DEPARTMENT OF TRANSPORTATION

Expanding the Success of Salt-Tolerant Roadside Turfgrasses through Innovation and Education

Eric Watkins, Principal Investigator
Department of Horticultural Science
University of Minnesota

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Research Project
Final Report 2020-03

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16. Abstract (Limit: 250 words)

Our project was based on the need to water new roadside installations more efficiently to ensure that the turfgrasses, especially the new salt-tolerant mixes, establish more successfully with a predictable and uniform amount of water during the establishment period. The first objective of this project was to do a preliminary investigation of alternative means of irrigating new installations of salt-tolerant seed and sod mixtures. We completed the testing of four drip-tape-style irrigation systems placed both above and below sod, two above-ground sprinkler system configurations, and eight water truck nozzles. We then evaluated these new irrigation methods compared to current practices. We also developed an online voluntary training and education program for installers of roadside turf. And finally, we developed online maintenance training for homeowners to maintain new roadside turf installations. Based on our research, we recommend the use of 18-inch (45.7-cm) irrigation tape laid above the germination blanket (when seeding), or above sod when using a hydrant adapter with a programmable irrigation system as this system is easier and cheaper to install, can be removed and possibly reused after establishment, and results in reduced water use.

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FINAL REPORT

Prepared by:

Eric Watkins
Jon Trappe
Kristine Moncada
Department of Horticultural Science
University of Minnesota

Sam Bauer
BauerTurf, LLC

Jonah Reyes
City of Roseville, Minnesota

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LIST OF ABBREVIATIONS

CCAPS – College of Continuing and Professional Studies
FPT – Female nominal pipe thread
gph – gallons per hour
LRRB – Minnesota Local Road Research Board
MnDOT – Minnesota Department of Transportation
mph – miles per hour
MPT – male pipe thread
NPT – American Standard pipe taper thread
PE – polyethylene
PGV – professional grade valve
PSI – pounds per square inch
PVC – polyvinyl chloride
rpm – revolutions per minute
TWD – thin-walled drip (line)
VWC – volumetric water content

EXECUTIVE SUMMARY

Our years of collaboration with the Minnesota Department of Transportation (MnDOT) and Minnesota Local Road Research Board (LRRB) have resulted in the introduction of new salt-tolerant sod mixtures, primarily consisting of fine fescues. Unfortunately, these new mixtures have not succeeded as well on roadsides as we predicted. Current watering practices have been insufficient for fine fescue sod and new options needed to be identified and implemented in a way that makes economic sense for MnDOT and sod and seed installers.

Following the design and preliminary evaluation of alternative watering systems, the University of Minnesota Turfgrass Science Team evaluated the efficiency of watering new seed and sod installations using these new watering methods on roadside research sites. A total of five new watering methods were tested. In research to compare the new systems to currently used techniques, the irrigation systems were constructed and put in place before or after new sod or seed installation, depending on the type of irrigation system. Effectiveness of these new systems was determined by collecting data on the total amount of water applied, irrigation efficiency, irrigation uniformity, turf establishment, turfgrass quality, and rooting characteristics. In addition, costs associated with installation, setup and operation were determined for each system to compare it to commonly used methods. Based on our results, when using a hydrant adapter with a programmable irrigation system, we recommend irrigation tape laid above the germination blanket (when seeding) or above sod at a spacing of 18 inches (45.7 cm).

In addition to alternative irrigation systems, we modified a water truck to determine whether it improved irrigation efficiency. Water truck irrigation is most often accomplished using a water gun that applies water very quickly without being diffused in any way. Modifications to current water truck irrigation techniques included the use of different nozzle designs to more effectively apply water. We investigated frequency and depth of irrigation through the growing season months by testing several watering regimes. The two nozzles we tested that showed the most promise for efficiently irrigating roadsides were the Niece fan nozzle and the Pancake adjustable nozzle.

In the educational portion of this project, contractors were provided an online training course with a series of educational modules that address basic turfgrass management and installation-specific issues. Continuing this education and training will be important because it will result in more highly educated turfgrass installers and managers, which will increase the chance for successful installations. An additional aspect of this project was the creation of a homeowner website on how to care for boulevard plantings. These materials will disseminate the knowledge we have gained through years of research on roadside turfgrasses.

CHAPTER 1: INTRODUCTION

Roadsides comprise more than 24,000 acres (9,712 hectares) in Minnesota (MnDOT Maintenance Manual, 2016) and exist in rural, urban and suburban environments. Roadsides are unique and challenging growing environments due to many stresses they face such as salt, heat, drought, surface disruption, traffic, diseases, weeds and insects. Limiting or reducing the incidence of stress is essential for a successful turf establishment. We have been working with the Minnesota Department of Transportation (MnDOT) and Minnesota Local Road Research Board (LRRB) over the past several years identifying and implementing salt-tolerant grasses for use on Minnesota roadsides. Our collaboration has resulted in the introduction of salt-tolerant sod mixtures (primarily consisting of fine fescues) that are certified by the Minnesota Crop Improvement Association and grown by Minnesota sod producers who are members of the Minnesota Turf Association (Friell et al., 2012; Friell et al., 2013). We have concluded that the numerous installation failures of these mixtures have been due to many factors including improper pre- and post-installation watering, poor soil preparation, seasonal weather influence, poor rooting of fine fescue grasses cut for sod, and lack of nutrients. Because we identified watering, in particular, as a major issue, we felt it was critical to develop recommendations for end-users about how to more efficiently water new roadside installations.

Access to water from either natural rainfall events or supplemental irrigation is one, if not the most, important factor during the establishment of turf roadsides. Many roadside establishments take place in areas with limited to no municipal water access. As a result, water trucks are often used to establish roadsides, which can be costly for both fuel and labor. In many cases, irrigation events are contracted in advance and irrigation is applied regardless of weather conditions. Based on communication with contractors, a 2.5-acre (1-hectare) roadside established with sod in Minnesota can cost up to $20,000 to irrigate to MnDOT recommendations for 30 days (Matt Cavanaugh, personal communication).

There is also an issue of overwatering. Many turfgrass managers overwater when using their own experience and observations (O'Neil & Carrow, 1982). A recent salt-tolerant sod installation in Minnesota of 16,000 square yards (13,378 m^2) received 414,000 gallons (1,567,160 liters) of water over a 10-day period, which was all done with a water truck (personal observation). This equates to filling a 3,000-gallon (11,356-liter) water truck 138 times. This is likely more water than is necessary, and we observed that the majority of the water was applied at a very high volume, with much of water running off the site prior to penetrating into the soil. When the water application rate exceeds the soil infiltration rate, significant runoff will occur (Leinauer & Devitt, 2013), which is an economic and environmental concern. To provide a healthy turfgrass system, irrigation must be able to infiltrate the surface within a reasonable time and hold water within the active rootzone (Leinauer & Devitt, 2013). When transplanted, sod has a shallow root system, meaning this active rootzone is much smaller and needs more consistent and efficient watering methods. Applying water at high volumes may not allow sufficient wetting of the active rootzone. Current watering practices done with a water truck most often try to put out as much water as quickly as possible.

It is clear that water trucks, as they are currently utilized, do not provide the type of watering that is needed to efficiently establish salt-tolerant and other turfgrasses. For some urban and suburban locations, there is access to water during establishment via fire hydrants but no viable way of efficiently delivering the water to the seed or sod. The idea was proposed to connect drip and above-ground irrigation systems to fire hydrants as a means of effectively delivering water frequently with few labor costs following installation. We believe options using alternative watering methods, such as with these water sources, will be more cost effective and more efficient and will allow for better turfgrass establishment. To address this idea, we accomplished two research objectives: a preliminary investigation of alternative means of irrigating new installations of seed and sod mixtures and evaluation of these new irrigation methods in comparison to current practices. In addition, we accomplished two other objectives by developing an online voluntary training and education program for installers of roadside turf and online education materials for homeowners on how to maintain new roadside turf installations.

CHAPTER 2: PRELIMINARY INVESTIGATION – DESIGN AND EVALUATION OF ALTERNATIVE STRATEGIES FOR WATERING

Prior to starting the replicated research experiment (see later in this report), our project team needed to first design and demonstrate the alternative irrigation strategies for establishment of both seed and sod installations on roadsides. This included using on-site fire hydrants and other sources, as well as modification to basic water truck delivery systems. Specific systems evaluated included drip-tape-style irrigation, above-ground-drip-line-style irrigation, below-ground-drip-line-style irrigation, and above-ground-sprinkler-style irrigation, as well as identifying more efficient water truck nozzles.

2.1 DRIP IRRIGATION METHODS

From a water conservation standpoint, drip irrigation systems offer the best option. This is because drip systems reduce water lost through evaporation and overspray and allow less potential for runoff. Drip systems also offer the advantage of irrigating directly at the soil/sod interface. There are a multitude of styles and configurations for drip irrigation systems for use in agriculture and turfgrass settings. For example, a single company such as Netafim has almost 20 different styles of drip irrigation and each style will have different options for wall thickness, inside diameter, flow rate, emitter spacing, and operating pressure. Wall thickness is important for longevity of the drip irrigation, although because our systems will likely be abandoned, wall thickness is not an important factor to us and it will not affect the performance of a system. The inside diameter of drip irrigation tubing or tape will affect the allowable length for each individual run; larger diameters allow for longer runs, which can reduce the number of valves that are required for a system.

Flow rate, emitter spacing, and row spacing are the biggest factors affecting the efficiency and uniformity of drip irrigation systems. Nominal flow rates of drip irrigation emitters vary from 0.16 to 2.0 gallons per hour (gph; 0.6 to 7.6 liters per hour) depending on the application. Flow rates will affect the uniformity of application and run time for the drip system. For turf applications, researchers have recommended and utilized flow rates up to 1.0 gph (3.8 liters per hour) and row spacing of no more than 18 inches (46 cm) apart with emitters spaced at 12 or 18 inches (30.5 to 46cm; Suarez-Rey, 2002; Debels and Soldat, 2013; Serena et al., 2014). However, all of these systems were buried into the soil to a depth of at least 4 inches (10 cm), whereas our systems were put on top of or below sod.

We set up a drip irrigation test site at our research center on the University of Minnesota-St. Paul campus. On this site we constructed two drip tubing systems set up to accommodate drip tape on either a 12 or 18 inch (30.5 or 46 cm) row spacing; emitter spacing is held constant with row spacing, which provides a grid pattern of uniform soil moisture. Drip tape chosen for this test was Netafim Streamline 630 series 8mil (0.3 inch) drip tape. Netafim is the original manufacturer of drip irrigation and an industry standard for quality and cost effectiveness. Drip tape purchased for these tests has nominal emitter values of 0.24 and 0.36 gph (0.9 and 1.4 liters per hour) at 10 psi. Maximum operating pressure for this tape is 15 psi, which results in emitter flows of 0.26 and 0.45 gph (1.0 and 1.7 liters per hour). By operating these systems at the maximum allowable pressure, we were able to reduce the number of valves required thus reducing cost. Our tests have involved installing the drip tape either below or above MNST-12 certified sod and assessing soil moisture distribution after running the systems to achieve 0.16 and 0.32 inches (0.4 and 0.8 cm) of water. Figures 2.1 and 2.2 show both the above-sod and below-sod installations.

2.2 PORTABLE ABOVE-GROUND IRRIGATION SYSTEMS

Portable above-ground systems will allow contractors to reuse the materials as opposed to the drip systems below sod that will be abandoned. Above ground systems consist of a variety of pipe, fittings and nozzles to apply water, and operation would be similar to a home lawn irrigation system (Figure 2.3). Much like the drip systems, combinations of pipe, fittings and nozzles are endless. However, when thinking about roadside watering and wanting to reuse these systems, ease of setup, takedown and transport from site to site should be the main concern.

2.3 WATER TRUCK METHODS

Water trucks are the only option for irrigating sites that do not have access to water. The efficiency associated with water truck irrigation has been called into question recently due to numerous roadside sod installation failures, particularly with MNST-12 certified sod. For this initial assessment we rented a 2000-gallon (7571 liter) water truck and outfitted it with various nozzle options in an effort to gain more insight into this method of irrigating roadsides. The truck we rented has a propulsion system driven by the power take-off. There are water trucks that have a completely separate pump to push that water, however we did not test this type of unit due to lack of availability during our trial period. In total, we purchased eight different nozzles from three manufacturers and assessed the distribution uniformity, width and distance of throw, output volume, percent increase in soil moisture, and various angle adjustments. Many of these nozzles would be an improvement on what we have seen in the field (Figure 2.4).

Observations from our initial investigation using a water truck that has the propulsion system tied to the power take-off:

1. There was not a “one size fits all” option for water truck nozzles due to the various dimensions of roadsides and boulevards. In some cases, efficiency and uniformity must be sacrificed in an effort to conserve water (water the grass, not the road) and to reach long distances.
2. The angle on which a nozzle is setup will greatly affect performance. There are an endless number of angles that could be tested, and we evaluated the angles made the most sense.
3. Water trucks will differ in output volumes, pipe sizes, and rpm vs. speed. This had a bearing on our tests. Taking this into account, we still feel confident that a good nozzle and watering method will be applicable for most water trucks.
4. The maximum distance of throw is 30 feet (9 m). To reach distances beyond this, a water gun must be used. For water guns, the efficiency and uniformity lie within the hands of the operator.

5. Nozzle output is linked with engine rpm for the truck we tested. The minimum speed of operation appeared to be 5 mph (8 km per hour) to obtain the proper rpm and pressure for nozzle operation. This may vary depending on the water truck, and for water trucks with separate engines to run the water pump.
6. The volume of water supplied by current water truck nozzles was lower than our initial assumptions. MnDOT specifications require 1 inch (2.5 cm) of water per week for days 11-30 after sod installation, and the goal may be to apply 0.33 inches (0.8 cm) three times per week. This would require approximately 9,000 gallons of water (34,000) for 1 acre (0.4 hectare), or 4.5 trips with the 2,000 gallon (7571 liter) water truck. However, an individual water truck nozzle (with our current propulsion system) may only supply between 0.009 and 0.062 inches (0.23 to 1.6 mm) of water in one pass, requiring anywhere from 5 to 37 passes over an area.

2.3.1 Nozzle options

Nozzle options vary by design, opening size, and pattern. Some nozzles are adjustable, and therefore adaptable to many situations (Figure 2.5). Other nozzles put out a large amount of water in a tight stream, which can be too much pressure for newly planted sod to handle (Figure 2.6). We evaluated this in the field experiment component.

The preliminary data in Table 2.1 shows that nozzle uniformity can range from 12% to 65%. Above ground sprinkler systems have the ability to achieve 85%, but this is unrealistic for water truck nozzles. Our goal with this work is to achieve uniformity > 40%, and as you can see there are nozzles that will produce this. The pancake adjustable nozzle achieved the highest uniformity, as well as a good width of throw when it was adjusted for an angle of approximately 180 degrees. Some nozzles have the ability to throw out some distance from the truck before water reaches the ground, and this will depend on the angle of adjustment. In our studies the goal will be to reduce the number of passes required to reach 0.33 inches (0.84 cm), while ensuring that uniformity is good and minimal water is lost through runoff and overspray.

2.4 RESULTS

2.4.1 Soil moisture uniformity

Soil moisture assessments were made with a POGO Volumetric Water Sensor (Steven's Water) and TDR 300 Soil Moisture Meter (Spectrum Technologies). The POGO tines penetrated to a depth of 2.5 inches (6.4 cm), which measures the 1.0-inch (2.5 cm) sod layer and additional 1.5 inches (3.8 cm) of soil just below the sod. The TDR 300 tines penetrated to a depth of 3 inches (7.6 cm). These tools are valuable for measuring soil volumetric water content both before and after running the irrigation systems. For each uniformity test, 90 measurements were taken. These measurements were used to determine two numbers: average water content over the trial area, and average water content of the lowest quartile group (lowest 22 measurements). The lowest quartile average was then divided by the overall average to calculate the distribution uniformity of soil moisture.

2.4.1.1 Soil moisture uniformity tests with drip-tape-style irrigation

Test results for both BELOW sod (Table 2.2) and ABOVE sod (Table 2.3) are shown below. Soil moisture uniformity prior to running the drip systems was consistently between 88-93%; this is a reflection of the uniformity of natural precipitation and consistent soil type across the trial areas. Generally, moisture uniformity was reduced as the systems were run, which is expected, and for some systems uniformity continued to decrease over time, while others stabilized. Greatest final uniformity values were achieved with 12-inch (30.5cm) drip spacing placed below sod (0.45 gph [1.7 liters per hour], 85.4%) and above sod (0.26 gph [1 liter per hour], 86.6%). These designs reduced initial (natural) uniformity by 5.6 and 5.1%, respectively, stabilizing near 85% uniformity after 0.32 inch (0.8 cm) of moisture was applied. Systems that produced the least uniformity were on 18-inch spacing below sod (0.26 gph [1 liter per hour], 75.7%) and above sod (0.45 gph [1.7 liters per hour], 78.4%). On average, 81.4% uniformity was achieved with the below-sod systems and 82.2% uniformity above sod. Above- and below-sod applications require further investigation.

All drip systems produced soil moisture uniformity above 75%, which is likely sufficient to meet the irrigation requirement in a roadside setting. Our tests were conducted on well-drained Waukegan silt-loam with 0% slope. Soil type and slope will have an influence on uniformity tests on roadsides. Sandy soils with good infiltration require closer emitter and lateral spacing because water moves more vertically in the soil, whereas clay soils have more horizontal capillary movement and can accommodate wider spacing. Our systems must be designed to meet the demands of various soil types. Because of this both 12-inch and 18-inch (30.5-cm and 46-cm) systems were utilized in the subsequent phase of testing.

2.4.1.2 Soil moisture uniformity tests with above-ground irrigation systems

Soil moisture uniformity tests prior to running the above-ground irrigation systems was approximately 80% (Table 2.4). Much like the drip systems, soil moisture uniformity was reduced over time the longer the systems were run, which is expected. Both single row and double row systems (Figure 2.7) produced soil moisture uniformity values above 70%; this is good uniformity for this type of application. For further testing we will be using single row systems.

