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Effects of Solid Matrix One-Step Planting Practice on Cool Season Turfgrass Germination in Unfavorable Conditions

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EFFECTS OF SOLID MATRIX ONE-STEP PLANTING PRACTICE ON COOL SEASON TURFGRASS GERMINATION IN UNFAVORABLE CONDITIONS

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Master of Science

By
Ben Duncan

May 2021

EFFECTS OF SOLID MATRIX ONE-STEP PLANTING PRACTICE ON COOL SEASON TURFGRASS GERMINATION IN UNFAVORABLE CONDITIONS

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I dedicate this thesis to my parents who encouraged me to enlist in this challenging endeavor. Also, I dedicate this thesis to my wife, Lauren, who has been my motivator and rock through this process.

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EFFECTS OF SOLID MATRIX ONE-STEP PLANTING PRACTICE ON COOL SEASON TURFGRASS GERMINATION IN UNFAVORABLE CONDITIONS

Ben Duncan May 2021 30 Pages

Directed by: Dr. William Strunk, Dr. Todd Willian, Dr. Paul Woosley

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The transition zone in the United States is a difficult area to grow and establish turfgrasses. To establish or repair damaged turfgrass areas, seed priming is an often-used practice. Turfgrass companies and researchers are expanding the practice of solid matrix priming to the practice of one step planting. These products contain seed, fertilizers, and often some type of inert matter and/or mulch. This study took place in Bowling Green, KY and Knoxville, TN during the same period to investigate the effects of using these one step planting products compared to standard cool season turfgrass seeding practices. Two Pennington and two Scotts products were chosen to compare to a standard seeding control. This study followed a randomized complete block design and used analysis of variance to analyze the effects of location, days after seeding, and treatment variation. Pennington One Step outperformed all other products in terms of turf cover (> 90% at both locations after 28 days), followed by the tall fescue control and Scotts PatchMaster. Pennington One Step, however, does not give a turfgrass manager the most value based on a cost analysis conducted ($4.60 per m^2). Based upon this research, Pennington One Step is best suited to repair small, damaged areas of turfgrass. Standard seeding practice of tall fescue would be recommended for larger turfgrass areas because of the economic value it provides in cost per m^2 ($0.31) and seeds per dollar of product (71,856 per $).

INTRODUCTION AND LITERATURE REVIEW

Germination is the process of initiating growth of a seed following dormancy. The three significant steps of germination are imbibition, lag phase, and radicle emergence (Stivers and Dupont, 2020). Imbibition is the process of a seed rapidly absorbing water, causing the seed coat to swell and soften. During the lag phase, cells begin to respire, and the internal physiology of the seed activates as the embryo metabolizes food stores and produces proteins. During radicle emergence, embryonic cells elongate and divide, causing the radicle to protrude from the seed. Similar to the biological processes that occur in all living things, germination has many environmental factors such as: water, oxygen, temperature, light, and nutrients, and of these, water is the most essential factor (Li et al., 2017). Secondary factors affecting germination include plant hormones such as abscisic acid (ABA), ethylene, cytokinin, auxin, and gibberellins. The relationship among hormones must be balanced correctly for effective germination and growth of a seed (Taiz and Zeiger, 1998).

Abscisic acid is a plant hormone known to be vital to the regulation of plant growth. The role of ABA in seed germination is to maintain seed dormancy. This dormancy is pivotal to ensure seed receives required internal and external needs before resuming growth. Ethylene contributes to the process of germination through interactions with other plant hormone signaling pathways, namely ABA (Corbineau et al., 2014). Cytokinin plays a pivotal part in all developmental aspects of plant maturation, including seed germination, because it promotes cytokinesis. Cytokinin has an antagonistic role on the suppressive effects of ABA on seed dormancy, which leads to the process of germination beginning (Wang et al., 2011). Auxin is a plant hormone that promotes development in versatile ways including powering signal pathways and promoting elongation of cells in the tips of all parts of the plant (Leyser, 2018). Auxins affect germination by contributing to the maintenance of dormancy via signal pathways where auxin response factors regulate growth along with ABA (Liu et al., 2013). Gibberellins have been used across agricultural and horticultural industries on mature plants to promote internodal elongation and fruit growth after pollination in cases where auxin is absent or ineffective (Taiz and Zeiger, 1998). Gibberellins are the most important hormone in germination because of the inverse relationship to ABA regarding dormancy. Gibberellins work to counteract ABA throughout the imbibition phase and end dormancy (Stivers and Dupont, 2020). For example, research with corn (*Zea mays* L.) suggested that gibberellic acid (GA_3) balances the effects of ABA by antagonizing ABA signaling and allowing the embryo of the seed to fully develop before the rest of the germination process was signaled (White and Rivin, 2000). After breaking dormancy and moving the germination process onto metabolic and growth phases, GA_3 is also responsible in some plants for activation of vegetative growth of the embryo, weakening of the endosperm, and mobilization of stored food reserves (Taiz and Zeiger, 1998). In tomatoes (*Solanum lycopersicum* L.), GA_3 has been shown to be essential for hydrolysis of the endosperm which releases reserve food sources to initiate germination (Karssen et al., 1989). The prompting of mobilization of food stores in the endosperm is heavily involved with the promotion of radicle emergence phase in germination, where actual plant growth begins. Gibberellic acid is also necessary, not only to prompt radicle emergence, but also to promote growth of the radicle through cell elongation.

