymers are starch-based polysaccharides that are made from grain crops such as corn and wheat. Natural polymers are most commonly used in the food industry as thickening agents.
2. Semi-synthetic polymers are derived from cellulose, which is chemically combined with petrochemicals. One of the first hydrogels specifically designed for horticulture was a polyethylene polymer combined with sawdust (Erazo 1987).
3. Synthetic polymers are made from petrochemicals and polyacrylamides (PAMs) are one of the most popular polymers that are chemically linked to prevent them from dissolving in solution. Linear chain polyacrylamides are used for erosion control, canal sealing, and water clarification whereas crosslinked polyacrylamide hydrogels are most commonly used in horticulture (Peterson 2002).

Factors Affecting Efficacy of Hydrogels

The absorptive capability of hydrogels is affected by their physical and chemical composition as well as environmental factors, such as the dissolved salts in the surrounding water solution.

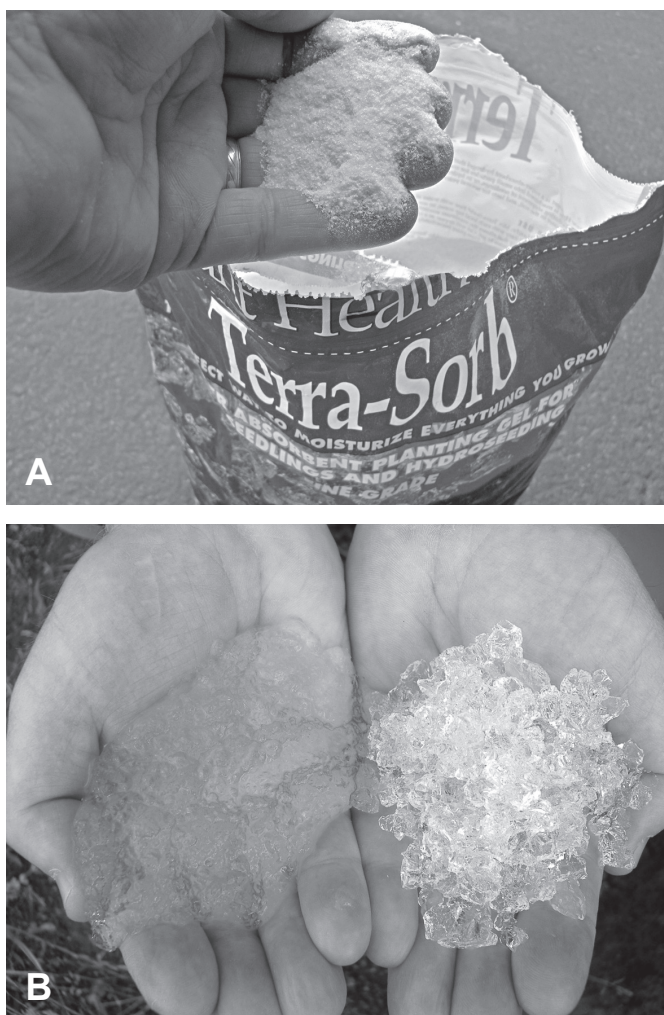


Figure 1. Hydrophilic gels, commonly known as hydrogels, are dry crystals that can absorb many times their own weight in water (A), and commercial products vary in chemical composition and particle size (B). [A, courtesy of David Steinfeld; B, courtesy of Diane Haase].

Chemical and physical composition

A web search will yield some information about the chemical composition of the various products, and most are either inorganic polymers or PAMs. The exact chemical composition of hydrogel products are trade secrets and many are simply described as “polymers” or “polyacrylamide”. Most are inorganically based but Zeba[®] is unique because it is starch-based (Table 1). Some hydrogel products also contain spores of mycorrhizal fungi, biostimulants, or slow release fertilizer.