2.4.1.3 Soil moisture uniformity tests with nozzles

Two nozzles that show the most promise for efficiently irrigating roadsides are the Niece fan nozzle and the Pancake adjustable. These nozzles achieve above-ground uniformity tests of 60% and 65%, respectively and also high uniformity of soil moisture. The Pancake adjustable nozzle has potential to irrigate roadsides a distance of 17 feet (5.2 m) from the truck. The Niece fan can be utilized for areas 6 feet (1.8 m) wide or less. We will advance both of these nozzles to Phase 2 of testing. Table 2.5 shows volumetric soil moisture and uniformity values for water truck nozzles tested on both 4 feet (1.2 m) and 10 feet (3 m) wide boulevards in Stillwater, MN.

2.4.2 Costs

Our initial assessment of irrigation methods for turfgrass included an analysis of the costs associated with setting up these systems.

2.4.2.1 Costs of drip irrigation systems

Exorbitant costs would prohibit contractors from utilizing many of the drip irrigation options due to the fact that below-sod installations are being designed to abandon the system after the 30 day Minnesota Department of Transportation specified watering period. Drip tubing is more rigid and is designed to be used long-term, which increases costs. Standard drip tube can range in price from $6000 to $9000 per acre ($2400 to $3600 per hectare), depending on the style. This is too high of a cost for tube that will be abandoned after the seed or sod grow-in period. Drip-tape-style irrigation is, however, very cost effective for this application and can range from $1500 to $3000 per acre ($600 to $1200 per hectare). This reduction in cost has to do with wall thickness of the pipe and emitter technology. However, the style of drip irrigation will not change the performance as long as proper design specifications are followed and the emitter flow rate and spacing remain the same.

One goal for utilizing drip irrigation systems for roadside watering is to reduce costs compared to water truck methods. The main factor determining cost is the quality of drip tape utilized and the maximum length of run for a particular style. The maximum length of run for the drip tape used in this study ranges from 470 to 815 feet (143 to 248 meters). Longer runs results in fewer valves, filters, and headers to irrigate an area. Depending on the drip tape chosen, the valve requirement will range from 9 per acre to 16 per acre (3.6 to 6.4 per hectare). Tables 2.6 and 2.7 show the parts cost for the various drip irrigation systems. The cost range for these systems, including tape and additional components, is approximately $1,500 to $3,000. Timers will add an additional cost from $750 to $1,350, but all of these will be reused. Valves, pressure regulators, headers, and filters can also be reused following establishment of seed or sod.

2.4.2.2 Costs of above-ground irrigation systems

Portable above-ground systems will have a higher up-front cost, but the ability to reuse the system will allow for a cost reduction over time. Systems that are cumbersome will not be adopted by contractors even if the price is low. One of the easiest fittings to use is called a Banjo fitting (Figure 2.8). These fittings will increase the cost of the system, but the time saved not having to thread pipe together is worth the price. Portable above-ground systems will also need to be low profile to prevent being a hazard to pedestrians walking along boulevards and sidewalks. With this in mind, parts needed for this type of system will range from $9,500 to $17,000 per acre ($3800 to $6800 per hectare). This price is also based on 1.5-inch (3.8-cm) schedule 40 polyvinyl chloride (PVC) pipe which will add durability to the portable system. Using a reusable portable above-ground system 6 times over a growing season will bring the price down to roughly $1,500 to $3,000 per acre ($600 to $1200 per hectare) putting it in line with the parts cost of the drip irrigation systems. Table 2.8 includes a price breakdown for each part required for this system. Final per acre price relates to single row systems with 20 feet (6.1 m) and 10 (3

m) feet PVC sections for one irrigation head. Sections as large as 30 feet (9.1 m) could be utilized and this will reduce the number of fittings required.

2.5 DISCUSSION

Watering roadsides with above-ground irrigation systems may present some issues. Potentially one of the biggest issues is vandalism or theft; however, there is not much that can be done to protect irrigation systems that are mostly above-ground. Valves, fittings and pipe can be an easy target for vandalism and just as easy of a target for someone looking for irrigation parts. This is one of the benefits of using drip tape below the sod, as most of the parts will be hidden from potential vandals. However, one major issue with using drip tape below the sod can occur during the sod installation process. Contractors will have to be walking over the drip tape if installing small roll sod (2 feet [0.6 m] wide X 6 feet [1.8 m] long). However, big roll sod (4 feet wide [1.2 m] X 100 feet [30.5 m] long or more) is often used on roadside installations. When this is done the use of large equipment is needed to install the sod. This equipment would then have to be driven over the drip tape which could easily damage the system.

Driveways, streets or breaks in sidewalks are also potential issues for above-ground systems (Figure 2.9). These breaks mean pipe will have to move over concrete or asphalt to irrigate the next area of sod. In some cases there may be multiple water sources (fire hydrants) to get around this, but in many cases pipe would have to be protected from vehicle traffic in order to provide irrigation. This will certainly increase labor and material cost, and also provide a potential hazard to pedestrians.

The amount of fire hydrants may also be a concern. Fire hydrants will potentially be a great source of water for roadside turf watering, however, on most residential roads, fire hydrants are only on one side of the street. Divided roads generally have hydrants on both sides, but in situations where the hydrant is only on one side or are long distances apart, could be a potential issue for above-ground systems.

Figure 2.1 Above sod drip irrigation system on 12-inch (30.5-cm) spacing with a flow rate of 0.45 gph (1.7 liters per hour).

Figure 2.2 Below sod drip irrigation system on 18-inch (45.7-cm) row spacing with a flow rate of 0.45 gph (1.7 liters per hour).

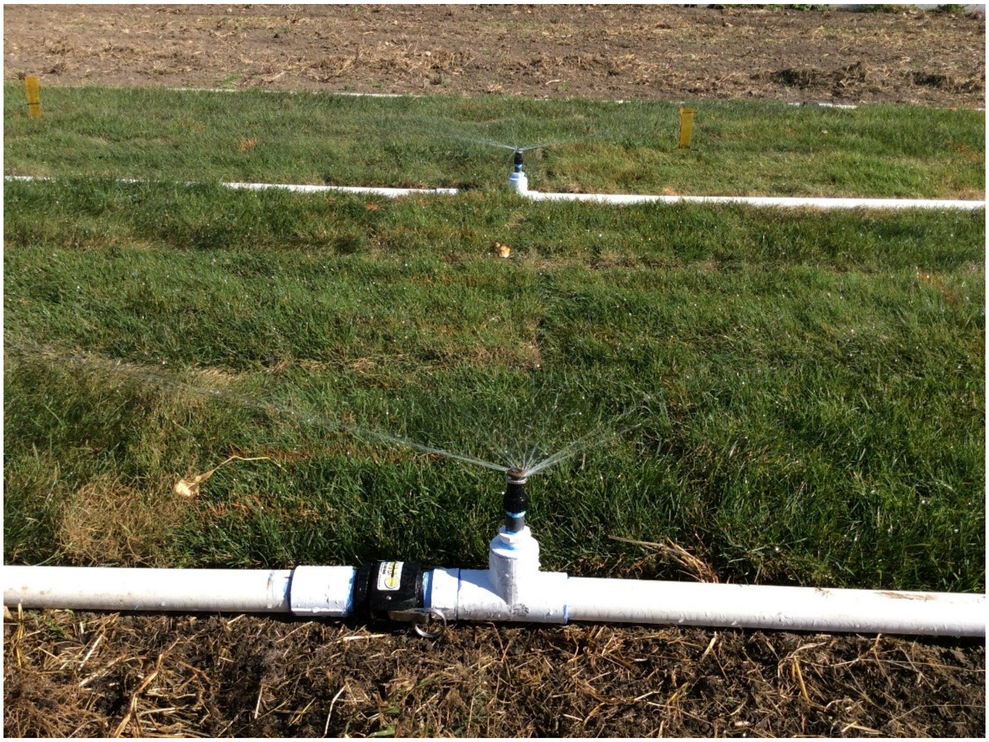

Figure 2.3 Double row irrigation system on 6 feet (1.8 m) spacing between rows and 30 feet (9 m) spacing between heads.

Figure 2.4 Sod staple taped to an open pipe for distribution of water. This is an example of a poor existing setup.

Figure 2.5 United Equipment adjustable water truck nozzle.

Figure 2.6 An example of a water truck nozzle with a tight pattern.

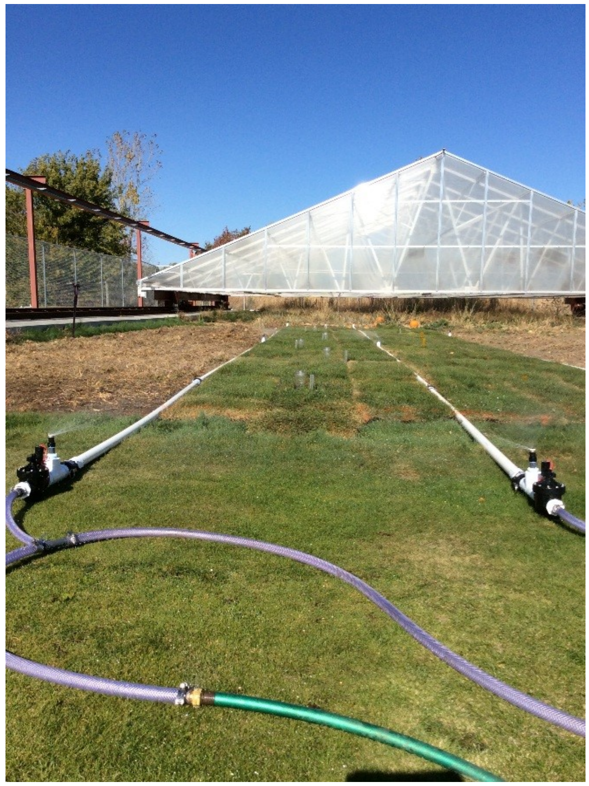

Figure 2.7 Double and single row systems showing valves and sprinkler spacing.

Figure 2.8 Banjo fitting used to allow for easy setup and takedown.

Figure 2.9 New roadside project shows breaks in turf where irrigation would have to move over a driveway.

Table 2.1 Preliminary data on nozzle throw, output and uniformity.

Nozzle type	Distance from truck in ft	Width of throw in ft	Output in inches	# of passes for 0.33 inch	Uniformity (catch can)
Kline small	0	17	N/A	N/A	N/A
Kline large	8	9	0.02	17	17%
Niece shower	13	8	N/A	N/A	N/A
Niece fan	0	6	0.062	5	60%
United small	0	19	0.009	37	38%
United tight	0	6	0.014	24	12%
Pancake adjustable	0	17	0.017	19	65%
Block fan	8	19	0.014	24	29%

Engine rpm = 1450; pressure = 40 psi; speed = 5 mph

Table 2.2 Soil moisture uniformity with four drip irrigation systems placed BELOW MNST-12 sod.

Style	Drip tape	Gallons per hour	Row and emitter spacing	Average initial VWC (uniformity)	Average VWC at 0.16" (uniformity)	Average VWC at 0.32" (uniformity)
1	Netafim streamline	0.26	12 X 12"	32.7 (91.9%)	36.0 (82.8%)	43.0 (82.0%)
2	Netafim streamline	0.45	12 X 12"	37.3 (91.0%)	42.4 (84.6%)	44.3 (85.4%)
3	Netafim streamline	0.26	18 X 18"	31.7 (88.8%)	36.4 (82.7%)	40.7 (75.7%)
4	Netafim streamline	0.45	18 X 18"	36.9 (90.7%)	40.7 (84.7%)	44.3 (82.5%)

Operating pressure: 15 psi

Run times to achieve 0.16- and 0.32-inch irrigation depths are as follows: Style 1 – 23 min and 46 min, Style 2 – 13 min 20 sec and 27 min, Style 3 – 52 min and 104 min, Style 4 – 30 min and 60 min

Uniformity values are based on lowest quartile calculation

Table 2.3 Soil moisture uniformity with four drip irrigation systems placed ABOVE MNST-12 sod.

Style	Drip tape	Gallons per hour	Row and emitter spacing	Average initial VWC (uniformity)	Average VWC at 0.16" (uniformity)	Average VWC at 0.32" (uniformity)
1	Netafim streamline	0.26	12 X 12"	34.2 (91.7%)	40.5 (85.4%)	45.4 (86.6%)
2	Netafim streamline	0.45	12 X 12"	33.9 (92.2%)	37.5 (85.8%)	41.4 (81.1%)
3	Netafim streamline	0.26	18 X 18"	35.7 (91.6%)	41.3 (83.6%)	45.3 (82.8%)
4	Netafim streamline	0.45	18 X 18"	34.0 (90.9%)	38.4 (82.2%)	42.7 (78.4%)

Operating pressure: 15 psi

Run times to achieve 0.16- and 0.32-inch irrigation depths are as follows: Style 1 – 23 min and 46 min, Style 2 – 13 min 20 sec and 27 min, Style 3 – 52 min and 104 min, Style 4 – 30 min and 60 min

Uniformity values are based on lowest quartile calculation

Table 2.4 Soil moisture uniformity with two above-ground irrigation systems over MNST-12 sod.

Style	Sprinkler	Gallons per hour (1 sprinkler)	Precipitation rate (in/hr)	Average initial VWC (uniformity)	Average VWC at 18 min (uniformity)	Average VWC at 36 min (uniformity)
Single row	Hunter Industries MP Rotator Side Strip	26.4	0.28	25.8 (79.7%)	32.8 (77.0%)	34.2 (72.6%)
Double row	Hunter Industries MP Rotator Side Strip	26.4	0.56	27.15 (79.8%)	34.65 (75.9%)	37.88 (71.8%)

Operating pressure: 40 psi

Uniformity values are based on lowest quartile calculation

Table 2.5 Soil moisture uniformity measurements with TDR 300 following irrigation with various nozzles.

Nozzle type	Boulevard test width (ft)	Average initial VWC (uniformity)	VWC after 1 pass (uniformity)	VWC after 2 passes (uniformity)	VWC after 3 passes (uniformity)
Kline small	10	22.6 (81.5%)	22.7 (80.3%)	25.2 (79.3%)	26.5 (84.6%)
Kline large	N/A	N/A	N/A	N/A	N/A
Niece shower	N/A	N/A	N/A	N/A	N/A
Niece fan	4	14.3 (65.7%)	19.0 (73%)	22.3 (74.7%)	23.7 (73.2%)
United small	10	21.2 (74.2%)	24.4 (73.1%)	26.3 (71.8%)	27.1 (80.2%)
United tight	4	17.6 (60.1%)	22.5 (70.9%)	26.2 (74.4%)	31.1 (73.2%)
Pancake adjustable	10	22.9 (79.5%)	26.4 (79.9%)	29.8 (77.0%)	32.7 (80.9%)
Block fan	4	22.3 (74.8%)	27.3 (75.4%)	32.1 (80.7%)	34.31 (78.9%)

Table 2.6 Cost of Netafim Streamline 630 Series drip tape.

Style	Drip tape	gph	Precipitation rate (in/hr)	Row and emitter spacing	Maximum length of run (ft)	Linear feet per acre	Price per acre
1	Netafim streamline	0.26	0.417	12 X 12”	620	43560	$1,597.52
2	Netafim streamline	0.45	0.722	12 X 12”	470	43560	$1,597.52
3	Netafim streamline	0.26	0.185	18 X 18”	815	29,040	$1,019.63
4	Netafim streamline	0.45	0.321	18 X 18”	620	29,040	$1,019.63

Table 2.7 Cost of additional parts for drip irrigation systems. All of these parts will be reused. TWD stands for thin-walled drip line and PGV stands for professional grade valve.

Part	Manufacturer	Specifications	Price	Number per acre	Price per acre
Flat tube header	Netafim	1 1/4", 40 PSI	$197/400ft	108 to 192	$53.19-94.56
Start Connector	Netafim	PE to 0.630mm TWD	$0.74/100ft	72 to 192	$0.53-1.42
Filter	Netafim	¾" disk filter, 120 mesh	$21 each	9 to 16	$189-336
Pressure regulator	Netafim	¾" 15 PSI	$8.80 each	9 to 16	$79.20-140.80
Valve	Hunter Industries	PGV, 1"	$21.38 each	9 to 16	$192.42-342.08
Timer	Hunter Industries	Single station battery	$84.74 each	9 to 16	$762.66-1,355.84

Table 2.8 Cost of parts for above-ground irrigation systems. All of these parts will be reused. PGV stands for professional grade valve.

Part	Manufacturer	Specifications	Price	Number per acre	Price per acre
1.5" PVC	Many	Schedule 40	$0.94/ft	7,260 ft	$6,824.40
1.5" tee	Many	Slip X Slip	$2.05	242	$496.10
1.5" coupling	Many	Slip to FPT	$1.70	726	$1,234.2
1.5" spigot	Many	Spigot to FPT	$1.97	242	$476.74
1.5" to 0.5 reducer	Many	Reducer bushing	$1.53	242	$370.26
Timer	Hunter Industries	Single station battery	$84.74	1	$84.74
0.5" nipple	Many	Nipple	$0.53	242	$128.26
Shrub adaptor	Many	Adaptor	$0.96	242	$232.32
MP rotator	Hunter Industries	Side Strip	$7.7	242	$1,863.40
Banjo fitting	Banjo	1.5" male	$3.09	484	$1,495.56
Banjo fitting	Banjo	1.5" female	$7.82	484	$3,784.88
Valve	Hunter Industries	PGV 1.5" with flow control	$46.42	2	$92.84

Price listed is the actual price paid. In many cases these costs will be reduced. For example, we paid $0.94/ft of schedule 40 PVC pipe, but we found a supplier offering the same pipe for 2/3 cost.

CHAPTER 3: ROADSIDE IRRIGATION COMPONENT DESCRIPTIONS

This chapter provides additional instructions regarding the components for the new setup that our team devised for roadside irrigation.