In the absence of optimum environmental parameters, seeds remain at rest in a state known as quiescence. Under optimum conditions, seeds may break quiescence and begin to germinate and develop. However, most seeds go through a state of dormancy in addition to quiescence in which a viable seed will not germinate even though all necessary environmental conditions for growth are satisfied (Taiz and Zeiger, 1998). Primary dormancy is an important step in the growth cycle of a seed because it provides a temporal delay in germination, providing additional time for greater seed dispersal or to increase the probability of plant survival and growth. Many seeds have developed a mutation where seeds will stagger germination to increase establishment rate (Stivers and Dupont, 2020). The occurrence of secondary dormancy can develop after seed dispersal and primary dormancy. Secondary dormancy occurs when a seed returns to a dormant state after the seed is surrounded by optimum conditions that do not last long enough for the seed to completely germinate (Karssen, 1980). This can be an advantageous adaptation for seeds in a natural setting, but not necessarily for seeds dispersed for agricultural or horticultural use. Secondary dormancy could disrupt grower timelines or hinder financial and temporal efforts used to break primary dormancy.

For more efficient use in agricultural and horticultural practices, growers prefer to initiate seed germination and maturation after breaking primary dormancy. If a seed is dormant, typical breaking of dormancy will require mechanical or chemical action from the grower to promote germination. There are two main strategies for breaking dormancy: stratification and scarification. Stratification is a practice in horticulture and forestry in which seeds are chilled to break dormancy (Taiz and Zeiger, 1998). Most seeds require a certain amount of cold temperatures during the imbibition period of germination, and stratification is a common practice to reach the chilling requirements. Scarification of seeds is defined as a technique to physically damage the seed coat to allow water absorption while keeping the seed viable (Islam and Kimura, 2012). Mechanical scarification involves physically opening or scratching the hard seed coat. Chemical scarification can involve application of sulfuric acid, or a similar chemical, to weaken or alter the seed coat. Similar to chemical scarification is seed soaking, often labeled seed priming, which is commonly practiced in the agriculture and turfgrass industries.

Seed priming is the pretreatment of seeds (usually via soaking in a solution) to improve germination rate, germination percentage, and improve uniformity of seedling emergence (USDA National Agricultural Library, 2020). The pretreatment of seed initiates early stages of germination but does not allow the final stage, the radicle protrusion stage, to proceed. Seed priming is capable of positively impacting germination in unfavorable conditions such as drought stress. Seed priming controls the amount of water and other nutrients available in the seed by allowing seeds to slowly imbibe water to begin water based biological processes before they are totally ready for establishment. Hydropriming is defined as soaking seeds in only water. Hydropriming is known to have positive effects on plant seeds, especially in drought stress conditions. Hydropriming increased seed germination percentage and overall morphological growth in endangered Fir trees (*Abies* ssp.) growing in drought regions of Mexico (Zulueta-Rodriguez et al., 2015). Osmopriming is a form of hydropriming in which the pretreatment solution contains a mixture of water and chemicals. Osmopriming, as a pretreatment process, has been shown to further improve germination results in drought stress conditions.

Osmopriming maize (*Zea mays* L.) via urea solution resulted in significantly improved germination and seedling growth presented as final germination percentage, germination index, seedling vigor index, and length of seedling under drought stress conditions in a University of Tehran study (Janmohammadi et al., 2008). Osmopriming has also been proven effective in alfalfa (*Medicago sativa*) when using polyethylene glycol (PEG) to increase germination percentage (Hesabi et al., 2014). In arid rangelands, *Bromus inermis* is a grass introduced as a livestock improvement crop and showed improved speed of germination, root length, seedling length and mean germination time when osmoprimed with PEG solution (Tavili et al., 2011). Osmopriming can also be effective at counteracting other abiotic stresses such as low temperatures. Research has shown that osmopriming maize seed with chitosan to counteract cold stress can benefit many germination factors, especially mean germination time (Guan et al., 2009). Research with bell peppers (*Capsicum annuum* L.) showed that osmopriming with potassium nitrate and PEG significantly increased the rate and percentage of germination as well as seedling survival response after exposure to 4˚C temperatures for 10 days (Yadav et al., 2011). The pretreatment of seeds via hydropriming and osmopriming with various elements and solutions to improve seed germination is a common practice in the agriculture, horticulture, and turfgrass industries.

As discussed previously, gibberellin is the most influential plant hormone within the process of germination. Gibberellic acid, while little used in osmopriming techniques, has several commercial applications in the plant sciences. The most common commercial applications occur in the use of GA_3 to promote fruit set and increase fruit size in seedless grapes and to decrease germination time during malting of barley (Taiz and Zeiger, 1998). Osmopriming with GA has been studied among several plant species. In an Iranian herb (*Kelussia odoratissima*), osmopriming with PEG and immediately applying GA_3 significantly improved seedling growth compared to an untreated control and a control only pretreated with PEG (Amooaghaie, 2011). Priming caper (*Capparis spinosa* L.) seeds with GA_3 resulted in increased germination and dry seedling weight (Khaninejad et al., 2012). Gibberellic acid is not only known to positively affect germination process under optimum, or even drought stress, conditions, but could overcome inhibition of germination due to low temperature stress. Changes in GA_3 levels are often seen in response to the amount of chilling seeds have undergone which suggests there is a correlation between cold stress and GA_3 concentration (Taiz and Zeiger, 1998). Gibberellic acid metabolism and signaling can be disrupted by cold stress resulting in suppressed growth and late flowering in mature plants. The exogenous application of GA_3 was shown to counteract these complications within *Arabidopsis*, tobacco (*Nicotiana tabacum*), and tomatoes (*Solanum lycopersicum*) (Eremina et al., 2015). Rice (*Oryza sativa*) is grown in temperate climates around the world where planting season can be influenced by cold stress. When pretreated with GA_3, certain cultivars of rice seeds have increased seedling emergence speed and increased seedling height and dry matter (Chen et al., 2005). In a multi-year study of osmopriming wheatgrass (*Leymus chinensis*) with GA_3, not only was seedling vigor improved but the a single GA_3 treatment lasted two years, noted by increased above ground fresh and dry weight when compared to the untreated control (Ma et al., 2018). Wheat (*Triticum aestivum* L.) is commonly grown in the transition zone and other temperate climates during the winter as a cash or rotation crop. Chilling of the seeds that is necessary to break dormancy is a constraint to germination during cold temperatures for wheat if planted too late in the season. Gibberellic acid application via both osmopriming and exogenous post-dispersal application increased wheat seed germination rate, germination index, weight, and lengths of coleoptile and radicle while decreasing mean germination time (Xiangnan et al., 2013).