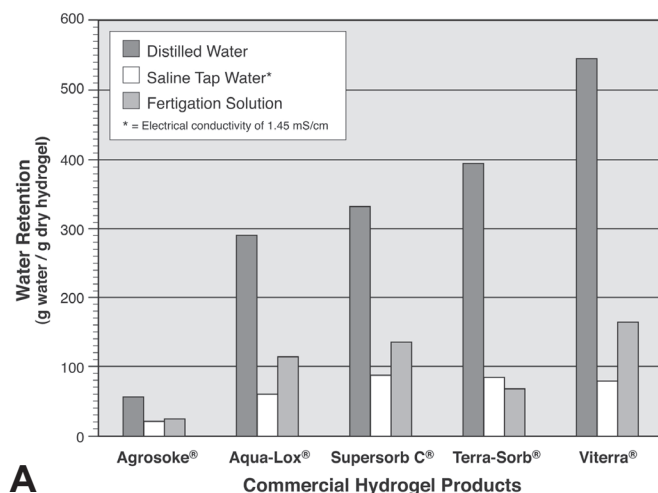
Table 1. Chemical composition of typical hydrogels used in horticulture or restoration.

Brand Name	Chemical Class	Other Additives
Boiler 1-2-3 [®]	Inorganic Polymer	Mycorrhizal spores and biostimulant
Bio-Organics [®]	Inorganic Polymer	Mycorrhizal spores
Soil Moist [®]	Polyacrylamide	Some contain mycorrhizal spores, and one contains slow-release fertilizer
Stockosorb [®]	Polyacrylamide	None
Viterra [®]	Inorganic Polymer	None
Zeba [®]	Starch polymer	None

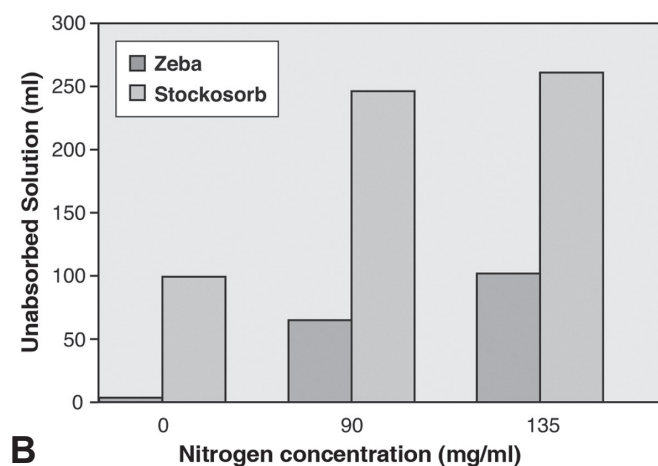
Physically, the particle size of the various hydrogel products can vary considerably and this attribute has a significant effect on how they are best used. Fine-textured products are best for root dips, whereas coarser grades are better for soil incorporation (Figure 1B). Soil Moist[®] is available in several different formulations for specific applications, including soil incorporation, root dips, hydroseeding, seed coatings, or even to retain moisture in cut Christmas trees (JRM Chemical Inc).

Dissolved Salts

Mikkelsen (1994) states that divalent ions, such as calcium (Ca⁺⁺) and magnesium (Mg⁺⁺), are more restrictive than monovalent ions, such as ammonium nitrogen (NH₄⁺) and potassium (K⁺). One research trial (Wang and Gregg 1990) soaked commercially available hydrogels with several different solutions including distilled water, moderately saline tap water (electrical conductivity of 1.45 mS/cm), and a dilute fertilizer solution. After soaking, the saturated hydrogels were allowed to drain to determine their absorptive capacity. The optimal absorption is reflected by the weight of water retained in the distilled water treatment, in which the hydrogels varied considerably (Figure 2A). Agrosoke absorbed and retained considerably less water than the other hydrogels, with Viterra retaining the most. The effect of dissolved salts of the amount of water that can be absorbed



A



B

Figure 2. The amount of water that can be retained depends on the hydrogel’s chemical composition and environmental factors like the salts dissolved in the surrounding solution (A). Increasing levels of fertilizer can reduce the amount of water absorbed by hydrogels (B). [A, modified from Wang and Gregg (1990), B, modified from NTC (2007a)].