3.1 HYDRANT METER ASSEMBLY

The water source may vary, but the setup will be similar to what is pictured in Figure 3.1. In the case of a hydrant adapter + meter, a saw-horse or stand should be assembled under the hydrant meter to support the weight of the assembly. Unless otherwise noted, all pipe threading used in this report are American Standard Pipe Taper Thread (NPT). All PVC-PVC connections were constructed using PVC primer and glue and Teflon tape was used for all threaded fittings.

Most fire hydrants have two 2.5 inch (6.4 cm) connections and one 4.5 inch (11.4 cm) connection outlets (Figure 3.2, label 1). Hydrants also typically have a unique “fire hose thread” that may not be compatible with standard pipe threading. Most municipalities that rent out a fire hydrant meter will provide a meter with the correct size and threading for the hydrant closest to the site to be irrigated. Check with the municipality for the pipe threading and size options available for the end of the meter assembly that you will be connected.

Figure 3.2 (label 2) shows the check valve/backflow preventer. This can be connected before or after the hydrant meter (if present) but needs to be connected before the ball valve. The check valve is typically constructed of either brass or copper. Verify with the municipal water supplier to determine local ordinances on whether a check valve or a backflow preventer is required between the water source and your connection.

The hydrant meter (Figure 3.2, label 3) should be supplied by the local water municipality and will vary in connection and output sizes. The ball valve (Figure 3.2, label 4) should be constructed of brass and be the final component before the PVC elbow. The ball valve handle should be removed or locked after the system is pressurized or when not in use in order to limit the risk of vandalism. Figure 3.2 (label 5) shows the connection to the irrigation control assembly.

3.2 IRRIGATION CONTROL VALVE ASSEMBLY

The irrigation control valve assembly should be contained 4 to 6 inches (10 to 15 cm) below ground in a protective case. A 12 X 17 inch (30.5 X 43.2 cm) control valve box was large enough to contain the principal irrigation control valve components (Figure 3.3, labels 1-4). A 1-inch (2.5-cm) SCH-40 PVC union was used at the start and end of the irrigation control valve assembly to allow for quick assembly and disassembly on-site. The union connection from hydrant meter assembly is shown in (Figure 3.3, label 1).

The programmable irrigation controller (Figure 3.3, label 2) will likely require battery operation. There are numerous models available that are capable of programming run start times and length, and other “smart” controllers that are capable of working with rainfall sensors, soil moisture sensors, and other water-saving technology.

The irrigation control valve (Figure 3.3, label 3) will be controlled by the irrigation controller that will turn on and turn off the water to the system as directed. The solenoids for the control valves may need to be replaced with 24V DC latching solenoids to allow for the use of a battery-operated controller. There are numerous control valve models available.

A 120-mesh disc element filter (Figure 3.3, label 4) was used to remove any sediments that may plug drip emitters in the irrigation drip tape. Ensure that the filter is appropriate for the drip tape emitter specifications.

To ensure proper operating pressure for the drip tape system, a 15-psi pressure reducer (Figure 3.3, label 5) was installed after the control valve and filter. Ensure that the pressure reducer is appropriate for the drip tape used. Figure 3.3 (label 6) shows the union connection to the header.

3.3 HEADER ASSEMBLY

Class 200 PVC was chosen for the headers and footers for its durability as well as reduced price. The width of the header and footer as well as the number of dripline connections will depend on the area to be irrigated. From our preliminary work, we determined that 18-inch (45.7-cm) spacing between drip tapes (emitting 0.24 gallons per hour [0.9 liter per hour] at 10 PSI) was sufficient for turf established as either seed or sod (Figure 3.4). Once pressurized with water, the headers and footers should be secured with sod staples to maintain proper placement and spacing.

For the slip corner, a 1-inch (2.5-cm) slip X ½-inch (1.3-cm) female pipe thread (FPT) fitting is placed at both ends of the header. For the twist lock fitting, a ½-inch (1.3-cm) male pipe thread (MPT) X 0.630-inch (1.6-cm) thin wall diameter twist lock fitting is threaded into each PVC FPT fitting for attachment of the dripline. A series of 1-inch (2.5-cm) slip X ½-inch (1.3-cm) FPT tees that will be equally spaced across the header. The spacing between PVC connections will be based on the distance from center between drip tapes. A 1-inch (2.5-cm) slip tee should be installed in the middle of the header assembly to allow for the PVC connection from the irrigation control valve assembly (Figure 3.3).

3.4 FOOTER ASSEMBLY

The construction of the footer is identical to the header, with the exclusion of the tee (Figure 3.4) used to connect to the irrigation control valve assembly and the addition of an air-relief valve (Figure 3.5). For the slip corner, 1-inch (2.5-cm) slip X ½-inch (1.3-cm) FPT fitting is placed at one end of the footer. For the twist lock fitting: A ½-inch (1.3-cm) MPT X 0.630-inch (1.6-cm) thin wall diameter twist lock fitting is threaded into each PVC FPT fitting for attachment of the dripline. A series of 1-inch (2.5-cm) slip X ½-inch (1.3-cm) FPT tees that will be equally spaced across the footer. The spacing between PVC connections will be based on the distance from center between drip tapes. For the air-relief valve, a ½-inch (1.3-cm) MPT fitting which is threaded into a 1-inch (2.5-cm) slip X slip X ½-inch (1.3-cm) FPT side outlet fitting that is pointed up.

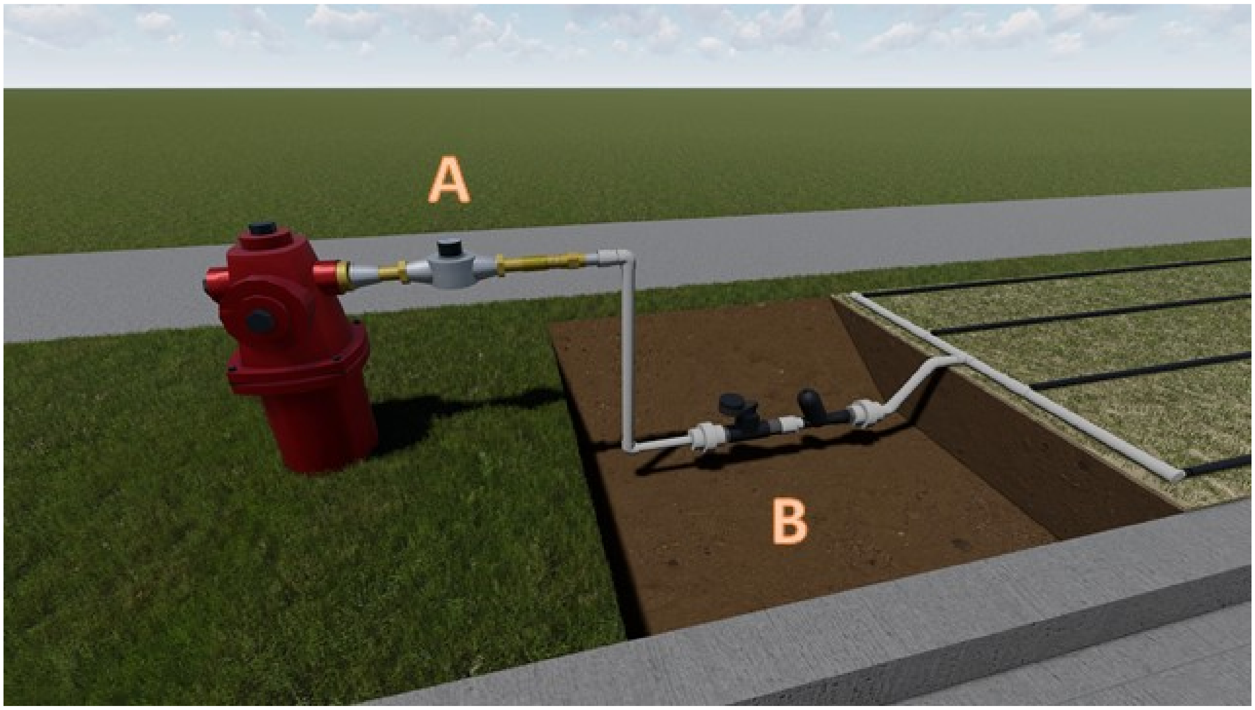

Figure 3.1 Overview of irrigation components. The section labeled "A" is shown in more detail on Figure 3.2 and section labeled "B" is shown with more detail in Figure 3.3.

Figure 3.2 Hydrant meter assembly.

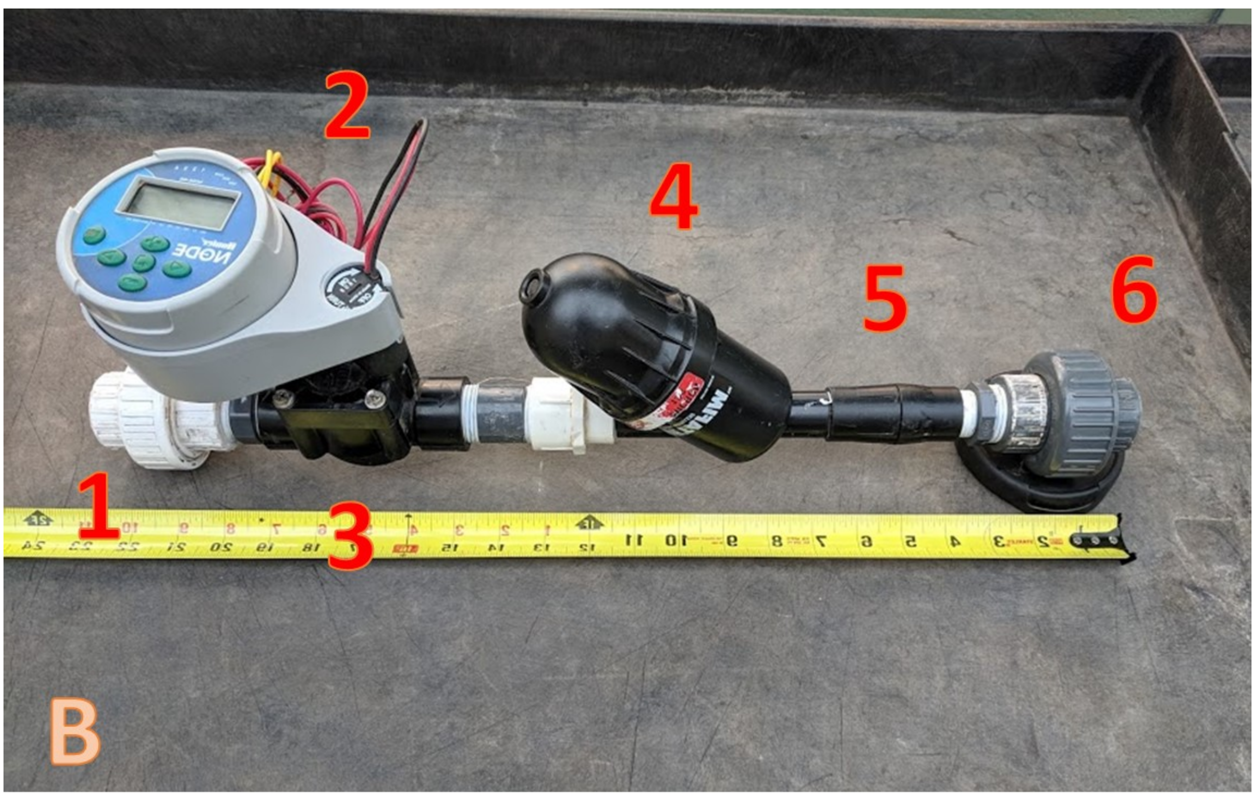

Figure 3.3 Arrangement of meter and irrigation controller assemblies.

Figure 3.4 Header assembly.

Figure 3.5 Footer assembly.

CHAPTER 4: ASSESSMENT OF NEW IRRIGATION STRATEGIES VS CURRENT STRATEGIES

Following the design and preliminary evaluation of alternative watering systems, our team evaluated the efficiency of watering new seed and sod installations using these new watering methods on roadside research sites. A total of five new watering methods were tested and four roadsides were chosen by the University and MnDOT; two roadside irrigation experiments were conducted in 2016 and two in 2017. A non-roadside fifth site was also selected to determine the effect of slope on watering methods. These sites were controlled research areas receiving no maintenance from contractors, and therefore all work was carried out by the U of M. Existing vegetation at each site was controlled with a non-selective herbicide and the areas were prepared for seeding or sodding by removal of the dead vegetation. Irrigation systems were constructed and put in place before or after new sod/seed installation, depending on the type of irrigation system. Each site was irrigated and evaluated weekly for 60 days after sodding or seeding. These evaluations took place from May 2016 – November 2017 in the Twin Cities metro area. Effectiveness of these new systems was determined by collecting data on total amount of water applied, irrigation efficiency, irrigation uniformity (using time-domain reflectometry to determine soil moisture throughout the site), turf establishment, turfgrass quality, and rooting characteristics. Additionally, costs associated with installation, setup and operation were determined for each system to compare to commonly used methods.

4.1 MATERIALS AND METHODS

4.1.1 Sites

Location 1 was a 5 feet (1.5 m) wide boulevard on Larpenteur Avenue between Gortner and Cleveland Avenues in Falcon Heights, MN. Each plot measured 15 feet (4.6 m) long, for an area of 75 feet^2 (7 m^2) per plot (Figures 4.1 and 4.2). The study was initially installed on May 19, 2016 and monitored for a 60-day period until July 19, 2016.

Location 2 was an 11 feet (3.4 m) wide boulevard along Como Avenue between Fifield and Gibbs Street in Falcon Heights, MN. Plot length remained consistent at 15 feet (4.6 m), for a total area of 165 feet^2 (15.3 m^2) per plot. The trial at this location was established on July 1, 2016 and was monitored for a 60-day period until August 29.

Location 3 is a sloped area at the Turfgrass Research, Outreach and Education Center located on the St. Paul campus. The plot width at this location was 8 feet (2.4m) and plot length was 15 feet (4.6 m), for a total area of 120 feet^2 (11.1m^2) per plot. Location 3 included an evaluation of the 12-inch (30.5-cm) and 18-inch (45.7-cm) drip systems as well as a control plots sodded with the MNST-12 sod. The trial at this location was established on August 1, 2016 and was monitored for a 60-day period until September 29.

Location 4 was between Ponds at Battle Creek Golf course and Century Avenue in Maplewood, MN. The area was established by MNST-12 seed and sod on June 27, 2017. Because the area was not constrained by a boulevard, we elected to use a larger plot size – 10 by 15 feet (3.0 by 4.6 m), for an area of 150 feet^2 (13.9 m^2) per plot.

Location 4 was a 5 feet (1.5 m) wide boulevard on Larpenteur Avenue between Gortner and Fairview Avenues in Falcon Heights, MN. Each plot measured 15 feet (4.6 m) long, for an area of 75 feet^2 (7 m^2) per plot. The area was established by seed and sod on August 9, 2017.

These sites were controlled research areas receiving no additional maintenance from contractors.

4.1.2 Study treatments

The following are the irrigation treatments for the trials at Locations 1 and 2 in 2016 and locations 4 and 5 in 2017 (location 3 was a separate trial conducted on a sloped area at the TROE Center):

Sod Trials:

1. 12-X-12-inch (30.5-X-30.5-cm) drip-tape-style irrigation placed BELOW sod
2. 12-X-12-inch (30.5-X-30.5-cm) drip-tape-style irrigation placed ABOVE sod
3. 18-X-18-inch (45.7-X-45.7-cm) drip-tape-style irrigation placed BELOW sod
4. 18-X-18-inch (45.7-X-45.7-cm) drip-tape-style irrigation placed ABOVE sod
5. Overhead irrigation with MP Rotator
6. Unirrigated control

Seed Trials:

1. 12-X-12-inch (30.5-X-30.5-cm) drip-tape-style irrigation placed to a ½-inch depth in soil
2. 12-X-12-inch (30.5-X-30.5-cm) drip-tape-style irrigation placed at the soil surface
3. 18-X-18-inch (45.7-X-45.7-cm) drip-tape-style irrigation placed to a ½-inch depth in soil
4. 18-X-18-inch (45.7-X-45.7-cm) drip-tape-style irrigation placed at the soil surface
5. Overhead irrigation with MP Rotator
6. Unirrigated control

The following is the irrigation treatment list for the trial at Location 3 at the TROE Center on the St. Paul campus. We omitted the below-sod drip systems in this trial because the above-sod systems showed the most promise.

1. 12-X-12-inch (30.5-X-30.5-cm) drip-tape-style irrigation placed ABOVE sod
2. 18-X-18-inch (45.7-X-45.7-cm) drip-tape-style irrigation placed ABOVE sod
3. Unirrigated control

4.1.3 Site preparation

Initial site preparation began one month prior to the start of the trial at each location. RoundUp WeatherMax (glyphosate) was applied at a rate of 64 ounces per acre (4.7 liters per hectare) in two separate applications spaced approximately two weeks apart. Applications were made using a CO_2

research sprayer calibrated to deliver 44 gallons of solution per acre (412 liters per hectare) or a Turfco T3000 calibrated for the same rate. When the existing vegetation was fully controlled, it was mechanically removed and disposed of. The existing soil profile was then tilled to a depth of 2-3 inches (5.1-7.6 cm) and rough graded for the installation of the irrigation system treatments. Tilling and rough grading were completed using a Toro Dingo mini track loader equipped with a power box rake and grading bar. Once the irrigation treatments were completed and installed, the plots were hand raked to remove any remaining debris.

4.1.4 Experimental design

The trials were set up as a randomized complete block design with three replications of each treatment (Figure 4.5). Each irrigation treatment was designed as an individual complete system and was installed on plots seeded or sodded with the MNST-12 salt-tolerant mixture of 80% fine fescue species and 20% Kentucky bluegrass (by original seed weight). Two-foot (0.6 m) buffer strips were added between treatments to minimize irrigation overspray as well as to provide an area to install the control valves. The entire irrigation system for each location was designed to be reusable (with the exception of the below-ground-drip-style tape).