A relatively new form of seed priming in agriculture is solid matrix priming, a technique accomplished by mixing seeds with a solid or semi-solid material and specified amount of water (Mercado and Fernandez, 2004). Solid matrix priming utilizes the chemical and physical characteristics of a solid material to restrict water uptake of seeds to raise water potential and slowly allow the seed to imbibe water prior to planting. Dry matter materials involved in solid matrix priming can be soft rock, wood, or other organic matter substances. Solid matrix priming has been studied for a short amount of time relative to other priming methods in agriculture and horticulture but has been proven effective in many cases. Some forms of priming are ineffective or even damaging to some seeds so alternative forms, such as solid matrix priming, are being researched further. For example, soybeans (*Glycine max*) can suffer from soaking injury if primed in a liquid solution. In a study on soybeans, seeds were primed by being mixed with sawdust, carbonized bagasse, and rice hull and wetted with different amounts of water. This study found that soybean seeds that were solid matrix primed could increase moisture content as opposed to a control (Mercado and Fernandez, 2004). This increase in moisture content meant that seed had greater ability to imbibe water after it was primed via solid matrix. Priming of Chewing’s fescue (*Festuca rubra* L. ssp. *Fallax* (Thuill.) Nyman), creeping red fescue (*Festuca rubra* L.), hard fescue (*Festuca brevipila*

(Tracey)), and tall fescue (*Festuca arundinacea* (Schreb.) Dumort.) in a solid matrix of exfoliated vermiculite increased germination rates at all different priming temperatures and duration, but most notably at the coldest temperature (15˚C) (Frett and Pill, 2010). Solid matrix priming of muttongrass (*Poa fendleriana*) and bluebunch wheatgrass (*Pseudoroegneria spicata*) seeds increased germination rates and standability in unfavorable soil and dry conditions (Madsen et al., 2018).

Turfgrass managers in the transition zone of the United States attempt to maintain consistently optimal conditions on their courses or fields despite the climatic hindrances of drought, sunlight availability, and fluctuating temperatures. Cool season turfgrass species can still grow in most of the summer conditions in the transition zone, though not always effectively. The conundrum in the transition zone is that neither warm nor cool season turfgrass species can begin to grow or maintain growth when extreme low temperatures occur. Turfgrass managers also face difficult growing challenges from traffic stress on their courses or fields. In relation to traffic stress, quick establishment of turfgrass is essential because the turf area is commonly used; while in relation to cold stress, quick establishment is essential to limit the opportunity of complications to arise from cold temperatures. Turfgrass managers often rely on the process of overseeding to reestablish or revitalize the health and aesthetic look of turf areas when attempting to overcome these stresses. Overseeding is the practice of repetitively seeding an existing stand with a rapidly germinating turfgrass species (Gannett et al., 2021). Since overseeding is a process most often used in challenging times of growth for turfgrasses, conditions are often not optimal for seedling establishment. Seed priming is a potential pretreatment to overcome the challenge of seedling establishment in tough conditions because it can provide a pathway to quicker germination and establishment. Seed priming allows for minimal effort from the seed post-dispersal, which means the harsh conditions during which turfgrass managers often attempt to establish an overseeded stand will provide significantly less impedance. Much research has been conducted on the effect of seed priming grasses to understand the various ways turfgrass managers can overcome obstacles of both abiotic and biotic stresses. A study on optimizing seed priming techniques among the cool season range grasses of bluebunch wheatgrass (*Pseudoroegneriu spicata* (Pursh), thickspike wheatgrass (*Elymus lanceolatus* (Scribn. and J.G. Smith) Gould), sandberg bluegrass (*Poa sandbergii* Vasey.), and bottlebrush squirreltail (*Sitanion lzystrix* (Nutt.) J.G. Smith), which behave similarly to cool season turfgrasses, revealed that hydropriming seeds with water the same temperature of optimal germination increased seedling germination time and vigor among the grasses (Hardegree, 1996). A study of the effects of seed priming on winter annual cover crop seed used cool season grass species perennial ryegrass (*Lolium perenne*) and found that perennial ryegrass final germination response was higher in seeds that were hydroprimed, reaching 50% germination nine hours faster than the untreated control (Snapp et al., 2008). Glycine betaine (GB) seed priming enhances stress tolerance in plants. Research analyzing the effects of GB priming on six turfgrass species showed that this method of osmopriming increased daily germination percentage in both Kentucky bluegrass (*Poa pratensis* L.) and bermudagrass (*Cynodon dactylon* (L.) Pers.) while also increasing stress tolerance in tall fescue (*Festuca arundinacea* Schreb.) and perennial ryegrass (*Lolium perenne* L.) (Zhang et al., 2014).