by the various products can be seen in the other two treatments: the saline tap water and the fertigation solution. The tap water reduced the water retention of the commercial hydrogel products substantially, from a 65% decrease in Agrosoke to almost 85% in Viterra. Because it contained a variety of fertilizer ions, the water retention for dilute fertilizer treatment was different again (Wang and Gregg 1990). In a similar study, 2.5 g of hydrogel was added to 450-ml replications of water containing 0, 90, or 135 mg N/ml. After 40 hours, the amount of unabsorbed solution was measured and was significantly higher with increasing amounts of nitrogen (NTC 2007a)(Figure 2B). The bottom line is that the laboratory absorption values using distilled water are significantly different than the amount of water that can be absorbed and retained in the nursery or on the outplanting site.

Application of Hydrogels in Nurseries, Reforestation, and Restoration

Exactly how hydrogels benefit plants depends on how they are applied, and the most common used in nurseries or during outplanting are incorporation or root dips. The main use of hydrogels has been to retain water for plant growth especially when irrigation isn't provided, but new uses are continually being discovered.

Gel seeding

This was one of the first applications of hydrogels in horticulture and involves sowing seeds mixed into a hydrogel. The objective is that the hydrogel will retain moisture around the germinating seeds and improve establishment either in a nursery or on an outplanting site. Research trials coating leguminous tree seeds with hydrogels before sowing in a greenhouse or in field soil showed mixed results between plant species; larger-seeded species survived and grew better. One hypothesis was that coating seeds with hydrogels may reduce germination and emergence by reducing aeration around the seeds (Henderson and Hensley 1987). In a more recent test, hydrogels were applied to seeds of Scotch pine (*Pinus sylvestris* L.) and Austrian pine (*Pinus nigra* L.) prior to germination tests in the laboratory, a greenhouse, and a bareroot nursery. The hydrogel treatment reduced germination percentage for both species in the laboratory but Scotch pine treated with hydrogel germinated better than the controls in the greenhouse. In spite of these germination problems, the authors considered that the improved seedling growth after 2 years in the bareroot nursery justified the use of hydrogels in future trials (Sijacic-Nikolic and others 2010). The paucity of other published trials in recent years suggests that gel seeding has little application in forest and native plant nurseries or for direct seeding on project sites.

Root dips

When applied as a root dip, hydrogels coat fine roots and protect them against desiccation. One potential benefit is that hydrogel dips may function similarly to the natural polymeric mucilages produced by healthy roots. One recent study demonstrated that mucilage weakens the drop in water potential at the rootsoil interface, increasing the conductivity of the flow path across soil and roots and reducing the energy needed to take up water (Carminati and Moradi 2010). Hydrogel root dips could provide the same function, improving root- to-soil contact (Thomas 2008), and filling-in air spaces around transplants or outplanted seedlings (Figure 3).

The concept of dipping plant roots before transplanting or outplanting has been around for many years because it is intuitively attractive. Roots of nursery plants can dry as they are exposed to the atmosphere

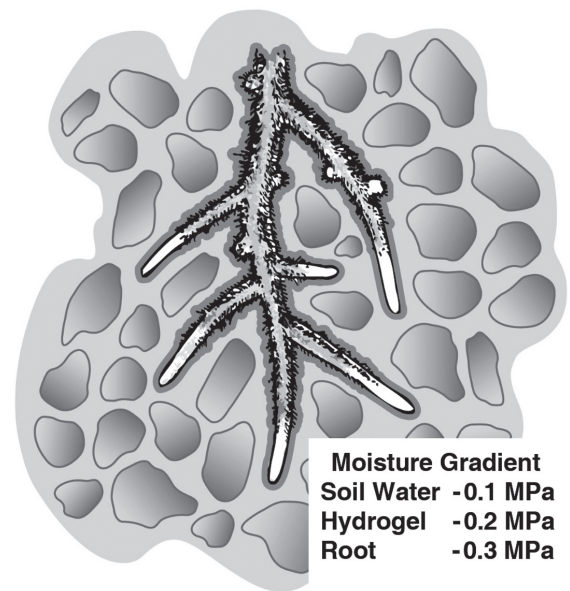


Figure 3. When hydrogels are applied as root dips, they function like the mucilage naturally produced by healthy roots and improve water uptake by increasing root-to-soil contact and filling-in air spaces.