4.1.5 Water source

To evaluate the five irrigation treatments, a city water hydrant was used to provide a water source for the irrigation systems at Locations 1, 2, and 5. The water source for Location 3 was provided by the irrigation mainline at the TROE Center and Location 4 was provided by the adjacent golf course. We received permission from the local water municipality, Saint Paul Regional Water (SPRWS), and the city to use the hydrants. In a typical city, water hydrants are located either within or near the boulevard. Figure 4.6 provides an example of water hydrant locations for an area within the city of Roseville, MN. The example area is a section of Roselawn Avenue in which there are 7 hydrants located within that area, approximately 350 feet (107 m) apart. With the quantity and accessibility of water hydrants in city locations, utilizing modular drip systems to irrigate roadside turfgrass can be a reasonable method.

4.1.6 Water hydrant connection

The necessary connection, equipped with a backflow device and meter, along with the hydrant wrench, were provided by St. Paul Regional Water Service (SPRWS; Figure 4.7). The municipality requires a $1,000 damage deposit that is refundable when returned. Hydrant permits require monthly photos of the assembly to be submitted for automatic renewal for any duration of use exceeding one month. The connection device is approximately 2 ½ feet (0.76) long and, depending on the hydrant location, may require protection from potential damage or right-of-way obstruction; this was not an issue during our trials. The point of connection (POC) for the irrigation mainline was a ¾ inch (1.9 cm) male hose pipe thread (HPT) fitting; additional sizes may be available from the municipality. Prior to the system installation, the connection was tested to confirm proper function. Pressure readings for each water hydrant were recorded: Location 1 recorded 52 psi and Location 2 recorded 80 psi. An initial meter reading was taken prior to the start of the trial which was used to calculate total gallons of water used.

As a preventative measure against theft or vandalism the hydrant connection was secured to the hydrant with a chain and lock.

4.1.7 Irrigation system components

4.1.7.1 Mainline and point of connection (POC)

Modular drip and overhead irrigation systems were constructed using 1-inch (2.5-cm) schedule 40 PVC pipe for the mainline and 1-inch (2.5-cm) Class 200 PVC pipe for the headers and footers. Slip type PVC fittings were constructed using PVC glue and primer and Teflon tape was used for all threaded fittings. For the purposes of this trial all mainline construction was designed and installed using 1-inch (2.5-cm) Banjo cam-lock couplings and/or 1-inch (2.5-cm) PVC union fittings to aid in disassembly after the trial was completed. Schedule 40 PVC was selected primarily for durability as the mainline was installed on the surface of the trial therefore potential damage could occur. Class 200 PVC was chosen for the headers and footers for its durability as well as reduced price. The mainline was connected to the POC using a combination of fittings in a way that would allow easy disassembly after the trial was completed. As pictured in Figure 4.8, we used a ¾-inch (1.9-cm) spigot fitting that was female pipe thread (FPT) on one side and male pipe thread (MPT) on the other side. The male threaded side was inserted into a 1-inch (2.5-cm) slip X ¾-inch (1.9-cm) female pipe thread reducer fitting. The reducer fitting was glued into a 1-inch (2.5-cm) slip X 1-inch (2.5-cm) slip-90-degree elbow. From the elbow the mainline was installed to a point 4 to 6 inches (10 to 15 cm) below the surface of the trial area. At the subsurface level, an isolation valve was installed as a means to rapidly turn off the water in the event of a break. The isolation valve was enclosed in a 6-inch (15-cm) round valve box to prevent any tampering. Mainline was then installed the remaining distance to the edge of the boulevard and elbowed up to the surface. At the surface a 1-inch (2.5-cm) PVC tee was installed to enable mainline installation along the entire length of the trial.

4.1.7.2 Drip and overhead control valve installation

Control valve assembly for the drip systems included the following components; a 1-inch (2.5-cm) FPT X FPT Hunter PGV valve, a ¾-inch (1.9-cm) MPT X MPT Netafim or Dig brand 120 mesh disc element filter and a Netafim ¾-inch FPT X FPT 15 psi pressure reducer. A 15-psi pressure reducer was selected based on the optimal operating pressure and flow rate for the dripline used in the trial. The fittings that were used to connect the control valve to the filter included a 2-inch (5.1-cm), 1-inch (2.5-cm) MPT nipple and a 1-inch (2.5-cm) FPT X ¾-inch (1.9-cm) FPT adapter. Figure 4.9 shows the drip valve assembly that was used for the trial. The solenoids for the control valves were replaced with 24V DC latching solenoids to allow for the use of a battery-operated controller. The valves used for the overhead irrigation systems were the same 1-inch (2.5-cm) Hunter PGV valves that were used for the drip systems. To maintain the proper operating pressure for the selected nozzles, a 40-psi pressure reducer was installed after the valve. Figure 4.10 shows an example of the overhead valve assembly installed in a standard rectangular valve box. At the outgoing side of each type of valve assembly 1-inch (2.5-cm) schedule 40 PVC was installed to the ground level surface using 1-inch (2.5-cm) slip X slip 90 degree elbows.

4.1.7.3 Header and footer installation

Headers and footers were constructed prior to the installation of the trial to accelerate the process. The use of PVC enabled the headers and footers to lay flat which aided in the ease of installing the dripline. Each header consisted of one 1-inch (2.5-cm) slip (S) X ½-inch (1.3-cm) FPT fitting on either end, a series of 1-inch (2.5-cm) S X ½-inch (1.3-cm) FPT tees, and one 1-inch (2.5-cm) S X S tee. The spacing of the tees with the ½-inch (1.3-cm) threaded side was based on the distance between the two different drip treatments that were being tested. The one slip tee was installed approximately in the middle of the header to allow for the connection of the pipe that extended from the outgoing side of the control valve to the header. Once constructed, ½-inch (1.3-cm) MPT X 0.630-inch (1.6-cm) thin wall diameter twist lock fittings were threaded into each PVC FPT fitting for attachment of the dripline. Footers were constructed in the same way as the headers with the exception of the tee used to connect the header to the valve. An additional design component included adding an air relief valve on the end in order to purge the air from the system once watering was activated. The air relief valve is a ½-inch (1.3-cm) MPT fitting which was threaded into a 1-inch (2.5-cm) S X S X ½-inch (1.3-cm) FPT side outlet fitting as shown in Figure 4.11. Dripline was attached to the twist lock fittings and extended between the header and footer, spaced according to the treatment specifications. Headers and footers were secured down with metal staples to maintain proper spacing.

4.1.7.4 Dripline type

Netafim Streamline 630 Series 8-mil (0.3 inch) thin wall dripline was initially selected for both the 12-inch (30.5-cm) spacing and 18-inch (45.7-cm) spacing drip systems. The 12-inch (30.5-cm) and 18-inch (45.7-cm) spacing referenced both the emitter spacing as well as the spacing between the rows of dripline. Durability issues, attributed to the mil or thickness of the dripline, were observed during the trial at Location 1. To prevent similar issues, 15-mil (0.6-inch) dripline was chosen for the remainder of the trial. The increase in thickness was effective as minimal repairs were needed at Locations 2-5.

4.1.7.5 Overhead system

Overhead irrigation treatments consisted of 1-inch (2.5-cm) PVC class 200 lateral lines equipped with a 2-inch (5.1-cm) riser, shrub adaptor, filter and MP Rotator nozzle. Lateral lines, fittings and heads were assembled in the field to aid in accurate placement of the heads. MP Rotator nozzles were selected based upon the uniform, matched precipitation performance that they provide. For the systems at Location 1 and 4, side strip (MPSS530) 5-X-30-foot (1.5-X-9.1-m) nozzles were used, for Locations 2 and 5 side strip (MPSS530) 5-X-30-foot (1.5-X-9.1-m), right corner (MPRCS515) 5-X-15-foot (1.5-X-4.6-m), and left corner (MPLCS515) 5-X-15-foot (1.5-X-4.6-m) nozzles were used. The plot dimensions for Locations 1 and 5 were approximately 5-X-30-foot (1.5-X-9.1-m); a single head was centered on the plot and adjusted to water in a 180-degree radius (Figure 4.12). The dimensions for Locations 2 and 4 were approximately 11 X 30 feet (3.4 X 9.1 m), a single head was centered on the plot on one side and adjusted to water in a 180-degree radius, on the other side a single head was placed in each corner affixed with the appropriate left or right corner MP Rotator nozzle. Due to the size of the plots at

Location 2 and the nozzle pattern limitations, three heads were installed in a triangular type arrangement.

4.1.7.6 Controller and rain sensor

Operation of the control valves required the use of battery controllers as electricity was not available at any of the locations. Hunter Node controllers were used for this trial and due to the design; multiple controllers were needed for each location. For the purposes of this trial, controllers were located in two separate areas spaced according to the maximum distance allowable for proper operation. Treatments of the same type were wired to the same station number on the controller using 14-gauge irrigation wire. A Rainbird Rain-Clik rain sensor was wired to each controller to prevent systems from operating after a rain event. The rain sensors were set to interrupt operation after 0.25 inch (0.64 cm) of rain.

4.1.8 Drip irrigation system costs

A cost analysis was calculated for the 12-inch (30.5-cm) and 18-inch (45.7-cm) drip irrigation systems. The cost analysis includes all materials and parts needed for installation of each system type on an area 6 feet (1.8 m) wide by 2,500 feet (762 m) long (15,000 feet^2 [1394 m^2]). Costs associated with obtaining water hydrant access vary and are refundable; therefore, they are not included in the analysis. Table 4.1 is a cost comparison of the 12-inch (30.5-cm) and 18-inch (45.7-cm) drip systems.

Cost effectiveness is a major factor in making recommendations for an alternative watering method for roadside turfgrass and the 18-inch (45.7-cm) spacing drip system is the most economical choice. Due to the system's reusable design, both materials and labor savings could be significant. A detailed cost analysis for the 12-inch (30.5-cm) and 18-inch (45.7-cm) systems are shown on Tables 4.2 and 4.3.

4.1.9 MNST-12 sod and seed establishment

Locations 1, 2, 4, and 5 were seeded with the MNST-12 seed mixture purchased from Twin City Seed (Edina, MN) at a rate of 4 pounds per 1,000 feet^2 (0.02 kg/m^2). Seeded plots were seeded by hand, overlaid with Futerra netless blanket (Profile Products LLC), secured with 4-inch (10.2-cm) sod staples, and watered evenly to moisten the surface. MNST-12 sod purchased from Dahle sod farm (Morristown, MN) was used for all locations. The sod was cut and installed the same day. Prior to sod installation, the plots were watered to wet the soil surface. All plots were fertilized at the time of establishment with 14-14-14 at a rate of 1 pounds P_2O_5/1,000 feet^2 (0.005 kg/m^2). Dates of establishment and termination of irrigation are shown in Table 4.4.

4.1.10 Data collection

Each site was evaluated weekly during the 2016 and 2017 trials. Site evaluation included:

- Weekly ratings for establishment and visual turfgrass quality
- Soil moisture measurements two times per week with a Spectrum TDR 300 including GPS mapping (12 measurements per plot per rating date)

- Species grid counts following the 60-day establishment period to distinguish between desirable grasses and weeds (75 counts per plot, covering entire plot area)
- Shear strength and density measurements 55 days after trial completion using a Turf-Tec Shear Strength Tester
- Total water use and cost for water

4.1.11 Data analysis

Data were analyzed in SAS (SAS Institute Inc., 2015, ver. 9.4, Cary, NC, USA) using PROC GLM. When treatment F tests were significant ($p \leq 0.05$), Duncan's multiple range test ($\alpha = 0.05$) was used to separate means.

4.2 RESULTS

4.2.1 MNST-12 sod

Above sod drip irrigation systems were sufficient to maintain acceptable quality of MNST-12 sod throughout the 60-day trial period at Location 1. The highest ratings for green tissue and quality were observed with the 12-X-12-inch (30.5-X-30.5-cm) drip irrigation design placed above sod, followed by 18-X-18-inch (45.7-X-45.7-cm) above-sod systems; quality ratings were never statistically different between these two treatments. Below sod drip systems provided intermediate quality, while the overhead irrigation design received the lowest quality ratings of the irrigated treatments. The poor performance of the below-sod drip systems can be attributed to lack of turf quality and rooting of sod directly above the drip tape (Figure 4.13). The unirrigated control treatments did not produce acceptable establishment and the sod appeared to be dead approximately 5-6 days after planting. Table 4.5 includes the quality characteristics for sod grown under different irrigation treatments at Location 1.

All drip systems at Location 2 provided acceptable quality of MNST-12 sod during the establishment phase, while the overhead and unirrigated control treatments provided below acceptable (rating of < 6) for a majority of the trial. Statistically there was little difference between above- or below-ground systems, and between 12-inch (30.5-cm) and 18-inch (45.7-cm) spaced drip-tape. Overall, 12-inch (30.5-cm) and 18-inch (45.7-cm) above-sod drip systems provided the highest sod quality throughout the trial, with few differences observed between these treatments (Table 4.6).

At Location 3 (sloped area), ratings for turf quality and percent green were recorded on eight dates during the trial. During the initial establishment period the control treatments showed lower than acceptable ratings for both turf quality (rating of < 6) and percent green (50% or less). As the trial continued, control treatment ratings improved to the acceptable levels of both the 12-inch (30.5-cm) and 18-inch (45.7-cm) drip treatments based on frequent precipitation. The drip irrigation treatments remained at or above acceptable levels for the entire trial period. On the last four rating dates all treatments met or exceeded acceptable sod quality ratings with no measurable differences. In 2016, the area received above average rainfall totals for the duration of the trial, 13.69 inches (34.77 cm) total in

60 days. The rain sensor was activated and prevented operation on 18 days during the trial. Due to the excessive amount of rainfall there was little difference between treatments. Figures 4.14 and 4.15 show a sod control treatment 25 days after planting and 116 days after planting, respectively.

Irrigation treatments significantly affected turfgrass quality and the amount of green coverage on all rating dates at Location 4 (Table 4.7). In general, the irrigation treatments of 12 inches (30.5 cm) above, 12 inches below (30.5 cm), 18 inches (45.7 cm) above and 18 inches (45.7 cm) below were among the treatments resulting in the highest turf quality, followed by the overhead control treatment. Not surprisingly, the unirrigated control had the lowest turf quality across all rating dates. The overhead irrigation treatment and the unirrigated control consistently resulted in turf quality below the acceptable threshold.

Throughout the duration of the experiment at Location 5, each irrigation treatment maintained an acceptable level of turf quality, excluding the unirrigated control (Table 4.8). When differences existed among irrigation treatments, the unirrigated control was always among the plots with the lowest turf quality or amount of green coverage. On the September 8th and 15th rating dates, the 18-inches-below (45.7-cm-below) treatment had reduced turf quality compared to the 18-inches-above (45.7-cm-above) treatment. This was similarly observed in Location 1 (Figure 4.13) and was likely the result of sod not rooting or over-heating above the irrigation tape.

4.2.2 MNST-12 seed

For Location 1 at Falcon Heights, initial data on seed germination and percent cover favored the drip irrigation systems versus overhead irrigation (Tables 4.9 and 4.10). Approximately 30 days after seeding, unirrigated control ratings were comparable to the irrigated treatments due to sufficient rainfall for adequate germination. The best final percent cover was achieved with the 12-X-12-inch (30.5-X-30.5-cm) drip irrigation systems, although statistically these systems were no different than the 18-inch spaced systems, overhead irrigation, or the unirrigated control. As a whole, 2016 was the wettest year on record in the Twin Cities, and unirrigated plots seeded in late May at Location 1 were able to achieve 75% turfgrass cover by November 1st. In years with insufficient rainfall, irrigation systems for seeded roadsides will likely improve establishment significantly. Annual differences in rainfall highlight the importance for multi-year experiments and was an important factor in our request to extend this experiment.

Results from the seeded trials at Location 2 (St. Paul, MN) reflect those observed at Location 1 (Tables 4.11 and 4.12). Overall, final percent turfgrass cover from the June seeding resulted in an average of 51% turf cover across all treatments by November 1st; data were not statistically different among treatments.

For Location 4 (Maplewood, MN), irrigation treatment significantly affected germination, percent green coverage, and turf quality across multiple rating dates at Location 4 (Table 4.13). Similar to the other roadside testing locations, the unirrigated control had the lowest germination rating, percent green coverage, and turf quality across all rating dates.

For Location 5 (Falcon Heights, MN), irrigation treatments significantly affected percent green coverage and turf quality across multiple rating dates (Tables 4.14 and 4.15). Similar trends among irrigation treatments occurred in Location 4 compared to Locations 1 and 2. When differences among irrigation treatments existed, the unirrigated control was always among the treatments with the lowest green coverage and lowest turf quality. On some rating dates, the overhead treatment and the 18-inch-below (45.7-cm-below) treatment had reduced turf quality compared to the 12-inch-above (30.5-cm-above) or 12-inch-below (30.5-cm-below) treatments, which were always among the highest for turf quality at Location 5.

4.2.3 Soil moisture results

Volumetric water content (VWC) was measured at least every 7 days from establishment to at least 60 days after planting using a FieldScout TDR 300 (Spectrum Technologies, Aurora, IL). A total of 12 measurements were recorded for each plot to determine soil moisture variability within plots and across irrigation treatments. Mean volumetric water content (%) and standard deviation data are presented (Tables 4.16 to 4.24).

Soil moisture content was highly influenced by irrigation treatment, sampling date, establishment type (seed or sod) and trial location. In general, irrigation treatments that resulted in the highest soil moisture content in both seeded and sodded plots also were among the treatments having the highest visual coverage, germination ratings (within seeded plots), turf quality, shear strength, and overall turf coverage, and these treatments included all of the drip irrigation treatments. Similarly, the irrigation treatments that resulted in the lowest soil moisture content in both seeded and sodded plots were among the treatments having the lowest visual coverage, germination ratings, turf quality, overall turf coverage, shear strength, and highest weed coverage, and these treatments included the unirrigated control followed by the overhead irrigation treatment.