Although the summer months within the transition zone are not optimum for cool season turfgrass growth, the majority of the year provides adequate conditions making cool season turfgrasses the preferred choice in many situations, especially home lawns. Kentucky bluegrass is selected for aesthetics and durability but is very slow to germinate. In the absence of priming or pretreatment with growth regulators, emergence may take anywhere from 2 to 5 weeks. Field studies conducted with several cool season turfgrasses stated that Kentucky bluegrass was the slowest germinating species (Yamamoto and Turgeon, 1998). This is an issue for turfgrass managers who use Kentucky bluegrass on their courses or fields and often must repair these spots in a critical moment or tight window. Seed priming Kentucky bluegrass to decrease time to germination has become a common technique for turfgrass managers in the transition zone. Seed priming via hydropriming without drying before dispersal and osmopriming with potassium nitrate or PEG decreased time to germination for Kentucky bluegrass (Pill and Korengel, 1997). Research in a controlled environment analyzed the effects of hydropriming duration and temperature revealed that soaking duration and temperature had a significant effect on Kentucky bluegrass mean germination time, a long soaking period (24 hours) and a mild soaking temperature (20˚C) optimized the pretreatment technique (Campbell et al., 2019). Matrix priming has been proven effective in Kentucky bluegrass. Field studies on solid matrix priming among cool season turfgrass species at 10.5˚C and 21.5˚C respectively, including 11 cultivars of Kentucky bluegrass, revealed that priming increased germination rate in the early stages of priming and significantly increased final germination percentage in colder trials (Yamamoto and Turgeon, 1998). Another study revealed that matrix priming bluegrass in fine vermiculite at 15˚C led to faster germination than an untreated control at the same temperature (Pill and Korengel, 1997).

Kentucky bluegrass is a popular choice for turf managers and homeowners in cooler climates, but in the transition zone, other cool season grasses are preferred because of time to emergence, heat tolerance, and economic costs. Instead, a hardier and heat tolerant cool season grass is often chosen at the expense of aesthetic qualities. A very common choice for turfgrass managers and homeowners is tall fescue, and it has much more tolerance for plant stresses, greater germination success in unfavorable conditions, and greater affordability than most other cool season turfgrasses. Cool season turfgrasses are often planted in cold temperatures because warmer months in the transition zone are heavily trafficked. A study on the seedling establishment of tall fescue in long term cold stress demonstrated that tall fescue has tremendous survivability. Tall fescue was grown from seed at 4˚C for 210 days, and it displayed several anatomical changes to adapt to the cold including cell wall thickening, undifferentiated plastids, increased root hairs, and reduced xylem lignification (Pompeiano et al., 2016).

Priming tall fescue and other cool season turfgrass seeds to increase germination and establishment has been researched, analyzed, and practiced. Turfgrass companies are now looking to expand upon the practice of matrix priming during the pre-sowing process. Companies such as Scotts® and Pennington® have seeding products for home lawns and other turfgrass areas in which priming materials (soil components and inert matter as well as seed coating) and post-sowing materials (such as fertilizers) are mixed with turfgrass seed in order to create a one-step planting process. These products aim to increase germination rates and success for turfgrass managers and homeowners. In theory, these products should make it much easier to develop a stand of turfgrass in unfavorable conditions by providing seed priming materials and additives to increase water content, germination rate, and success. Although several studies have evaluated solid matrix priming of cool season grasses, one-step turfgrass products have been minimally researched in their success compared to sowing seed in the conventional manner. This research aimed to compare the germination success and standability of these one-step planting products to that of tall fescue established by traditional seeding practices (seed, cover material, fertilizer) and to conduct a cost-analysis of each product.

MATERIALS AND METHODS

Experimental areas for this study were located in Knoxville, TN at the East Tennessee Research and Extension Center of the University of Tennessee on Shady loam soil (fine-loamy, mixed, subactive, thermic Typic Hapludults) and in Bowling Green, KY at the Western Kentucky University Agriculture Research and Education Center on Crider silt loam soil (fine-silty, mixed, active, mesic Typic Paleudalfs) in October of 2020. Four commonly available cool season turfgrass seed products specific to do-it-yourself lawn care and a control were planted in a randomized complete block design (RCBD) with three replications. Products used at both locations were from the same lot number and were expected to be similar in age and subjected to the same storage conditions. Individual plots in the experimental area measured approximately 1.5 x 1.5 m. Plots were established at varying seeding rates according to directions provided by the manufacturer. The control simulated standard seeding practices according to state extension guidelines (University of Massachusetts Amherst, 2011) and was established at a seeding rate of 44 g per m^2 and covered in straw. A preplant fertilizer was applied at a rate of 9.5 kg P_2O_5 per ha using 19-19-19. Pennington® Lawn Booster (Madison, GA, USA), hereinafter called Lawn Booster, consisted of tall fescue (*Festuca arundinacea*) cultivars ‘Rebel XLR’ and ‘Vert’, perennial ryegrass (*Lolium perenne*) cultivars ‘Trek’ and ‘Pennington APR2190’, and Kentucky bluegrass (*Poa pratensis*) cultivar ‘Aries’, other crop seeds, seed coating material, fertilizer, and mulch from inert matter and paper byproduct. It was established at a product rate of 39 g per m^2. Pennington® One Step (Madison, GA, USA), hereinafter called One Step, consisted of tall fescue cultivars ‘Rebel XLR’, ‘Pennington ATF1376’, ‘Pennington ATF1254’, and ‘Rebel V’, other crop seed, wood fiber mulch, fertilizers, and inert matter. It was established at a product rate of 2.5 L per m^2, which equated to 1 kg per m^2. Scotts® PatchMaster (Marysville, OH, USA), hereinafter called PatchMaster, consisted of tall fescue cultivars 'Duration', 'Endeavor II', and 'Dynamic II', other crop seed, mulch, fertilizer, and inert matter. It was established at a product rate of 343 g per m^2. Finally, Scotts® Thick'R Lawn™ (Marysville, OH, USA), hereinafter called Thick'R Lawn, consisted of tall fescue cultivars 'Duration', 'Endeavor II', and 'Dynamic II', other crop seed, inert matter, and fertilizer. It was established at a product rate of 39 g per m^2. No irrigation, soil nutrients, or simulated traffic was applied to the plots after the planting process was complete.