during harvesting and handling and so it makes sense to apply a coating to protect them (Chavasse 1981). Southern nurseries have been dipping the roots of their bareroot stock in a clay slurry for decades, but many have switched to hydrogels in recent years (e.g. Bryan 1988). In the western states, the use of root dips is less common but some forestry organizations sell protective root dips as part of their tree distribution programs (for example, Kansas State Forest Service 2010). For a comparison of the various root dip products and their effectiveness, see Landis 2006.

In a comprehensive literature review of root dips, Sloan (1994) concluded that they were detrimental to bareroot stock when applied before storage. After outplanting, most of the research at that time showed that hydrogel root dips do not increase survival or growth under very dry conditions and are merely an added expense. One important conclusion is that, while root dips can be beneficial in protecting seedlings from exposure to sun and wind, tree planters should not assume that root dipping will restore seedling vigor after improper handling.

Another limitation of comparison trials of root dips is that all too often no appropriate control was included. Many dips were compared against no root dip at all but, since all hydrogels are applied in a water slurry, it makes sense to use a water dip as a control. One recent research study did just that, and tested 3 hydrogel-based root dips against a water dip control (Bates and others 2004). The seedlings of four bareroot conifers were dipped into one of 3 commercial root dips or a water control. When evaluated for survival, none of the products showed a significant improvement over the water dip; likewise, the commercial root dips gave no appreciable shoot growth benefit after 2 years (Figure 4). In another study, Douglas-fir seedlings (*Pseudotsuga menziesii* Mirb. Franco) were treated with a water dip and three hydrogel treatments varying rates of soluble fertilizer. After one growing season, there were no differences among treatments for xylem water potential, height growth, stem diameter growth, or survival (NTC 2007b).

The vast majority of research has been with bareroot conifer seedlings at the time of outplanting. We only found one published article on dipping the roots of container plants in hydrogel prior to outplanting. When two species of Eucalyptus container seedlings had their

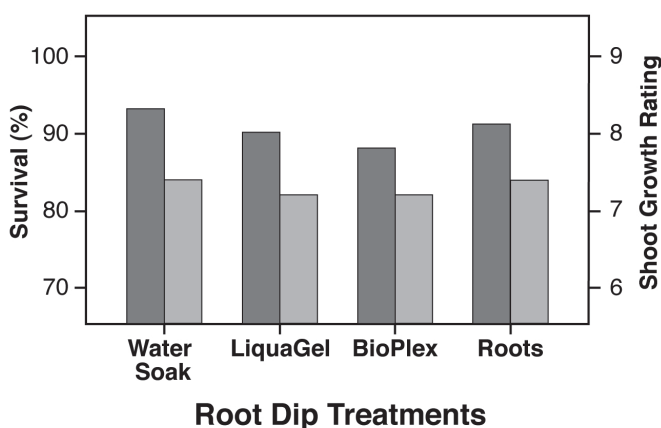


Figure 4. Compared to a water soak, none of three hydrogel root dips improved survival or shoot growth of conifer seedlings two years after outplanting (Bates and others 2004).

root plugs dipped in a hydrogel slurry, mortality at 5 months after outplanting was more than cut in half (Thomas 2008). Likewise, only one study looked at the effects of hydrogel dips on bareroot hardwood seedlings. When the roots of red oak (*Quercus rubra* L.) seedlings were dipped into a hydrogel slurry, and then subjected to drought stress, the hydrogel-treated seedlings had greater root moisture content and less root membrane leakage than plants without root dipping. These differences were not reflected in increased growth, however (Apostol and others 2009). Both of these studies stress the importance of using fine grade hydrogel when root dipping; using hydrogel with dry particle sizes from 0.2 to 0.3 mm covered roots much better than larger grades which clumped and fell off the roots (Sarvas 2003). Terra-Sorb® is available in three particle diameters: coarse (2 to 4 mm), medium (0.75 to 2 mm), and fine (0.10 to 0.75 mm), with the fine grade recommended for root dipping (Plant Health Care 2010). We only found one article on the use of hydrogel dips before transplanting in a bareroot nursery: dipping bareroot Norway spruce (*Picea abies* L.) seedlings prior to mechanical transplanting increased shoot height and root collar diameter compared to the controls (Sarvas 2003).