On several rating dates for Locations 1, 2, and 5, the unirrigated control was among the plots with the highest soil moisture in sodded plots (Tables 4.16, 4.18, and 4.23). In most cases, this occurred at least 4 weeks after planting, with the control plots experiencing drought conditions. These drought-stressed plots had a lower water requirement and an effective mulch layer (wilted sod) that prevented evapotranspiration, resulting in higher soil moisture. This agrees with lower turf quality ratings in control plots on or near these same collection dates (Tables 4.5, 4.6, and 4.8), as well as reduced turf coverage in the control plots at the end of the experiment (Table 4.26).

Standard deviation is a measure of variance within a set of data. In the case of soil moisture, we can use it to measure variance across subsamples within an irrigation treatment to better understand how uniformly these irrigation delivery methods distribute water. The two treatments most often having the highest standard deviation (low uniformity) in soil moisture were the 18-inch-below (45.7-cm-below) and overhead irrigation treatments. The high variability in soil moisture rankings across rating dates and locations demonstrates the difficulty of field evaluations for soil characteristics like soil moisture and emphasizes the importance of frequent soil moisture sampling events with a high number of subsamples for each representative area.

4.2.4 Shear strength

Shear strength of all plots was measured 55 days after planting using a Shear Strength Tester; measurements were recorded in Newton Meters (N m). In general, when differences in shear strength existed among irrigation treatments, the unirrigated control resulted in the lowest shear strength (Table 4.25). Location 5 was the only location that irrigation treatment affected shear strength in seeded plots, and a similar trend existed among irrigation treatments compared to sodded plots, excluding the 12-inch-below (30.5-cm-below) treatments, which resulted in a higher shear strength compared to all other treatments. At the time of installation weather conditions were hot and dry which could have contributed to poor sod rooting even after the significant amount of rainfall the area received during 2016.

4.2.5 Grid count cover measurements

Grid count cover measurements were collected 60 days after planting using a 25-point grid measurement, with 3 subsample measurements collected from each plot. When differences in turf or weed coverage existed among irrigation treatments in both seeded (Table 4.26) and sodded (Table 4.27) plots, the control plot generally had the lowest turf coverage and the highest weed coverage. These results strongly agree with the visual turf quality data for each location, which takes into account a combination of turfgrass density, uniformity, and turf and weed cover. A reduction in soil moisture in the control plots during establishment (Tables 4.16 to 4.24) likely allowed summer annuals and broadleaf weed species to be more competitive than the MNST-12 seed or sod.

4.2.6 Total water use and cost

Throughout the trial period at Location 1, irrigation volumes were programmed based on observed soil moisture requirements. Prior to planting sod, the soil was pre-wetted to minimize the initial shock from sod placed on dry soil. On the day of planting, 0.15 inch (3.8 mm) of irrigation was applied in two separate cycles. For the 10-day period following planting, both seed and sod treatments were irrigated with 0.15 inch (3.8 mm) of water 2X per day for a daily total of 0.30 inch (7.6 mm) and a weekly total of 2.1 inches (5.3 cm). Days 11-30, seed and sod were irrigated with 0.15 inch (3.8 mm) per day (1.05 inch [2.7 cm] weekly), and days 31-60 irrigation was applied every other day at 0.15 inch (0.45 to 0.60 inch [1.1 to 1.5 cm] weekly). Run times for each treatment were programmed accordingly; 18-inch (45.7-cm) drip – 52 minutes, 12-inch (30.5-cm) drip – 24 minutes, and overhead – 32 minutes and amended by number of start times and days to achieve the appropriate daily irrigation total throughout the trial. Over the 60-day trial period at Location 1, 14,212 gallons (53,798 liters) or an equivalent of 11 inches (28 cm) of water was applied to the trial area, costing $52.06.

Water usage is traditionally billed by the unit, with 1 unit being equal to 100 feet^3 (2.8 m^3) or 748 gallons (2831 liters). The price per unit generally varies by season. The city of Falcon Heights (Locations 1, 2, and 5) charged a summer rate of $3.14 per 100 feet^3 (2.8 m^3) in 2016 and $2.74 per 100 feet^3 (2.8 m^3) in 2017 (Table 4.28). Departments of Transportation commonly specify water cost by the square yard. The locations in this study had a water cost that ranged from $4.32 to $9.47 per square yard (Table 4.28). In addition to the water usage cost are fees for hydrant inspection, permit administration, right-of-way recovery, and a water service base fee.

4.3 DISCUSSION

Above average rainfall during 4 of the 5 experiments in 2016 and 2017 likely limited the effect of irrigation treatment on the response variables we used to evaluate seed and sod establishment (Table 4.29). The effect of increased rainfall is apparent in control plots having similar turf quality, shear strength, turf coverage, and weed coverage to the other irrigation treatments on several rating dates across each of the five locations, despite not receiving any supplemental irrigation after establishment. Furthermore, lack of differences in soil moisture among irrigation treatments on or across specific rating dates can often be attributed to specific rainfall events that happened immediately prior to the collection of soil moisture for that date. For example, St. Paul received 1.48 inches (3.8 cm) of water on 6/14 (Table 4.29), resulting in consistent soil moisture content across all treatments for that date (Table 4.16). We predict that in normal or below normal rainfall years, differences in irrigation delivery method would have a larger effect on turf establishment.

Based on other research comparing seeding and sodding date throughout the growing season and irrigated to MnDOT standard specifications for Kentucky bluegrass sod, seeded plots typically are more affected by planting date than sodded plots (Watkins and Trappe, 2017). In this previous experiment, plots that were seeded between May and July had decreased turf quality and increased weed coverage compared to sodded plots. The authors of the report concluded that establishing a roadside with MNST-12 sod could be attempted from May to November if access to irrigation was available. The irrigation delivery treatments we examined in this experiment established MNST-12 sod during the most difficult time of year for sod establishment on roadsides and suggest these irrigation delivery methods could be successfully implemented throughout the growing season.

Contractors interested in implementing the hydrant adapter and delivery system outlined in this report to establish MNST-12 seed or sod will need to weigh both immediate and long-term costs associated with seed or sod establishment. Compared to the traditional water delivery system of a water truck, the initial cost of a using a hydrant adapter with a programmable irrigation system and drip tape may discourage some contractors from adopting this system. However, the reusability of this system reduces the cost of irrigating seed or sod over time compared to water trucks, considering the higher labor and fuel costs associated with delivery. Furthermore, the use of weather sensors with the programmable irrigation system would likely use less water over time compared to a water truck.

4.4 CONCLUSIONS

Irrigation for seed or sod installations on roadsides is essential for successful establishment. A hydrant adapter is one tool contractors may use that can provide dependable access to water. Little differences in germination rates, coverage, or turf quality were observed between the 12-inch (30.5-cm) and 18-inch (45.7-cm) irrigation tape, or when the tape was laid above the sod or germination blanket or below. Should contractors choose to use a hydrant adapter with a programmable irrigation system, 18-inch (45.7-cm) irrigation tape laid above the germination blanket (when seeding) or above sod is recommended. Another reason to avoid irrigation tape laid below the sod is that it can eventually be exposed and present complications for mowing operations. The use of an 18-inch (45.7-cm) irrigation tape placed above the turf surface is easier and cheaper to install, can be removed and possibly reused after establishment, and will result in reduced water use.

Figure 4.1 Larpenteur Avenue installation.

Figure 4.2 Larpenteur Avenue installation.

Figure 4.3 Como Avenue site following installation.

Figure 4.4 Como Avenue site showing drip irrigation covered by soil for the below-ground seed treatment.

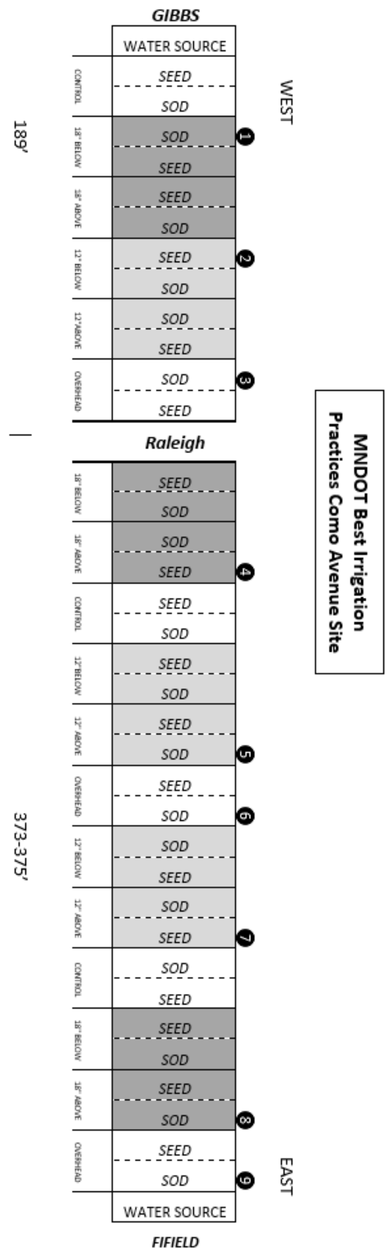

Figure 4.5 Como Avenue site study layout.

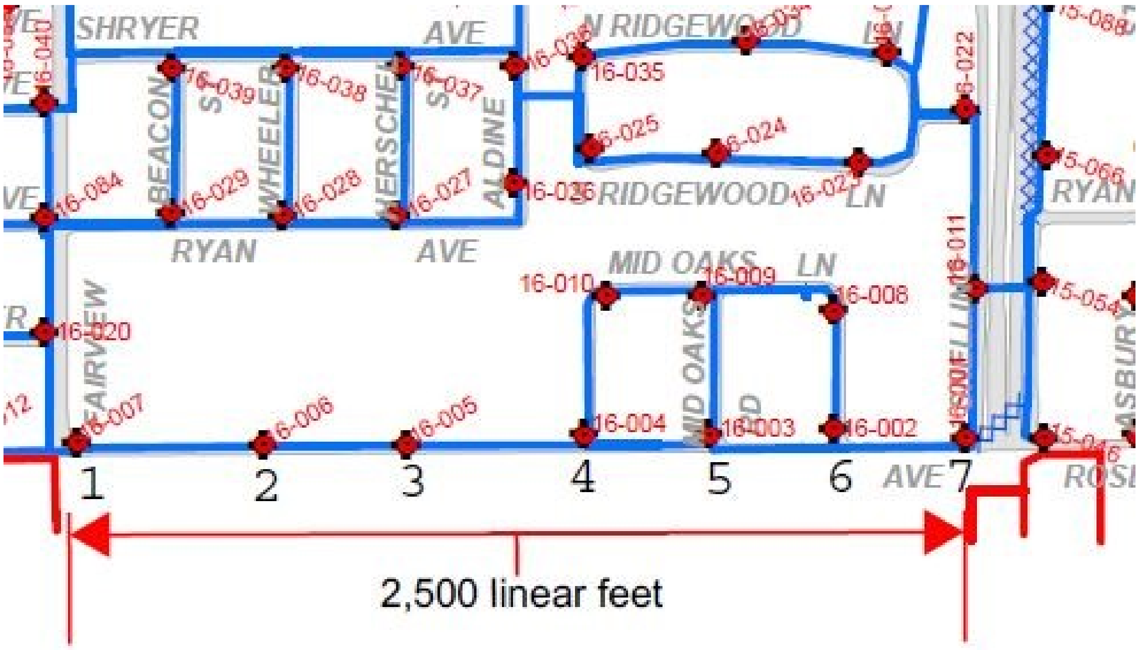

Figure 4.6 Example of Roseville city water hydrant layout.

Figure 4.7 Hydrant connection with backflow prevention, meter, and wrench.

Figure 4.8 Mainline point of connection.

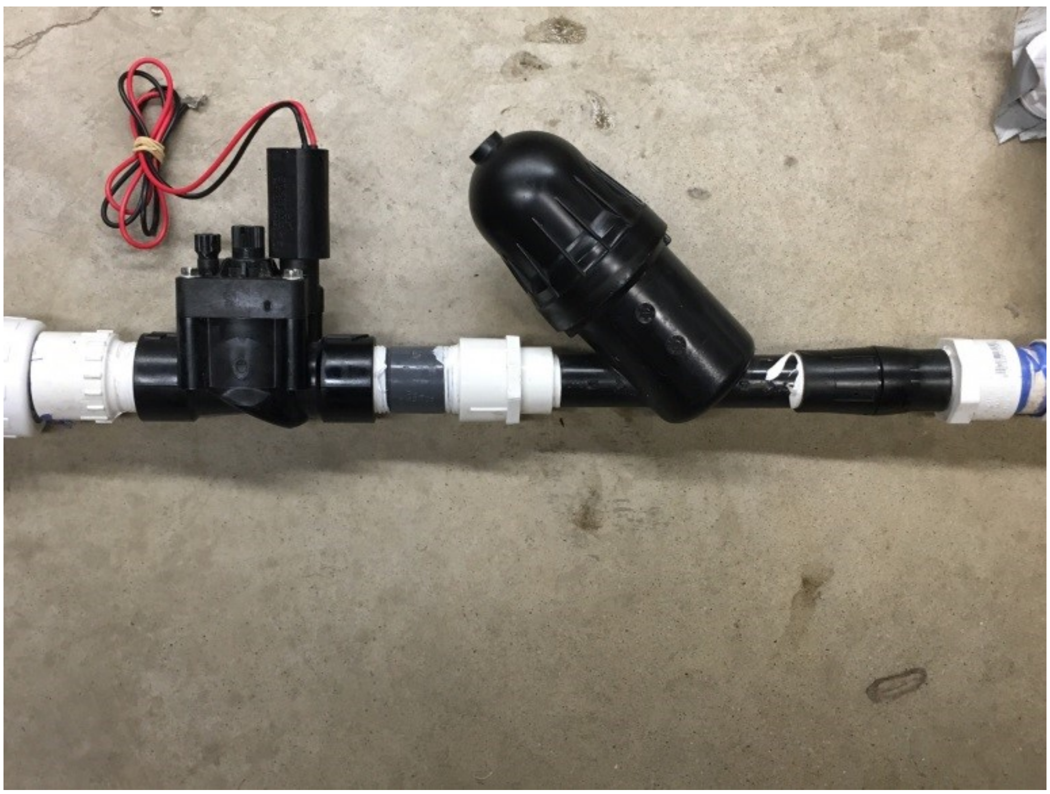

Figure 4.9 Drip valve assembly.

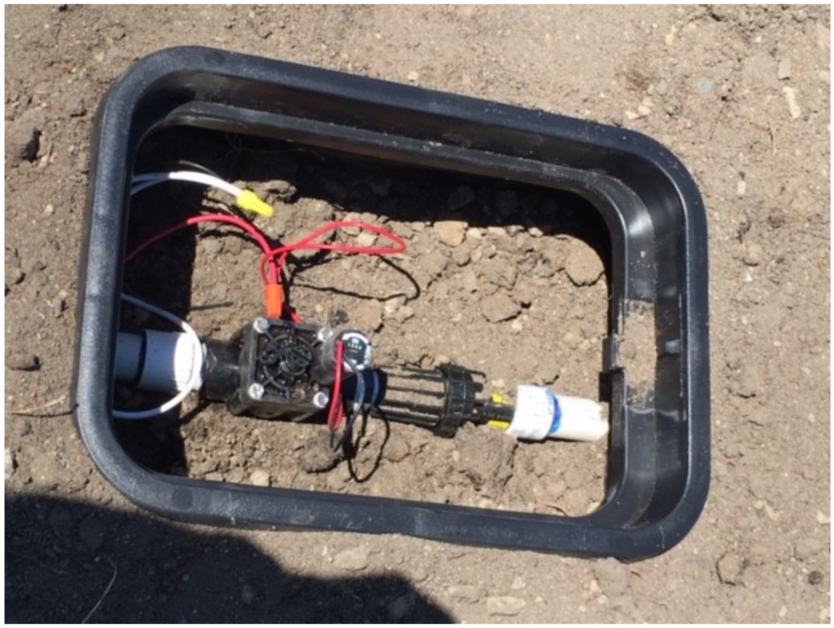

Figure 4.10 Overhead valve assembly.

Figure 4.11 Drip footer with air relief valve.

Figure 4.12 Overhead irrigation system.

Figure 4.13 Sod not rooting directly above drip irrigation lines.

Figure 4.14 Slope control treatment at 25 DAP.

Figure 4.15 Slope control treatment at 116 DAP.

Table 4.1 Cost comparison for 12-inch and 18-inch drip systems (15,000 feet^2).

System (6 X 2,500')	PVC	Fittings	Valves and components	Controllers, sensors	Dripline, components	Total
12" spacing	\$834.66	\$1,135.13	\$138/24	\$398/48	\$699/46	\$3,205.97
18" spacing	\$747.04	\$951.89	\$69/12	\$199/24	\$438/38	\$2,405.67

Table 4.2 Detailed costs for 12-inch drip system (15,000 feet²).