Plots were seeded on 27 October 2020 in Knoxville, TN and on 19 October 2020 in Bowling Green, KY, respectively. Beginning seven days after seeding at each location (3 November 2020 in Knoxville, TN and 26 October 2020, in Bowling Green, KY) plots were monitored and observed for turf cover. Data collection occurred every seven days in Knoxville, TN for 28 days (4 weeks) and every seven days in Bowling Green, KY for 49 days (7 weeks). Plots in Bowling Green, KY were cut at a height of 6.35 cm 63 days after seeding to analyze the reaction of the plots to mowing. Turf cover percentage was visually determined and used to estimate germination of cool season grasses within the plots.

A cost-analysis was conducted for each treatment for the number of seeds per m^2, cost per kg of product, and cost per m^2. Seed count of the control was taken from the extension guidelines used for planting instructions and converted to grams (University of Massachusetts Amherst, 2011). Seeds of Lawn Booster and Thick'R Lawn were counted by weighing one-fourth of a pound of each product, separating and counting seeds, and multiplying the number of seeds by 4 before converting to grams. Seeds of One Step and PatchMaster were counted by measuring and weighing one cup of each product, dividing in half, separating and counting seeds, multiplying the count by two, and then converting to grams. Seed count was repeated three times for each turfgrass product. The price of each product was collected from online pricing of Lowe’s in Bowling Green, KY as of March 21, 2021.

Data was analyzed using analysis of variance (ANOVA) in SAS (v.9.4, Cary, NC, USA). There was no block by treatment interaction, so analyses were limited to main effects of location, treatments, and days after seeding. In cases in which main effects and interactions were significant, mean separation was performed using Fisher’s protected least significant difference at $\alpha = 0.05$.

RESULTS AND DISCUSSION

Statistical analysis of turf cover indicated a significant interaction between location and treatment (Table 1). Turf cover for the untreated control and Thick'R Lawn were not statistically different as means were within least significant difference ($LSD_{0.5}$ = 5.195; Figure 1). Lawn Booster, One Step, and PatchMaster varied significantly between locations as the difference in average turf cover among these treatments was greater than the least significant difference value. Both Lawn Booster and PatchMaster performed significantly better in Tennessee than they did in Kentucky, while One Step performed significantly better in Kentucky than it did in Tennessee. One Step was the highest performing product in both locations with an average of 90.67 percent in Tennessee and 93.33 percent in Kentucky, respectively (Figure 2). One Step contained about 83 percent wood fiber mulch. The performance of the tall fescue varieties mixed with this wood fiber was consistent with past research conducted on soybeans where solid matrices containing sawdust increased seed moisture (Mercado and Fernandez, 2004). One Step contained a heavier mulch substance than both other treatments that were statistically different based on location (PatchMaster and Lawn Booster), which potentially could allow it to withstand more adverse conditions during early stages of establishment. This was consistent with previous research conducted on solid matrix priming of native grasses using seed pods constructed from rigid materials such as calcium bentonite, compost, and diatomaceous Earth, which displayed increased germination among primed seeds in unfavorable soils (Madsen et al., 2018). PatchMaster was the next highest performing product across both locations with turf cover of 89.67 percent in Tennessee and 68.33 percent in Kentucky, followed by the untreated control at 80 percent in

Tennessee and 71.67 percent in Kentucky, Lawn Booster at 51.33 percent in Tennessee and 38.33 percent in Kentucky, and finally Thick'R Lawn with 18.33 percent in Tennessee and 38.33 percent in Kentucky. The difference in response of the products in the two locations was likely due to environmental factors. Total rainfall was relatively similar in Tennessee and Kentucky during the first observation week of each location, but Kentucky had a greater total overall (Figure 3). The significant interaction of treatment and location could also be attributed to invasive large animal foot traffic in Kentucky. During the first week of the study period, some plots were damaged by a loose stocker calf (*Bos taurus*) in Bowling Green on the Western Kentucky University Agricultural Research and Education Center. Plots that received the greatest damage were Lawn Booster in block number two and PatchMaster in block number three (Figure 4).

Treatments in Tennessee were slower to emerge than those at the Kentucky location (Figure 2), and this difference in emergence timing was likely the result of environmental factors. Although rainfall was similar during the first week (Figure 3), Kentucky had higher temperatures with an average daily temperature of 16.6˚C compared to 13.8˚C in Tennessee (Figure 5). Treatments were planted 8 days earlier in Kentucky than Tennessee. During the second and third weeks, treatments in Tennessee had significantly greater increases in turf cover. Average temperatures in Tennessee during weeks two and three were 13.5˚C and 14.4˚C, respectively, while the temperatures in Kentucky for those weeks were 11.4˚C and 11.8˚C respectively, providing further evidence that temperature may have contributed to the varied growth rates.

Differences in turf cover were expected to diminish past four weeks after seeding as turf matured. Although data collected beyond four weeks after seeding was limited to the Kentucky location, differences in turf cover among treatments decreased at seven weeks. The Thick'R Lawn treatment increased 30 percent in turf cover from day 28 to day 49 while Lawn Booster had a two-fold increase in turf cover from day 28 to day 49, rising from 38.33 percent to 76.67 percent (Figure 6). The control in Kentucky also had a large increase in turf cover between day 28 and day 49. There was a 16 percent turf cover increase from 71.67 percent to 87.67 percent in the control from day 28 to day 49 and the control looked much more visually favorable when compared to the highest performing treatment, One Step (Figure 7). This increase to 87.67 percent turf cover made the untreated control significantly different from PatchMaster for the first time at the Kentucky location, distinguishing the control alone as the second-best performing product after seven weeks. This late surge in turf cover when temperatures began to cool even further was consistent with previous research that found that tall fescue derived from untreated seed could regulate germination and display robust growth and development under prolonged unfavorable conditions (Pompeiano et al., 2016).