Amendment to container growing media

Another application which has been widely tested is the incorporation of hydrogels into growing media prior to sowing as a means to hold more water and reduce moisture stress. In addition to increasing water holding capacity, hydrogels have been shown to retain nutrient ions against leaching especially in growing media with low cation exchange capacities. One trial found this to be true for the cations ammonium and potassium, but not for the anionic nitrate which is one of the major causes of nutrient runoff from nurseries (Henderson and Hensley 1985).

Many earlier studies showed that, while hydrogels definitely increased the water holding capacity of the growing medium, this was not always reflected in increased plant growth. Douglas-fir container seedlings grown in hydrogel-amended medium averaged lower moisture stress than those in the unamended control media when subjected to desiccation following lifting. However, no differences were found among treatments for height, stem diameter, root volume, and shoot volume (NTC 2009). When European birch seedlings were grown in a hydrogel-amended medium, subsequent growth was actually reduced compared to the control seedlings (Tripepi and others 1991). The authors suggest that the reduced growth could be a result of reduced aeration resulting from less macropore space in the gel-amended



Figure 5. Many brands of growing media for the home gardener contain hydrogels.

media. This observation was supported by reduced root mass in the seedlings from the gel treatment. Another study found that air space in pine bark and pine bark/sand media was reduced in the hydrogel-amended growing media (Fonteno and Bilderback 1993).

In operational practice, few nurseries use a growing medium amended with hydrogels, although many such products are available for the non-professional or home gardener (Figure 5). Good growers want complete control of the water-holding capacity of their growing media, which would be lost with hydrogel amendments. Also, the swelling hydrogel particles must expand somewhere after hydration and undoubtedly reduce the amount of macropores which are so essential for good drainage and air exchange.

Soil amendment in bareroot nursery beds

Amending bareroot nursery soil to retain moisture may have some benefit, especially in areas of the nursery where variations in exposure, soil texture, or drainage patterns leave particular beds vulnerable to desiccation stress. Douglas-fir seedlings were transplanted into beds amended with three rates of hydrogel or a non-amended control treatment. Seedlings were measured periodically for xylem water potential just prior to irrigation. Stress levels were relatively low during the summer when the trial was conducted but one measurement date indicated that control seedlings had higher moisture stress levels compared to those grown in soil amended with hydrogel. At the time of lifting, no differences in seedling growth were found among treatments (NTC 2009).

Soil amendment during outplanting

The final application for hydrogel is to amend soils on the outplanting site, especially on droughty or severely-disturbed sites with the objective of retaining water that would normally be lost to evaporation or leaching. They have also been shown to retain nutrient ions that could be leached out of the root zone (Mikkelsen 1994). The method of application is important and incorporating hydrogels in the rooting zone is much more effective than applying in a band or layer (Kjelgren and others 1994). When 8 grams of hydrogel was applied per kilogram of three different soil textures, the available water content increased 1.8 times that of the unamended control for the clay, 2.2 times for the loam, and 3.2 times for the sandy loam soil (Abedi-Koupai and others 2008). In another study, two rates of hydrogel were added to 5 different soil textures ranging from sand to clay and then seedlings of nine different tree species were planted in pots with both treatments and a control (Agaba and others 2010). The plants were subjected to moisture stress treatments in a greenhouse until some seedling mortality occurred. The percentage of plant available water increased from around 100% in the clay to almost 300% in the sandy soil, and these results were mirrored very closely by the survival of the tree seedlings (Figure 6).