12" Drip System (6 X 2,500')				
2" Hydrant Connection	**Part/Fitting**	**Quantity**	**Cost**	**TOTAL**
	2" - 90 degree Combo Elbow S X FPT	1	$2.38	**$2.38**
	2" S X 1" S- Reducing PVC Pipe Bushing	1	$0.85	**$0.85**
	1" S X S- PVC Union	1	$2.76	**$2.76**
	1" S X S- PVC Elbow	4	$0.38	**$1.52**
	* 1" Schedule 40 PVC	Approx. 10'	$0.43	**$4.30**
Mainline to Valve Connection				
	1" S X S- PVC Tee	4	$0.50	**$2.00**
	1" S X S- PVC Elbow	8	$0.38	**$3.04**
	1" S X S- PVC Union	4	$2.76	**$11.04**
	1" S X MPT PVC Pipe Adapter	4	$0.38	**$1.52**
	* 1" Schedule 40 PVC	Approx. 12'	$0.43	**$5/16**
Valve Assembly				
	1" S X FPT- Isolation valve	4	$2.07	**$8/28**
	1" Hunter PGV MPT X MPT	4	$13.46	**$53.84**
	1" Filter w/ Red 120 Mesh Disc Element	4	$14.48	**$57.92**
	3/4" Netafim 15 PSI Pressure Regulator	4	$6.62	**$26.48**
	Hunter Node- single station	4	$83.77	**$335.08**
	1" S X MPT- PVC Coupler	4	$0.44	**$1.76**
	1" FPT X 3/4" FPT reducer coupling	4	$0.91	**$3.64**
	1" S X 1/2" MPT Male adapter	4	$0.47	**$1.88**
	1" S X S PVC elbow	4	$0.38	**$1.52**
	1" S X S - PVC Union	4	$2.76	**$11.04**
Valve to Header Connection				
	1" S X S - PVC Elbow	8	$0.38	**$3.04**
	* 1" Class 200 PVC	Approx. 8'	$0.30	**$2.40**
Header Assembly				
	1" S X S- PVC Tee	12	$0.50	**$6.00**
	1" S X 1/2" FPT PVC Tee	16	$0.63	**$10.08**
	1" S X 1/2" FPT PVC Elbow	8	$0.80	**$6.40**
	1/2" MPT to .630 TWD Twist Lock start connector	24	$0.74	**$17.76**
	* 1" Class 200 PVC	Approx. 24'	$0.30	**$7.20**
Footer Assembly				
	1" S X 1/2" FPT PVC Tee	4	$0.63	**$2.52**
	1" S X 1/2" FPT PVC Elbow	4	$0.80	**$3.20**
	1" S X 1" S X 1/2" FPT- 90 degree elbow side outlet	4	$1.65	**$6.60**
	1/2" MPT to .630 TWD Twist Lock start connector	24	$0.74	**$17.76**
	1/2" MPT-Netafim Air/Vacuum Relief Vent	4	$4.68	**$18/72**
	* 1" Class 200 PVC	Approx. 24'	$0.30	**$7.20**

Mainline				
	* 1" Schedule 40 PVC used	1,880	$0.43	**$808/40**
	1" S X FPT PVC Female Adapter	188	$0.39	**$73.32**
	1" Banjo Camlock Female Coupler- MPT	Approx. 94	$6.67	**$626.98**
	1" Banjo Camlock Male Coupler- MPT	Approx. 94	$3.08	**$289/52**
Additional Parts				
	Rectangle Valve Box- 17" L X 11-3/4" W X 6-3/4" H	4	$12.48	**$49/92**
	Hunter Rain-Clik Sensor	4	$15.85	**$63.40**
	Blazing TLC-10 small wire nuts-silicone filled	16	$0.34	**$5.44**
	1/2" Teflon Tape	4	$0.40	**$1.60**
	PVC Cement	1 Pint	$8/00	**$8/00**
	PVC Primer	1 Pint	$8/00	**$8/00**
	Netafim Streamline Drip Tape- 15 mil, 12", 7500'	2 Rolls	$305	**$610.00**
	4" Sod staples	1 box	$16.50	**$16.50**
	Total materials cost			**$3,205.97**

Table 4.3 Detailed costs for 18-inch drip system (15,000 feet^2).

18" Drip System (6 X 2,500')				
2" Hydrant Connection	**Part/Fitting**	**Quantity**	**Cost**	**TOTAL**
	2" - 90 degree Combo Elbow S X FPT	1	$2.38	**$2.38**
	2" S X 1" S- Reducing PVC Pipe Bushing	1	$0.85	**$0.85**
	1" S X S- PVC Union	1	$2.76	**$2.76**
	1" S X S- PVC Elbow	4	$0.38	**$1.52**
	* 1" Schedule 40 PVC	Approx. 10'	$0.43-0.50	**$4.30**
Mainline to Valve Connection				
	1" S X S- PVC Tee	2	$0.50	**$1.00**
	1" S X S- PVC Elbow	4	$0.38	**$1.52**
	1" S X S- PVC Union	2	$2.76	**$5.52**
	1" S X MPT PVC Pipe Adapter	2	$0.38	**$0.76**
	* 1" Schedule 40 PVC	Approx. 6'	$0.43	**$7.74**
Valve Assembly				
	1" FPT X FPT- Isolation valve	2	$2.07	**$4.14**
	1" Hunter PGV MPT X MPT	2	$13.46	**$26.92**
	1" Filter w/ Red 120 Mesh Disc Element	2	$14.48	**$28/96**
	3/4" Netafim 15 PSI Pressure Regulator	2	$6.62	**$13.24**
	Hunter Node- single station	2	$83.77	**$167.54**
	1" S X MPT- PVC Coupler	2	$0.44	**$0.88**
	1" FPT X 3/4" FPT reducer coupling	2	$0.91	**$1.82**
	1" S X 1/2" MPT Male adapter	2	$0.47	**$0.94**
	1" S X S PVC elbow	2	$0.38	**$0.76**
	1" S X S- PVC Union	2	$2.76	**$5.52**
Valve to Header Connection				
	1" S X S- PVC Elbow	4	$0.38	**$1.52**
	* 1" Class 200 PVC	Approx. 4'	$0.30	**$5.40**
Header Assembly				
	1" S X S- PVC Tee	2	$0.50	**$1.00**
	1" S X 1/2" FPT PVC Tee	4	$0.63	**$2.52**
	1" S X 1/2" FPT PVC Elbow	4	$0.80	**$3.20**
	1/2" MPT to .630 TWD Twist Lock start connector	8	$0.74	**$5.92**
	* 1" Class 200 PVC	Approx. 12'	$0.30	**$3.60**
Footer Assembly				
	1" S X 1/2" FPT PVC Tee	4	$0.63	**$2.52**
	1" S X 1/2" FPT PVC Elbow	2	$0.80	**$1.60**
	1" S X 1" S X 1/2" FPT- 90 degree elbow side outlet	2	$1.72	**$3.44**

	1/2" MPT to .630 TWD Twist Lock start connector	8	$0.74	**$5.92**
	1/2" MPT-Netafim Air/Vacuum Relief Vent	2	$4.68	**$9/36**
	* 1" Class 200 PVC	Approx. 12'	$0.30	**$3.60**
Mainline				
	* 1" Schedule 40 PVC used	Approx. 1,680'	$0.43	**$722.40**
	1" S X FPT PVC Female Adapter	168	$0.39	**$65.52**
	1" Banjo Camlock Female Coupler- MPT	Approx. 84	$6.67	**$560.28**
	1" Banjo Camlock Male Coupler- MPT	Approx. 84	$3.08	**$258/72**
Additional Parts				
	Rectangle Valve Box - 17" L X 11-3/4" W X 6-3/4" H	2	$12.48	**$24.96**
	Hunter Rain-Clik Sensor	2	$15.85	**$31.70**
	Blazing TLC-10 small wire nuts-silicone filled	8	$0.34	**$2.72**
	1/2" Teflon Tape	3 rolls	$0.40	**$1.20**
	PVC Cement	1 Pint	$8/00	**$8/00**
	PVC Primer	1 Pint	$8/00	**$8/00**
	Netafim Streamline Drip Tape- 15 mil, 18", 7500'	1.3 Rolls	$290.00	**$377.00**
	4" Sod staples	1 box	$16.50	**$16.50**
	Total materials cost			**$2,405.67**

Table 4.4 Establishment and irrigation termination dates for each location.

Timing	Location 1 – W Larpenteur Ave	Location 2 – Como Ave	Location 3 – TROE	Location 4 – Maplewood	Location 5 – E Larpenteur Ave
Establishment	5/19/16	7/1/16	8/1/16	6/27/17	8/9/17
Termination of irrigation	7/19/16	8/29/16	9/29/16	8/28/17	10/9/17

Table 4.5 Sod quality data based on irrigation treatment at Location 1 (Larpenteur Avenue) in 2016.

Treatment	5/27[1]	6/2	6/10	6/17	6/24	7/1	7/7	7/14	8/5	10/3	11/1
	% Cover[2]	% Cover	TQ[3]	TQ	TQ	TQ	TQ	TQ	TQ	TQ	TQ
12" above	91.7 a	95.0 a	7.7 a	7.3 a	7.3 a	7.0 a	7.0 a	7.0 a	7.0 a	7.0 a	6.3 ab
12" below	63.3 a	66.8 b	5.0 b	5.3 a	5.0 a	5.0 a	5.0 a	5.0 b	5.7 a	6.0 a	5.7 b
18" above	83.3 a	90.7 ab	7.0 ab	7.0 a	6.7 a	6.0 a	6.0 a	6.0 ab	6.3 a	6.7 a	6.7 a
18" below	80.0 a	82.1 ab	6.0 ab	6.3 a	6.3 a	5.7 a	5.7 a	6.0 ab	6.0 a	6.7 a	6.0 ab
overhead	68.3 a	77.0 ab	5.7 ab	5.7 a	5.3 a	5.0 a	5.0 a	5.0 b	6.0 a	6.7 a	6.3 ab
control	1.7 b	0.2 c	1.0 c	1.0 b	1.0 b	1.0 b	1.0 b	1.0 c	1.0 b	1.0 b	1.0 c
LSD	26.2	18.6	2.2	2.3	2.43	2.1	2.1	2.0	1.7	1.7	0.2

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments.
[2] % Cover= Visual estimate for percent green coverage.
[3] TQ = Turfgrass quality (1=dead, 9=ideal), a quality rating of 6 is considered acceptable.

Table 4.6 Sod quality data based on irrigation treatment at Location 2 (Como Avenue).

Treatment	7/14[1]	7/22	7/22	8/5	8/11	8/22	8/26	8/31	10/3	11/1
	% Cover[2]	% Cover	TQ[3]	TQ	TQ	TQ	TQ	TQ	TQ	TQ
12" above	96.4 a	96.4 a	6.3 a	6.7 a	6.7 a	7.3 a	7.3 a	7.3 a	6.7 a	7.0 a
12" below	90.4 ab	92.0 ab	5.7 ab	6.7 a	6.7 a	6.7 a	6.7 ab	6.7 ab	6.3 a	6.7 a
18" above	95.3 a	98.0 a	6.7 a	6.3 a	6.7 a	7.3 a	7.3 a	7.0 a	7.0 a	6.7 a
18" below	91.8 ab	92.8 ab	5.7 ab	6.0 ab	6.0 ab	6.7 a	6.0 bc	6.0 ab	6.3 a	6.3 ab
overhead	87.0 b	83.8 b	4.3 b	4.3 b	4.7 b	5.0 b	5.3 c	5.7 b	4.7 b	5.0 bc
control	41.5 c	44.9 c	1.7 c	2.0 c	2.3 c	3.0 c	3.0 d	3.0 c	2.3 c	3.7 c
LSD	8.1	9.9	1.6	1.9	1.5	1.4	1.3	1.5	1.6	1.5

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] % Cover= Visual estimate for percent green coverage.
[3] TQ = Visual rating of turfgrass quality (1=dead, 9=ideal), a quality rating of 6 is considered acceptable.

Table 4.7 The effect of irrigation treatment on turf establishment in sodded plots at Location 4 (Maplewood) in 2017.

Treatment	7/13[1]	7/21	7/27	8/3	8/10	8/17	8/25	8/28	9/14	9/28	10/20
	Cover[2]	Cover	TQ[3]	TQ	TQ	TQ	TQ	TQ	TQ	TQ	TQ
12" above	93.3 a	97.7 a	6.7 a	5.7 ab	7.7 a	5.7 a	5.3 ab	5.0 ab	4.7 a	4.3 ab	4.0 a
12" below	92.7 a	97.0 a	7.0 a	5.7 ab	7.3 a	6.3 a	6.0 a	5.0 ab	4.3 a	4.3 ab	4.3 a
18" above	91.7 ab	98.0 a	7.0 a	6.0 a	7.0 a	6.0 a	5.7 ab	5.3 a	5.0 a	5.0 a	4.3 a
18" below	85.0 ab	89.0 ab	6.0 a	5.3 ab	6.7 a	5.7 a	5.7 ab	5.0 ab	5.0 a	4.7 ab	4.3 a
overhead	80.0 b	80.0 b	4.0 b	4.7 b	5.0 b	4.0 b	5.0 b	4.3 b	4.3 a	4.0 b	4.0 a
control	1.7 c	1.0 c	1.0 c	2.0 c	2.0 c	2.0 c	2.3 c	2.7 c	2.7 b	3.0 c	3.0 b
LSD	12.5	12.1	1.1	1.1	1.1	0.7	0.8	0.7	0.8	0.7	0.7

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments).
[2] Cover = Visual estimate for percent green coverage.
[3] TQ = Turfgrass quality (1=dead, 9=ideal), a quality rating of 6 is considered acceptable.

Table 4.8 The effect of irrigation treatment on turf establishment in sodded plots at Location 5 (E. Larpenteur Avenue) in 2017.

Treatment	8/18[1]	8/25	8/25	8/31	9/8	9/15	9/22	9/29	10/10
	Cover[2]	Cover	TQ[3]	TQ	TQ	TQ	TQ	TQ	TQ
12" above	95.0	98.3 ab	7.0 a	7.0 a	7.0 ab	7.3 ab	7.3 ab	7.0 a	7.3 a
12" below	91.7	93.3 c	6.3 ab	7.0 a	7.3 ab	7.3 ab	7.7 ab	7.7 a	8.3 a
18" above	98.3	98.3 ab	7.3 a	7.3 a	7.7 a	7.7 a	8.0 a	8/0 a	8.0 a
18" below	91.7	95.0 bc	6.3 ab	6.3 a	6.3 b	6.3 b	7.0 b	7.0 a	7.3 a
overhead	95.0	99/7 a	7.3 a	7.0 a	7.3 ab	7.3 ab	7.7 ab	7.3 a	7.3 a
control	90.0	88.3 d	5.3 b	5.0 a	4.7 c	4.3 c	4.7 c	4.7 b	5.3 b
LSD	7.3	4.2	1.2	1.2	1.2	1.0	0.8	1.3	1.4

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] Cover = Visual estimate for percent green coverage.
[3] TQ = Turfgrass quality (1=dead, 9=ideal), a quality rating of 6 is considered acceptable.

Table 4.9 The effect of irrigation treatment on turf establishment in seeded plots at Location 1 (W. Larpenteur Avenue) in 2016.

Treatment	5/27[1]	6/2	6/2	6/10	6/17	6/24	7/1	7/7
	Germ[1]	Germ	Cover[2]	Cover	Cover	Cover	Cover	Cover
12" above	2.7 ab	4.7 a	20.0 ab	28.3 ab	51.7	51.7	70.0	66.7
12" below	2.7 ab	5.3 a	25.0 a	33.3 a	50.0	53.3	78.3	78.3
18" above	3.3 a	4.7 a	21.7 a	26.7 bc	45.0	46.7	61.7	63.3
18" below	2.7 ab	4.0 a	21.7 a	25.0 bc	41.7	41.7	66.7	65.0
overhead	2.0 b	4.0 a	13.3 b	21.7 c	43.3	43.3	63.3	61.7
control	1.0 c	2.0 b	5.0 c	10.0 d	45.0	43.3	51.7	50.0
LSD	0.9	1.6	8.1	6.0	16.1	18.1	18.9	20.4

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] Germ=Germination rating (1-9, 1= no germination, 9=fully germinated)
[3] Cover = Visual estimate for percent green coverage, a quality rating of 6 is considered acceptable.

Table 4.10 The effect of irrigation treatment on turf establishment in seeded plots at Location 1 (W. Larpenteur Avenue) in 2016.

Treatment	7/14[1]	8/5	8/5	10/3	10/3	11/1	11/1
	TQ[2]	TQ	Cover[3]	TQ	Cover	TQ	Cover
12" above	5.0	5.7	55.0	4.3	65.0	5.0	75.0
12" below	5.3	6.3	56.7	4.7	68.3	5.3	81.7
18" above	5.3	5.3	46.7	3.3	55.0	4.0	75.0
18" below	4.7	5.3	51.7	4.3	65.0	4.3	78/3
overhead	5.3	5.0	43.3	4.3	60.0	4.7	75.0
control	4.0	4.7	38/3	2.7	51.7	3.7	75.0
LSD	1.4	1.3	14.9	1.6	25.2	2.3	15.5

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] TQ = Turfgrass quality (1=dead, 9=ideal).
[3] Cover = Visual estimate for percent green coverage, a quality rating of 6 is considered acceptable.

Table 4.11 The effect of irrigation treatment on turf establishment in seeded plots at Location 2 (Como Avenue) in 2016.

Treatment	6/14[1]	7/22	7/22	8/5	8/11	8/22	8/26	8/31	8/31
	Germ[2]	Germ	Cover	Cover	Cover	Cover	Cover	Cover	TQ[3]
12" above	5.3	6.3	31.6 b	38.3	38.3 a	35.0 a	31.7 a	33.3	4.7
12" below	4.7	4.7	29.6 b	33.3	30.0 abc	30.0 bc	30.0 a	33.3	4.7
18" above	3.3	4.3	25.0 b	28.3	23.3 c	18.3 d	18.3 b	20.0	3.0
18" below	4.3	4.7	33.3 b	33.3	26.7 bc	26.7 c	26.7 a	28.3	4.0
overhead	5.7	6.0	33.2 b	43.3	33.3 ab	31.7 ab	28.3 a	30.0	4.3
control	3.3	3.3	59.1 a	23.3	21.7 c	16.7 d	16.7 b	18.3	3.0
LSD	2.0	1.9	1.2	14.9	9.1	4.9	6.6	12.2	1.4

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] Germ = Visual germination rating (1-9, 1= no germination, 9=fully germinated)
[3] TQ = Turfgrass quality (1=dead, 9=ideal), a quality rating of 6 is considered acceptable.

Table 4.12 The effect of irrigation treatment on turf establishment in seeded plots at Location 2 (Como Avenue) in 2016.

Treatment	10/3[1]	10/3	11/1	11/1
	Cover[2]	TQ[3]	Cover	TQ
12" above	40.0	3.3	50.0	4.0
12" below	40.0	3.3	50.0	3.0
18" above	28.3	2.3	45.0	2.3
18" below	36.7	3.0	53.3	3.3
overhead	45.0	3.3	58.3	4.0
control	25.0	2.0	48.3	3.0
LSD	24.0	1.3	25.7	2.0

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] Cover = Visual estimate for percent green coverage.
[3] TQ = Turfgrass quality (1=dead, 9=ideal), a quality rating of 6 is considered acceptable.