A cost analysis was conducted to determine the expense of the different treatments (Table 2). Cost analysis determined that Thick'R Lawn was the cheapest product to seed by m^2 at \$0.15, followed closely by Lawn Booster at \$0.17. The control cost \$0.31 per m^2 while the most expensive products were PatchMaster at \$1.63 per m^2 and One Step at \$4.60 per m^2. One Step, as the most expensive product per area, was also the highest performing product in terms of turf cover percentage in this study despite containing the second fewest amount of seeds per kilogram of product (18,700 seeds per kg) among treatments. The performance discrepancy with the amount of seed per kilogram could be due to the standardized rate being high, that One Step has almost a three times higher product rate (1 kg per m^2) than the next highest standardized rate of a product (PatchMaster at 343 g per m^2), therefore putting out the second most seeds per m^2 (18,700 seeds) behind only the control (26,993 seeds per m^2). PatchMaster performed well in this study based upon 5,425 seeds per kilogram of product and 1,867 seeds per m^2. Lawn Booster and Thick'R Lawn, despite requiring very comparable standardized product rates to the untreated control (both at 39 g per m^2 compared to 44 g per m^2 for the control), yielded considerably less seeds per pound of product (ten and eleven times less, respectively) and seeds per m^2 (fourteen and eight times less respectively). The control had the highest cost per kg of product ($6.95) and third highest cost in terms of cost per m^2 ($0.31), however when analyzed by the number of seeds per dollar spent, the control far outperformed the comparable products in this study (approximately four times more than the next treatment) by containing 71,856 seeds per dollar of product. The next closest products in number of seeds per dollar of product were Lawn Booster and Thick'R Lawn, which despite the relatively low cost cannot be considered good economic value because of poor performance during this study (Figure 2). One Step and PatchMaster were two of the better performing product treatments in this study but had the two lowest rated products in terms of value, yielding seeds per dollar of product rates of 4,065 (One Step) and 1,140 (PatchMaster).

CONCLUSIONS

Based on the results of this study, it should be recommended to proceed with caution when purchasing solid matrix one-step turfgrass products. Depending on the combination of seed, inert matter, and fertilizer, the product may be less effective than standard seeding practice. Products containing large amounts of mulch in their inert matter may be a viable option for seeding in unfavorable conditions regardless of associated economic costs. Based on the results of this study, it is recommended to use One Step if an all in one product is desired. PatchMaster may be a viable alternative to the standard seeding practice, but the inconsistency over the two locations provided some doubt. One Step and PatchMaster were considered repair or overseed solutions and were not solutions to starting a new turfgrass area because the costs were far too high for these products to be feasible on a large scale. For economic value and for large scale turfgrass areas, the standard seeding practice used in this study of untreated tall fescue seed, covering with straw, and applying starter fertilizer would be the recommended method. The standard cool season seeding method provided economic value and quality turfgrass cover, especially given several weeks to establish.

TABLES

Table 1. Analysis of Variance performed on lawn establishment products and standard seeding (control) based on the main effects of location, days after seeding, and treatment.

Effect	**DF**	**F Value**	**Pr > F**
Location	1	7.15	0.0088
DAS[a]	4	220.74	<.0001
Location * DAS	4	8.65	<.0001
TRT	4	78.39	<.0001
Location * TRT	4	7.98	<.0001
DAS * TRT	16	11.56	<.0001
Location * DAS * TRT	16	1.58	0.0896

[a] DAS = days after seeding; TRT = treatment

Table 2. Cost-Analysis conducted on lawn establishment products and standard seeding (control).

Product	**Recommended Product Rate**	**Standardized Rate (g per m^2)**	**Seeds per kg of Product**	**Seeds per m^2**	**Cost per kg of Product**	**Cost per m^2**	**Seeds per $ of Product**
Control	9 lbs / 1000 ft^2	44 g	499,400	26,993	$6.95	$0.31	71,856
Lawn Booster	9.6 lbs / 1200 ft^2	39 g	48,767	1,967	$4.31	$0.17	11,315
One Step	1 cup / 1 ft^2	1 kg	18,700	18,700	$4.60	$4.60	4,065
PatchMaster	4.75 lbs / 70 ft^2	343 g	5,425	1,867	$4.76	$1.63	1,140
Thick'R Lawn	10 lbs / 1200 ft^2	39 g	67,100	3,389	$3.79	$0.15	17,704

FIGURES

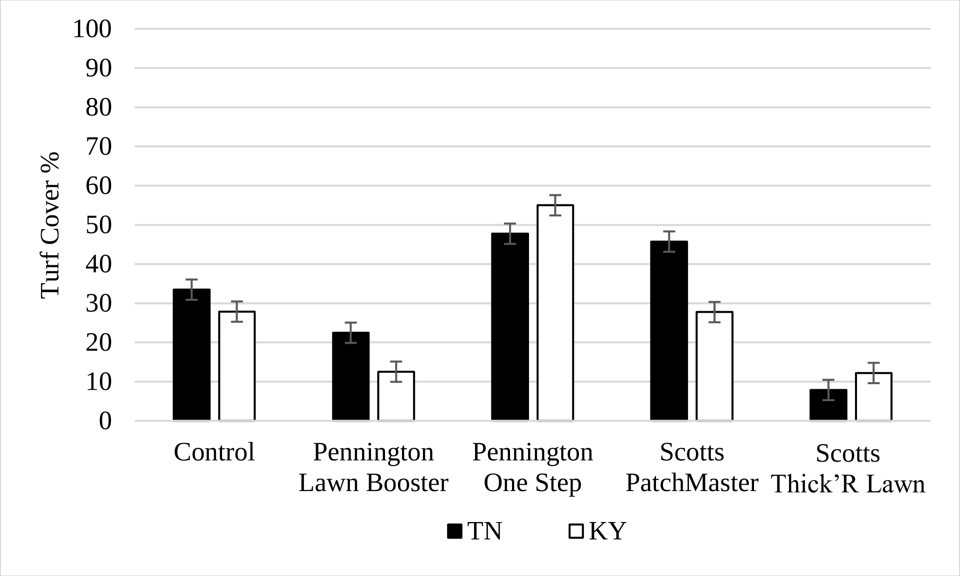

Figure 1. Turf cover of lawn establishment products and standard seeding (control) planted in Knoxville, TN and Bowling Green, KY. Error bars represent Fisher's protected least significant difference.