Hydrogel amendments are considered most effective on sandy soils and in droughty environments. When a sandy soil was amended with a range of hydrogel treatments and planted with *Pinus halepensis* Mill. seedlings, the water retention of the soil increased exponentially with increasing additions of hydrogel. When the seedlings were subjected to controlled desiccation, the seedlings in soils with the highest amount of hydrogel survived twice as long as those in the con-

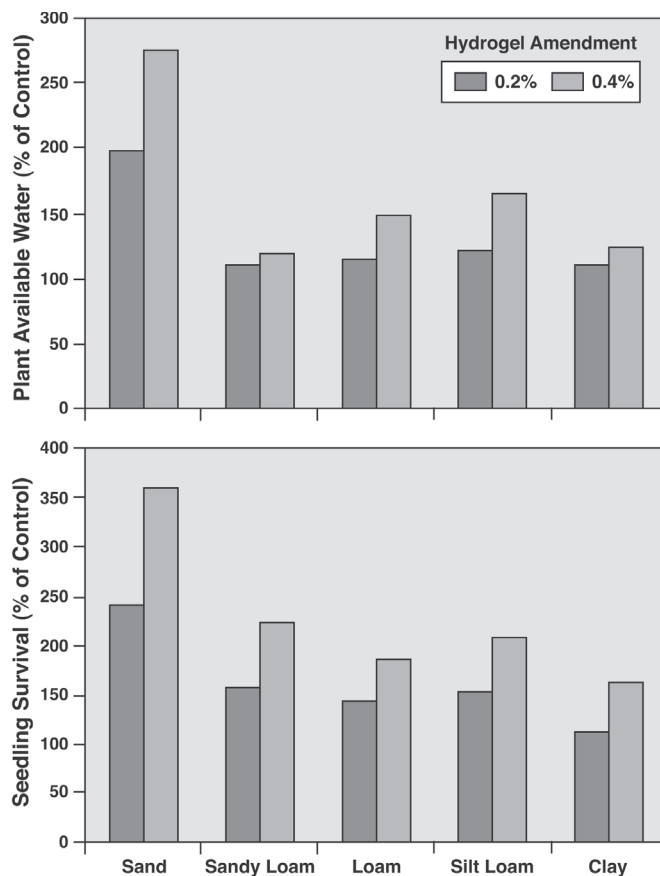


Figure 6. Hydrogel amendments incorporated into a range of soil textures significantly increased plant available water and seedling survival compared to the controls (modified from Agaba and other 2010).

trol soils. Water potential measurements showed that seedlings in the amended soils had considerably less moisture stress than the controls. Shoot growth and root growth were also significantly increased with the hydrogel amendment (Huttermann and others 1999). Conversely, Sarvas and others (2007) reported a 21% reduction in survival of Scots pine (*Pinus sylvestris* L.) as compared with the controls when polyacrylamide gel was placed in the planting hole. Similarly, a recent study showed that the use of hydrogels did not increase

loblolly pine (*Pinus taeda* L.) seedling survival and, in some cases, decreased survival (Starkey and others 2012). The authors concluded that the efficacy of hydrogels to increase seedling survival after outplanting is dependent upon the particle size and availability of soil moisture and recommended its use primarily as a root dip to protect roots from desiccation during the planting process.

One of the things almost never presented in research studies is cost of the hydrogel treatment. The only reference we found was for Eucalyptus seedlings where the hydrogel amendments to a sandy soil increased survival by a factor of 3 at a cost per plant of 17 to 27% (Callaghan and others 1989).

Summary

Hydrophilic polymers have been used in agriculture for over 40 years, and a variety of products are available for a wide range of uses both in the nursery and on the outplanting site. When incorporated into growing media or soil either at the nursery or on the outplanting site, hydrogels absorb and retain water that would normally be lost to evaporation or leaching. Hydrogels have also been shown to retain cationic nutrients against leaching. When applied as a root dip, hydrogels can protect roots against desiccation and increase the root-to-soil contact after outplanting. Results of nursery and field trials have been mixed. Because of the extreme variation between products and environmental conditions, it is impossible to generalize about whether to use hydrogels or not. As with any products, growers or planters considering the use of hydrogels should conduct small scale trials under their own conditions. For root dips, just giving plants the added measure of care to keep roots moist increases outplanting performance.

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