Table 4.13 The effect of irrigation treatment on turf establishment in seeded plots at Location 4 (Maplewood, MN) in 2017.

Treatment	7/13[1]	7/13	7/21	7/21	7/21	7/27	8/10	8/17	8/24	8/28	9/14	9/28	10/20
	Germ[2]	Cover[3]	Germ	Cover	Germ	Cover	TQ[4]	TQ	TQ	TQ	TQ	TQ	TQ
12” above	6.0 a	41.7 a	7.0 a	73.3 a	8.0 a	76.7 a	3.3	3.7 a	4.0 a	4.3 a	4.3 a	4.3 a	4.0 ab
12” below	5.7 a	36.7 a	7.0 a	70.0 a	7.7 a	71.7 a	3.0	3.7 a	4.0 a	4.3 a	4.3 a	4.3 a	4.7 a
18” above	5.7 a	36.7 a	6.3 a	63.3 a	7.7 a	65.0 a	3.0	3.3 a	3.7 a	3.7 a	3.7 a	3.7 a	4.3 a
18” below	5.7 a	41.7 a	6.3 a	68.3 a	7.7 a	75.0 a	3.3	3.3 a	3.7 a	3.7 a	3.7 a	3.7 a	4.3 a
overhead	5.0 a	38.3 a	6.0 a	65.0 a	7.7 a	70.0 a	3.7	4.0 a	4.0 a	3.7a	3.3 ab	3.3 ab	3.3 b
control	1.0 b	1.7 b	1.3 b	3.3 b	6.0 b	13.3 b	2.3	2.3 b	2.0 b	2.0b	2.3 b	2.3 b	2.3 c
LSD	1.8	14.8	1.8	11.0	0.9	14.1	1.3	0.9	0.6	0.9	1.0	1.0	0.9

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

[2] Germ = Visual germination rating (1-9, 1= no germination, 9=fully germinated).

[3] Cover = Visual estimate for percent green coverage.

[4] TQ = Turfgrass quality (1=dead, 9=ideal), a quality rating of 6 is considered acceptable.

Table 4.14 Seeded plot quality data based on irrigation treatment at Location 4 (E. Larpenteur Avenue).

Treatment	8/18[1]	8/18	8/18	8/25	8/25	8/25
	Germ[2]	Cover[3]	TQ[4]	Germ	Cover	TQ
12” above	5.7	13.3	3.7	8.0	56.7 a	4.0 a
12” below	5.7	13.3	3.7	7.7	48.3 bc	4.0 a
18” above	5.7	10.0	3.3	7.7	51.7 ab	3.7 a
18” below	5.7	13.3	3.3	7.7	48.3 bc	3.7 a
overhead	5.3	10.0	4.0	7.7	46.7 bc	4.0 a
control	6.0	10.0	2.3	6.7	41.7 c	2.0 b
LSD	0.9	3.6	0.9	0.93	7.3	0.6

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments [2] Germ = Visual germination rating (1-9, 1= no germination, 9=fully germinated)

[3] Cover = Visual estimate for percent green coverage.

[4] TQ = Turfgrass quality (1=dead, 9=ideal), a quality rating of 6 is considered acceptable.

Table 4.15 Seeded plot quality data based on irrigation treatment at Location 5 (E. Larpenteur Avenue).

Treatment	8/31[1]	8/31	9/8	9/15	9/22	9/29	10/10
	Cover[2]	TQ[2]	TQ	TQ	TQ	TQ	TQ
12" above	71.7 a	3.3	3.0 b	4.3 ab	5.0 ab	4.0 a	4.7 a
12" below	68/3 ab	3.0	3.0 b	4.3 ab	5.3 a	4.3 a	4.7 a
18" above	58.3 abc	3.0	3.7 a	4.7 a	4.7 abc	3.7 a	3.7 b
18" below	55.0 abc	2.7	3.0 b	4.0 ab	4.3 bc	4.0 a	4.0 ab
overhead	53.3 bc	3.0	2.7 b	3.3 bc	4.0 cd	3.7 a	3.7 b
control	45.0 c	2.7	2.0 c	2.3 c	3.3 d	2.7 b	2.7 c
LSD	16.8	1.0	0.6	1.2	0.8	0.8	0.9

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

[2] Cover = Visual estimate for percent green coverage.

[3] TQ = Turfgrass quality (1=dead, 9=ideal), a quality rating of 6 is considered acceptable.

Table 4.16 The effect of soil moisture on Volumetric Water Content (VWC) of sodded plots at Location 1 (Larpenteur Avenue) in 2016.

Treatment	6/7		6/10		6/14		6/17		6/21		6/24		6/28		7/1		7/5		7/11		7/14	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
12" above	27.4 cd	4.1	34.3	3.6	39.3 ab	4.0	36.2 a	4.0	22.1 b	4.9	17.3 b	5.2	8.2 d	3.7	8.7 c	3.1	7.5 c	3.7	29.2 a	4.7	20.8 a	5.7
12" below	30.0 ab	4.4	36.1	3.9	39.7 a	3.7	36.3 a	3.8	20.4 bcd	5.6	16.9 b	7.2	9.4 cd	5.1	10.6 bc	7.3	8.6 bc	5.1	27.8 a	6.9	16.4 bc	5.2
18" above	28.8 bcd	4.7	34.3	4.3	36.7 cd	4.2	35.1 ab	4.9	21.5 bc	3.7	22.9 a	7.5	12.8 ab	5.4	11.9 ab	4.8	10.4 ab	4.5	28.2 a	3.6	17.7 b	4.7
18" below	29.4 abc	4.7	34.4	3.1	38.0 abc	4.5	34.3 b	3.8	19.8 cd	3.1	17.2 b	4.4	11.3 bc	5.0	11.0 bc	4.7	8.1 c	3.0	27.2 a	5.1	14.8 c	4.4
overhead	27.0 d	5.8	33.8	3.5	37.6 bc	3.1	35.0 ab	4.2	19.1 d	6.1	17.5 b	8.2	10.8 bc	6.5	9.7 bc	6.9	8.0 c	5.7	26.8 a	4.3	15.7 bc	5.8
control	31.1 a	3.5	34.6	4.3	35.1 c	3.0	32.4 c	3.1	27.0 a	4.4	21.7 a	4.2	14.7 a	5.3	14.0 a	5.0	11.2 a	4.1	22.7 b	4.3	17.3 b	4.2
LSD	2.1		1.8		1.8		1.9		2.2		2.9		2.4		2.5		2.1		2.4		2.3	

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

[2] AVG = mean volumetric water content. Each data point represents 36 measurements.

[3] SD = standard deviation of volumetric water content. Each data point represents 36 measurements.

Table 4.17 The effect of soil moisture on Volumetric Water Content (VWC) of seeded plots at Location 1 (Larpenteur Avenue) in 2016.

Treatment	6/7		6/10		6/14		6/17		6/21		6/24		6/28		7/1		7/5		7/11		7/14	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
12" above	26.3 ab	3.8	28.8	4.2	31.6	4.3	31.7 ab	4.8	21.3 ab	4.0	20.0 b	6.0	12.0 cd	5.3	12.0 cd	4.9	12.4 c	5.8	29.2 a	4.96	22.6 a	4.0
12" below	25.4 b	3.0	28.6	3.0	30.7	2.7	30.3 ab	3.6	20.0 b	3.1	21.3 b	7.4	14.1 bc	7.8	14.4 bc	8.6	15.4 b	7.6	27.8 a	6.9	26.7 a	3.1
18" above	27.9 a	4.3	30.5	4.3	31.9	4.8	31.5 ab	3.6	23.3 a	5.4	24.6 a	6.4	17.3 a	7.5	21.6 a	7.8	18.4 a	5.3	28.2 a	5.1	23.1 a	4.2
18" below	27.4 a	3.2	29.9	4.8	32.6	5.6	32.3 a	5.6	22.1 a	4.6	22.2 ab	6.3	15.6 ab	6.4	15.1 b	6.7	12.3 c	6.2	27.2 a	5.7	22.7 a	4.7
overhead	25.6 b	3.0	29.2	3.0	33.4	3.8	30.1 b	5.1	17.7 c	5.5	16.8 c	6.1	10.8 d	5.2	10.3 d	5.2	10.9 c	6.5	26.8 a	4.7	21.8 ab	5.0
control	22.9 c	3.9	28.8	3.9	31.4	3.7	25.9 c	3.5	13.9 d	3.6	10.9 d	3.5	7.0 e	2.8	7.0 e	2.1	7.4 d	3.5	22.7 b	4.8	16.3 b	5.1
LSD	1.7		1.8		2.0		2.1		2.0		2.7		2.8		2.9		2.7		2.4		6.2	

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

[2] AVG = mean volumetric water content. Each data point represents 36 measurements.

[3] SD = standard deviation of volumetric water content. Each data point represents 36 measurements.

Table 4.18 The effect of soil moisture on Volumetric Water Content (VWC) of sodded plots at Location 2 (Como Avenue) in 2016.

Treatment	7/5		7/7		7/11		7/14		7/18		7/20		7/25		7/28		8/2		8/8		8/15		8/22	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
12" above	31.7	3.7	31.1	4.2	27.4 cd	4.1	34.3	3.6	39.3 ab	4.0	36.2 a	4.0	22.1 b	4.9	17.3 b	5.2	8.2 d	3.6	8.7 c	3.1	7.5 c	3.7	28.2 ab	3.3
12" below	33.3	4.2	31.7	4.1	30.0 ab	4.4	36.1	3.9	40.0 a	3.7	36.3 a	3.8	20.4 bcd	5.6	16.9 b	7.2	9.4 cd	5.1	10.6 bc	7.3	8.6 bc	5.1	26.2 c	3.2
18" above	31.1	4.3	30.9	3.3	28.8 bcd	4.7	34.3	4.3	36.7 cd	4.2	35.1 ab	4.9	21.5 bc	3.7	22.9 a	7.5	12.8 ab	5.4	11.9 ab	4.8	10.4 ab	4.5	26.5 c	4.2
18" below	31.8	4.0	30.5	4.8	29.4 abc	4.7	34.4	3.1	38.0 abc	4.5	34.3 b	3.8	19.8 cd	3.1	17.2 b	4.4	11.3 bc	5.0	11.0 bc	4.7	8.1 c	3.0	26.6 bc	4.1
overhead	31.3	3.8	29.2	4.1	27.0 d	5.8	33.8	3.5	37.6 bc	3.1	35.0 ab	4.2	19.1 d	6.1	17.5 b	8.2	10.8 bc	6.5	9.7 bc	6.9	8.0 c	5.7	28.2 ab	3.6
control	32.9	2.9	30.8	4.4	31.1 a	3.5	34.6	4.3	35.1 d	3.0	32.4 c	3.1	27.0 a	4.4	21.7 a	4.2	14.7 a	5.3	14.0 a	5.0	11.2 a	4.1	28.7 a	3.3
LSD	2.0		2.0		2.1		1.8		1.8		1.9		2.2		2.9		2.4		2.5		2.1		1.7	

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] AVG = mean volumetric water content. Each data point represents 36 measurements.
[3] SD = standard deviation of volumetric water content. Each data point represents 36 measurements.

Table 4.19 The effect of soil moisture on Volumetric Water Content (VWC) of seeded plots at Location 2 (Como Avenue) in 2016.

Treatment	7/5		7/7		7/11		7/14		7/18		7/20		7/25		7/28		8/2		8/8		8/15		8/22	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
12” above	26.6 bc	3.8	27.2 a	4.0	26.3 ab	3.8	28.8	4.2	31.6	4.3	31.7 ab	4.8	21. 3 ab	4.0	20.0 b	6.0	12.0 cd	5.3	21.0 cd	4.8	12.4 c	5.9	26.8 c	4.4
12” below	26.8 bc	4.3	26.3 a	3.7	25.4 b	3.0	28.6	3.0	30.7	2.7	30.3 ab	3.6	20.0 b	3.1	21.3 b	7.4	14.1 bc	7.8	14.4 bc	8.6	15.4 b	7.6	27.4 bc	3.2
18” above	28. 2 ab	5.3	28.1 a	5.2	27.9 a	4.3	30.5	4.3	31.9	4.8	31.5 ab	3.6	23.3 a	5.4	24.6 a	6.4	17.3 a	7.5	21.6 a	7.8	18. 3 a	5.3	29.0 ab	3.7
18” below	29.0 a	5.1	28.0 a	5.8	27.4 a	3.2	29.9	4.8	32.6	5.6	32.3 a	5.6	22.1 ab	4.6	22.2 ab	6.3	15.6 ab	6.4	15.1 b	6.7	12.3 c	6.2	27.1 c	4.6
overhead	27.6 ab	5.4	26.2 a	4.1	25.6 b	3.0	29.2	3.0	33.4	3.8	30.1 b	5.1	17.7 c	5.5	16.8 c	6.1	10.8 d	5.2	10.3 d	5.2	10.9 c	6.5	28.5 abc	3.7
control	24.7 c	4.3	23.8 b	4.1	22.9 c	3.9	28.8	3.9	31.4	3.7	25.9 c	3.5	13.9 d	3.6	10.9 d	3.5	7.0 e	2.8	7.0 e	2.1	7.4 d	3.5	29.3 a	3.6
LSD	2.2		2.1		1.7		1.8		2.0		2.1		2.0		2.7		2.8		2.9		2.7		1.8	

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

[2] AVG = mean volumetric water content. Each data point represents 36 measurements.

[3] SD = standard deviation of volumetric water content. Each data point represents 36 measurements.

Table 4.20 The effect of soil moisture on Volumetric Water Content (VWC) of sodded plots at Location 3 (TROE) in 2016.

Treatment	8/5		8/12		8/22		8/25		9/1		9/8		9/15		9/26	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
	---Volumetric water content (%)---															
12” above	46.4 a	6.8	47.7	5.4	50.5 a	4.6	47.6 a	4.9	51.4 a	3.7	54.2 a	4.5	46.5 a	3.9	55.5 a	3.3
18” above	45.5 a	5.7	47.9	6.3	46.5 b	6.1	42.0 b	4.9	44.0 b	6.3	47.2 b	4.1	42.6 b	6.4	51.5 b	3.4
control	42.4 b	6.6	47.0	5.9	42.1 c	5.2	38.3 c	5.1	35.9 c	5.3	44.3 c	4.1	30.6 c	4.4	47.5 c	3.0
LSD	2.9		2.0		2.0		2.3		2.5		2.0		2.1		1.5	

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

[2] AVG = mean volumetric water content. Each data point represents 36 measurements.

[3] SD = standard deviation of volumetric water content. Each data point represents 36 measurements.

Table 4.21 The effect of soil moisture on Volumetric Water Content (VWC) of sodded plots at Location 4 (Maplewood) in 2017.

Treatment	7/10		7/17		7/24		8/1		8/8		8/14		8/21		8/28	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
	----Volumetric water content (%)----															
12" above	43.4 a	9.3	39.5 ab	7.6	37.7 a	8.5	23.7 b	4.2	40.5 a	8.1	45.8 bc	4.2	42.6 b	5.2	36.1 a	6.8
12" below	26.7 b	8.5	35.5 c	5.5	31.3 b	5.3	24.8 b	4.6	28.6 c	6.8	44.3 c	4.0	40.3 b	5.7	31.4 c	4.9
18" above	45.2 a	7.3	41.8 a	6.7	40.1 a	7.1	28.5 a	5.5	40.6 a	5.5	49.4 a	3.1	47.6 a	5.1	37.4 a	5.3
18" below	44.3 a	11.5	43.0 a	11.1	40.3 a	10.5	24.6 b	5.8	42.5 a	9.4	46.8 b	3.4	41.2 b	5.8	38.6 a	7.9
overhead	32.9 b	10.7	36.4 bc	6.0	32.5 b	6.6	21.2 c	4.2	36.2 b	8.1	45.4 bc	3.2	41.8 b	5.2	34.3 bc	6.5
control	44.9 a	7.8	41.9 a	6.8	37.9 a	7.3	19.3 c	5.1	41.1 a	6.5	42.1 d	3.6	34.5 c	5.0	38.8 a	6.4
LSD	4.3		3.5		3.5		2.1		3.5		1.7		2.4		3.0	

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] AVG = mean volumetric water content. Each data point represents 36 measurements.
[3] SD = standard deviation of volumetric water content. Each data point represents 36 measurements.

Table 4.22 The effect of soil moisture on Volumetric Water Content (VWC) of seeded plots at Location 4 (Maplewood) in 2017.

Treatment	7/10		7/17		7/24		8/1		8/8		8/14		8/21		8/28	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
	--------Volumetric water content (%)--------															
12" above	42.1 abc	7.2	39.6 cd	7.8	37.6 b	6.2	22.9 bc	3.0	40.8 a	5.6	40.0 b	3.0	39.5 b	3.2	37.3 a	4.9
12" below	39.7 c	8.7	37.8 d	5.8	32.4 b	6.9	23.3 b	4.5	30.3 b	7.6	39.7 b	3.4	39.6 b	4.2	31.8 b	7.0
18" above	44.7 ab	13.3	42.7 bc	12.1	37.8 b	11.8	27.9 a	4.8	42.6 a	11.1	42.3 a	2.9	43.1 a	3.3	38.0 a	7.7
18" below	48.7 a	6.5	47.0 a	6.1	45.2 a	6.8	24.4 b	5.5	43.6 a	8.4	40.8 ab	3.4	38.1 b	5.0	40.0 a	6.1
overhead	42.1 bc	11.9	42.1 bc	6.4	38.6 b	8.0	20.9 c	3.9	41.5 a	9.2	40.3 b	3.1	39.2 b	3.0	38.2 a	6.0
control	44.0 b	11.4	43.2 b	8.2	39.1 c	7.8	14.7 d	6.2	40.2 a	6.9	39.8 b	4.9	31.8 c	3.4	37.2 a	6.6
LSD	4.4		3.6		3.6		2.2		3.7		1.6		1.7		3.0	

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

[2] AVG = mean volumetric water content. Each data point represents 36 measurements.