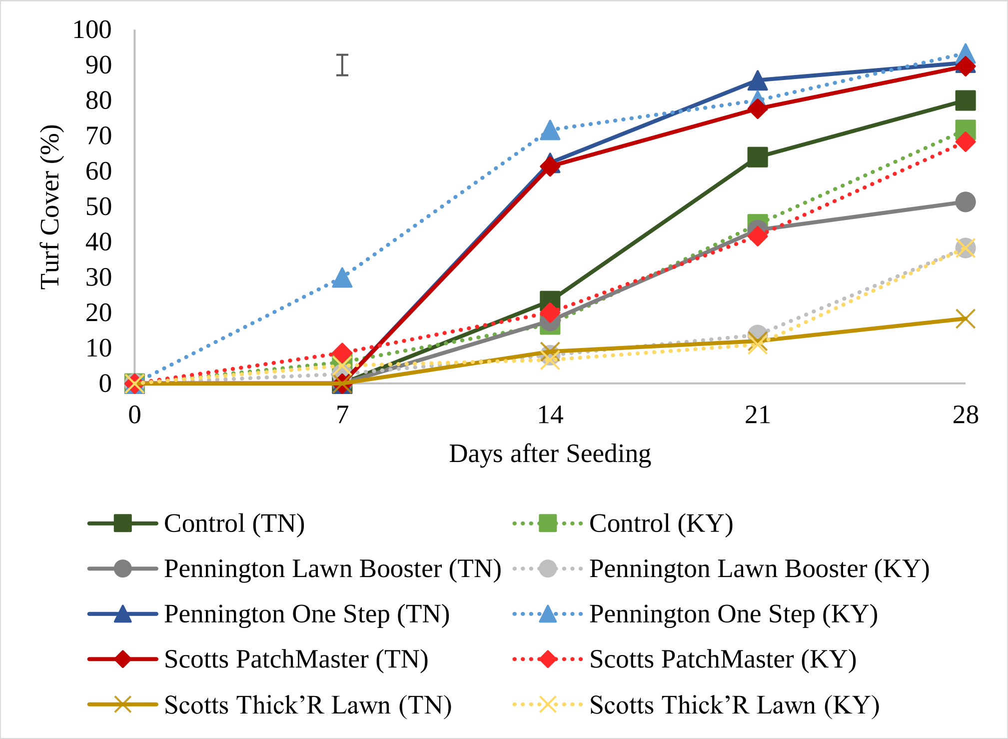

Figure 2. Turf cover of lawn establishment products and standard seeding (control) planted in Knoxville, TN and Bowling Green, KY based on days after seeding. Error bar represents Fisher's protected least significant difference.

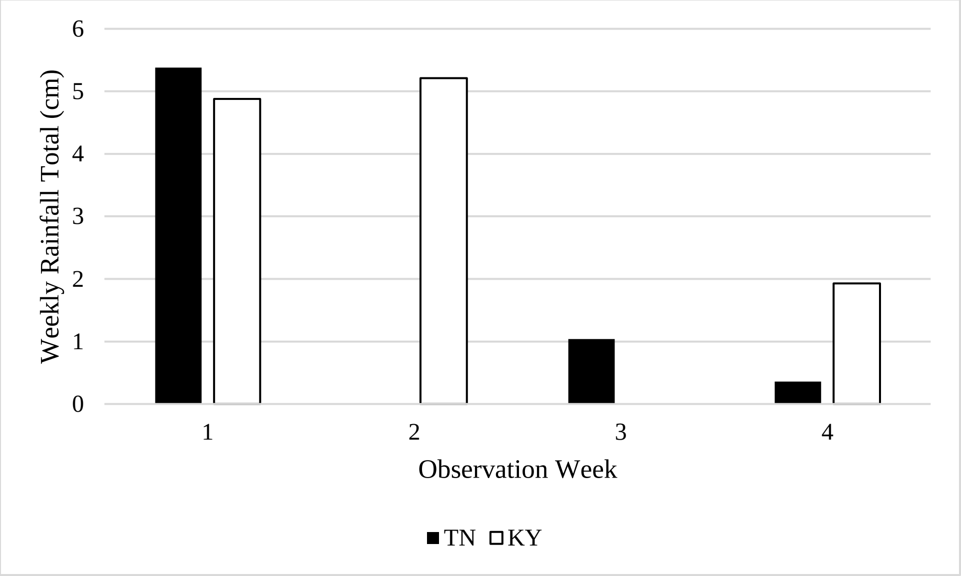

Figure 3. Weekly rainfall totals during the observation period in Knoxville, TN and Bowling Green, KY.

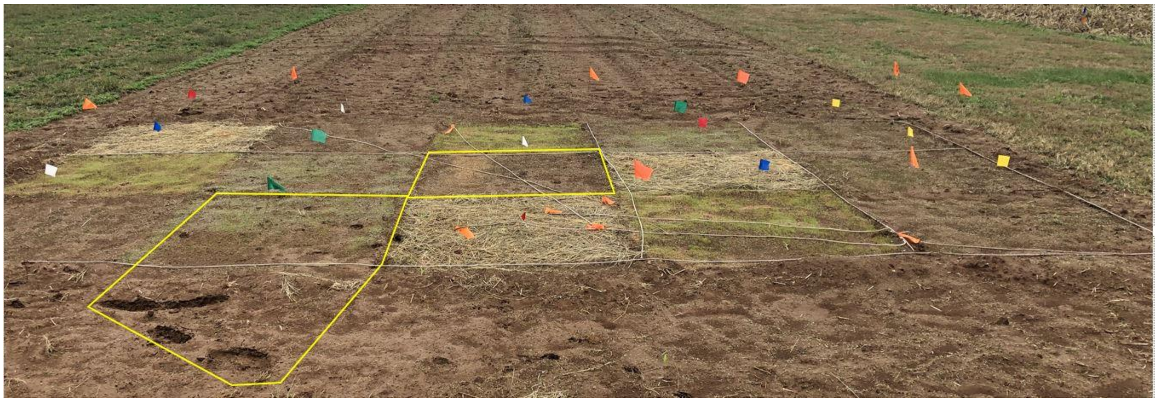

Figure 4. Research plot damage caused by a stocker calf at the Western Kentucky University Agriculture Research and Education Center during observation week one.

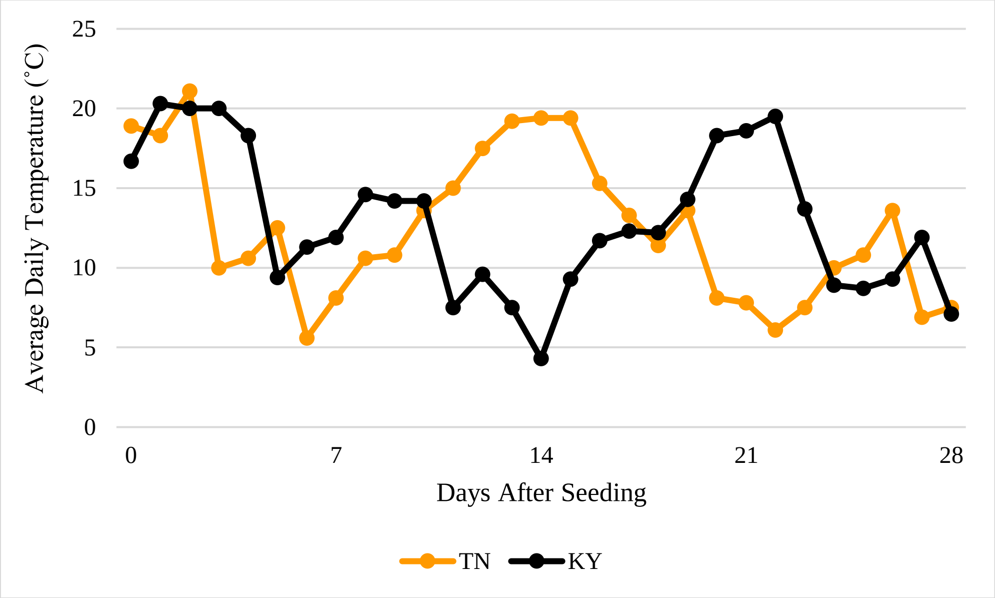

Figure 5. Average daily temperatures during the observational period in Knoxville, TN and Bowling Green, KY.

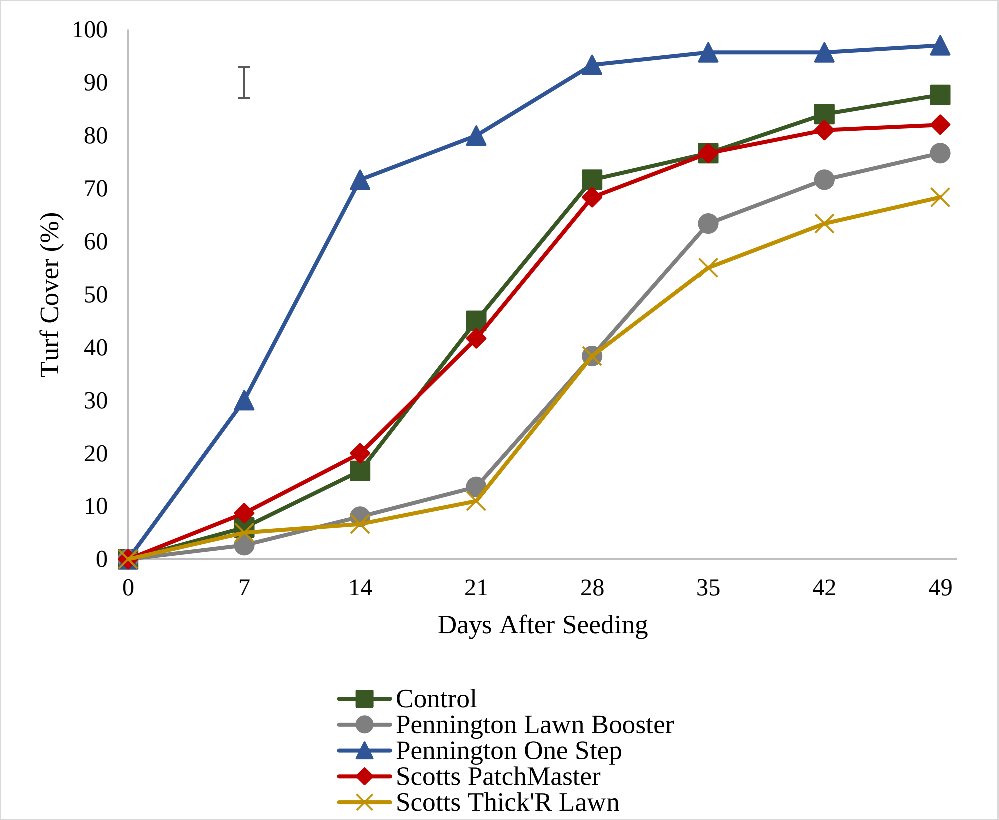

Figure 6. Turf Cover of lawn establishment products and standard seeding (control) planted in extended observation period in Bowling Green, KY. Error bar represents Fisher's protected least significant difference.

Figure 7. Images of lawn establishment products and standard seeding (control) at the end of the extended observation period (49 days) in Bowling Green, KY.

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