[3] SD = standard deviation of volumetric water content. Each data point represents 36 measurements.

Table 4.23 The effect of soil moisture on Volumetric Water Content (VWC) of sodded plots at Location 5 (E Larpenteur) in 2017.

Treatment	8/14		8/21		8/28		9/4		9/11		9/18		9/25		10/2		10/10		10/17	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
12" above	29.4 ab	4.6	34.7 b	3.8	35.3 a	6.2	28.8 b	5.8	11.7 cd	3.9	23.3 a	6.0	31.0	4.2	27.0 d	4.0	34.4 b	3.6	39.6 a	4.0
12" below	27.3 c	3.5	37.5 a	6.1	30.9 b	4.3	29.8 b	5.8	13.1 bc	5.1	25.2 a	6.1	32.1	4.0	30.5 bc	4.4	36.5 a	3.8	40.1 a	3.8
18" above	29.8 a	4.2	37.6 a	4.0	33.5 a	4.2	32.8 a	5.1	16.6 a	6.4	25.2 a	5.3	31.2	3.4	29.0 bc	4.7	34.0 b	4.6	36.6 bc	4.7
18" below	27.6 bc	3.6	39.2 a	3.6	33.9 a	4.4	32.1 ab	4.2	14.9 ab	5.5	24.0 a	6.1	30.0	4.8	29.0 bc	5.1	33.6 b	3.8	37.4 b	4.7
overhead	29.1 abc	5.6	39. 3 a	7.2	34.1 a	8.7	30.6 b	10.1	10.2 d	5.1	23.6 a	7.4	29.5	4.2	27.2 cd	5.9	34.0 b	3.2	37.9 b	3.0
control	29.2 ab	3.8	25.0 c	4.5	30.8 b	9.0	8.6 c	7.4	3.7 e	1.0	13.4 b	2.9	30.7	4.3	31.0 a	3.4	34.3 b	4.1	35.2 c	2.9
LSD	1.8		2.3		2.1		2.0		2.0		2.3		1.7		1.9		1.6		1.6	

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] AVG = mean volumetric water content. Each data point represents 36 measurements.
[3] SD = standard deviation of volumetric water content. Each data point represents 36 measurements.

Table 4.24 The effect of soil moisture on Volumetric Water Content (VWC) of seeded plots at Location 5 (E Larpenteur) in 2017.

Treatment	8/14		8/21		8/28		9/4		9/11		9/18		9/25		10/2		10/10		10/17	
	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD	AVG	SD
12" above	29.6 a	4.9	31.9 ab	3.6	32.3 b	7.7	29.1 ab	4.3	16.3 ab	5.2	27.8 a	5.4	27.0 a	4.2	26.0 bc	3.8	29.0	4.1	31.7 a	4.0
12" below	28.4 ab	4.5	30.5 b	5.4	36.9 a	6.1	27.4 bc	6.0	16.6 a	6.8	26.0 ab	5.7	26.3 a	3.7	25.4 c	2.8	28.5	3.0	30.8 b	2.6
18" above	29.4	2.6	33.4 a	4.5	35.8 a	5.8	30.8 a	4.7	18.6 a	8.3	27.8 a	6.6	28.1 a	4.9	27.9 a	4.4	30.6	4.1	32.2 ab	4.5
18" below	27.1 ab	2.4	30.9 b	4.5	37.4 a	5.1	29.2 ab	6.2	14.4 a	6.7	25.7 ab	5.8	27.9 a	5.4	27.1 ab	2.9	29.6	4.7	32.3 ab	5.3
overhead	29.4 a	2.9	30.7 b	5.8	28.2 c	6.5	26.8 c	6.1	14.1 b	7.3	25.0 b	5.8	26.3 a	3.9	26.0 bc	3.0	29.3	3.2	33.5 a	3.6
control	29.8 a	2.6	24.8 c	4.5	30.2 bc	6.5	10.2 d	5.5	3.2 c	2.5	18.7 c	4.2	24.4 b	4.3	23.7 d	4.4	29.4	3.7	31.7 b	3.4
LSD	1.5		2.1		2.0		2.1		2.4		2.2		1.8		1.5		1.6		1.7	

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments
[2] AVG = mean volumetric water content. Each data point represents 36 measurements.
[3] SD = standard deviation of volumetric water content. Each data point represents 36 measurements.

Table 4.25 Shear strength values for seed and sod plots at Locations 1, 2, 4, and 5.

Treatment	**Location 1 - W Larpenteur**		**Location 2 - Como**		**Location 4 - Maplewood**		**Location 5 - E Larpenteur**	
	Sod[1]	Seed	Sod	Seed	Sod	Seed	Sod	Seed
	Shear strength (N m)							
12" above	28.8 a	10.6	21.5	11.6	23.7 a	13.7	26.4 a	16.5 b
12" below	28.2 a	12.2	22.2	11.7	23.5 a	16.8	26.6 a	19.1 a
18" above	26.9 a	12.4	23.2	11.0	24.4 a	13.8	25.4 a	16.4 b
18" below	25.1 a	12.3	22.4	16.1	25.5 a	12.9	23.4 a	16.4 b
overhead	23.9 a	12.8	22.7	12.9	22.6 a	13.7	24.2 a	15.0 b
control	13.9 b	9.9	19.8	15.4	10.7 b	13.9	12.4 b	11.4 c
LSD	8.5	4.6	4.4	4.3	3.3	3.9	3.4	2.5

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

Table 4.26 Grid count coverage ratings 60 days after planting of percent turf, weed, or bare soil for seeded plots at Locations 1, 2, 4, and 5.

Treatment	**Location 1 - W Larpenteur**			**Location 2 - Como**			**Location 4 - Maplewood**			**Location 5 - E Larpenteur**		
	Turf[1]	Weed	Bare	Turf	Weed	Bare	Turf	Weed	Bare	Turf	Weed	Bare
	----------Percent cover----------											
12" above	48.7 a	44.4 b	5.1	33.1	55.8 b	11.1	43.1 a	49.8 b	7.1	60.7	33.1	6.2
12" below	64.7 a	26.4 b	8.9	36.2	44.7 bc	19.1	40.0 a	46.7 b	13.3	58.9	30.7	10.4
18" above	63.1 a	26.0 b	10.4	38.4	36.2 c	25.3	54.2 a	28.4 b	17.3	66.7	19.8	13.6
18" below	46.2 a	43.1 b	10.7	31.3	51.3 bc	17.3	38.2 a	49.8 b	12.0	61.3	28.9	9.8
overhead	55.1 a	37.6 b	7.3	39.8	42.4 bc	17.8	48.4 a	40.4 b	11.1	58.0	28.0	14.7
control	14.7 b	74.2 a	11.1	14.2	74.9 a	10.9	10.7 b	85.3 a	4.0	38.9	50.9	10.2
LSD	28.5	27.6	17.8	18.3	18.8	18.4	27.5	31.5	11.5	27.8	29.1	7.0

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

Table 4.27 Grid count coverage ratings 60 days after planting of percent turf, weed, or bare soil for sodded plots at Locations 1, 2, 4, and 5.

Treatment	**Location 1 - W Larpenteur**			**Location 2 - Como**			**Location 4 - Maplewood**			**Location 5 - E Larpenteur**		
	Turf[1]	Weed	Bare	Turf	Weed	Bare	Turf	Weed	Bare	Turf	Weed	Bare
	----------Percent cover----------											
12" above	85.3 a	13.8	0.9 b	94.2 a	5.1 b	0.7 b	91.6 a	8.4 b	0.0 b	91.6 a	7.1 b	0.9 bc
12" below	63.1 a	34.9	2.0 b	91.3 a	8.2 b	0.4 b	86.7 a	13.3 b	0.0 b	90.7 a	9.3 b	0.4 c
18" above	75.1 a	23.3	1.6 b	94.4 a	5.6 b	0.0 b	90.2 a	9.8 b	0.0 b	91.6 a	7.1 b	2.0 bc
18" below	82.9 a	16.0	1.1 b	92.4 a	7.1 b	0.4 b	89.8 a	9.8 b	0.4 b	89.6 a	8.9 b	2.0 bc
overhead	76.7 a	19.6	3.1 b	84.4 a	9.1 b	6.4 b	85.3 a	14.7 b	0.0 b	83.8 a	10.9 b	7.6 b
control	24.9 b	44.9	30.2 a	37.3 b	24.4 a	38.2 a	30.2 b	37.3 a	32.4 a	53.1 b	24.4 a	23.1 a
LSD	28.1	27.1	7.1	10.6	11.2	9.1	14.0	15.3	2.3	14.1	10.3	6.8

[1] Means within a column followed by a similar letter are not significantly different (α =0.05). Columns containing no letter groupings resulted in no significant differences among treatments

Table 4.28 The total amount and cost of water used by location for watering for 60 days.

Parameter	Location 1 – W Larpenteur Ave	Location 2 – Como Ave	Location 3 – TROE	Location 4 – Maplewood	Location 5 – E Larpenteur Ave
Total gallons of water used	14,212	19,467	14,513	23,175	10,575
Gal/1000 ft^2 [1]	6,316	3,933	4,031	4,682	4,700
Gal/yd^2 [2]	702	437	448	520	522
Total cost of water used	$52.06	$71.57	$53.36	$85.20	$38.88
Cost of water to irrigate 1000 ft^2	$23.14	$14.46	$14.82	$17.21	$17.28
Cost of water to irrigate 1 yd^2 [2]	$0.21	$0.13	$0.13	$0.16	$0.16

[1] Because plot area varied from location to location, gallons per 1000 ft^2 of plot space is presented.

[2] Square yard units are also presented as they are a commonly specified DOT unit.

Table 4.29 Rainfall events during irrigation treatments for each of the five testing locations.

Location 1 - W Larpenteur Ave		Location 2 - Como Ave		Location 3 - TROE		Location 4 - Maplewood		Location 5 - E Larpenteur Ave	
Date	**Amount (in)**	**Date**	**Amount (in)**	**Date**	**Amount (in)**	**Date**	**Amount (in)**	**Date**	**Amount (in)**
5/23/16	0.01	7/1/16	0.04	8/4/16	1.52	7/6/17	0.02	8/9/17	0.40
5/25/16	0.32	7/5/16	1.71	8/10/16	1.91	7/9/17	0.09	8/10/17	0.26
5/26/16	0.26	7/7/16	0.05	8/11/16	1.05	7/12/17	0.12	8/13/17	0.90
5/27/16	0.28	7/10/16	0.24	8/12/16	0.22	7/17/17	0.93	8/14/17	0.53
5/28/16	0.18	7/11/16	0.01	8/16/16	1.63	7/18/17	0.12	8/16/17	2.22
5/31/16	0.03	7/12/16	0.07	8/17/16	0.01	7/19/17	0.72	8/17/17	0.12
6/3/16	0.17	7/14/16	0.12	8/18/16	0.01	7/20/17	0.01	8/18/17	0.02
6/4/16	0.07	7/15/16	0.04	8/19/16	0.63	7/21/17	0.01	8/21/17	0.08
6/6/16	0.06	7/16/16	0/17	8/20/16	0.33	7/25/17	0.46	8/25/17	0.42
6/8/16	0.04	7/17/16	0.08	8/23/16	1.00	7/26/17	0.73	8/26/17	0.94
6/9/16	0.71	7/20/16	0.01	8/24/16	0.11	8/3/17	1.17	8/27/17	0.12
6/10/16	0.01	7/21/16	0.13	8/27/16	0.05	8/5/17	0.05	8/30/17	0.01
6/12/16	0.34	7/23/16	1.04	8/28/16	0.02	8/6/17	0.17	9/2/17	0.01
6/13/16	0.54	7/27/16	1.19	8/29/16	0.04	8/7/17	0.01	9/4/17	0.09
6/14/16	1.48	8/4/16	1.52	8/30/16	0.35	8/9/17	0.32	9/18/17	0.33
6/15/16	0.01	8/10/16	1.91	9/4/16	0.01	8/10/17	0.38	9/20/17	0.27
6/19/16	0.03	8/11/16	1.05	9/5/16	0.53	8/13/17	1.11	9/24/17	0.01
6/20/16	0.02	8/12/16	0.22	9/6/16	1.24	8/14/17	0.45	9/25/17	0.76
6/22/16	0.02	8/16/16	1.63	9/7/16	0.01	8/16/17	1.15	9/26/17	0.12
6/30/16	0.12	8/17/16	0.01	9/9/16	0.13	8/17/17	0.21	10/1/17	0.12
7/1/16	0.04	8/18/16	0.01	9/15/16	0.76	8/18/17	0.04	10/2/17	1.47
7/5/16	1.71	8/19/16	0.63	9/16/16	0.01	8/21/17	0.12	10/3/17	0.14
7/7/16	0.05	8/20/16	0.33	9/19/16	0.03	8/25/17	0.46	10/6/17	0.64
7/10/16	0.24	8/23/16	1.00	9/20/16	0.01	8/26/17	0.93	10/7/17	0.19
7/11/16	0.01	8/24/16	0.11	9/21/16	1.23	8/27/17	0.21		
7/12/16	0.07	8/27/16	0.05	9/22/16	0.32				
7/14/16	0.12	8/28/16	0.02	9/23/16	0.26				
7/15/16	0.04	8/29/16	0.04	9/24/16	0.01				
7/16/16	0.17			9/25/16	0.18				
7/17/16	0.08			9/27/16	0.08				
Total	7.23		13.43		13.69		9.99		10.17
30 year avg[1]	7.49		7.83		6.74		8.30		6.44

[1] Twin City 30-year average was calculated for the duration that the irrigation systems were supplying water for each location.

CHAPTER 5: DEVELOPMENT OF ONLINE EDUCATION AND TRAINING FOR INSTALLATION AND MANAGEMENT OF ROADSIDE TURFGRASSES

We created an online course to educate contractors and other personnel on the successful practices for installation and management of roadside turfgrasses. Our team developed this educational content based on the other objectives of this project as well as previous MnDOT-funded projects. We collaborated with The College of Continuing and Professional Studies (CCAPS) to use Canvas, a learning management system at the University of Minnesota, as the platform for the course (Figure 5.1). Prior to publishing, the course went through beta testing with several stakeholders and that input was been used to make improvements to the course. We also advertised the course by emailing prospective students, placing a permanent menu link on our project website (turf.umn.edu), posting a blog (https://turf.umn.edu/news/new-online-training-offered-installation-and-management-roadside-turfgrass), tweeting information on Twitter, and presenting a poster at the ASA-CSSA-SSSA meeting in San Antonio, TX on November 13, 2019 (https://www.acsmeetings.org).

Information about the course for the public and registration information can be found at https://ccaps.umn.edu/roadside-turfgrass. We anticipate that this course will serve as an excellent continuing education opportunity for roadside turfgrass installers for years to come.

5.1 COURSE MODULES

The course is divided into eleven separate modules designed for students to complete sequentially at their convenience. However, the deadline for completion is one year from when they initially registered.

5.1.1 Module 1: Roadside Vegetation Management in Minnesota

Module 1 is an introduction to roadsides, which represent a large area of managed vegetation often planted to turfgrasses. Students learn about the stresses, particularly salt application, that present a challenge for growing turfgrasses on roadsides. Activities in this module include watching a presentation, reading an article on Minnesota's efforts to reduce sodium chloride use, and taking a quiz.

After completing this module, students should be able to:

- List several reasons that turfgrasses are used along roadsides
- Describe the types of stresses that cause turfgrasses to decline along roadsides
- Explain how high levels of sodium chloride affect both the soil and the turfgrass plant
- Discuss trends in road salt use in the U.S.

5.1.2 Module 2: Turfgrass Selection for Roadsides in the Northern U.S.

In this module, students learn about the major turfgrasses species that can be found on roadsides in temperate climates such as the northern United States. Activities include watching a presentation, reading a MnDOT research report on salt-tolerant sod mixtures, using an online learning tool to learn some basic turfgrass identification and taking a quiz.

After completing this module, students should be able to:

- List the cool-season turfgrass species used on roadsides
- Describe primary identification characteristics of Kentucky bluegrass, perennial ryegrass, tall fescue and fine fescues
- Explain turfgrass attributes that are useful in a roadside turfgrass installation
- Describe the primary differences between traditional DOT roadside grass recommendations and new research results

5.1.3 Module 3: Soil Preparation for Roadsides

Soil preparation is a fundamental step in ensuring a successful turfgrass establishment and many of roadside turfgrass issues can be traced to poor soil conditions. This module provides an overview of the basics of soil preparation, the do's and don'ts of soil preparation and soil testing. Activities include watching a presentation, reading an article on site stabilization, reviewing soil test results, and taking a quiz.

After completing this module, students should be able to:

- List the important steps of soil preparation in turfgrass establishment
- Describe the benefits of soil testing for turfgrass establishment and maintenance
- Explain how to take a soil test

5.1.4 Module 4: Seeding Roadsides

This module covers the process of seeding a roadside, which is critical to both short- and long-term success. Students learn how to determine when and where to seed, along with the many steps needed to accomplish a successful roadside seeding. Activities include watching a presentation, watching a video on seeding rate calculation, reading a report on best management practices for establishing roadside turfgrasses, reading a publication on finding the right grass seed, visiting the Minnesota Department of Agriculture webpage on seed selling and labeling, and taking a quiz.

After completing this module, students should be able to:

- List considerations that should be made before seeding a site
- Compare and contrast sodding and seeding as roadside establishment options
- Compare germination and establishment rates of Kentucky bluegrass, perennial ryegrass, tall fescue, and fine fescues

- Describe the process of seeding a roadside
- Define three types of seeding
- Calculate the amount of seed needed for a roadside turfgrass establishment

5.1.5 Module 5: Sodding Roadsides

Sod is often planted on roadsides as a means of immediate soil stabilization and turf coverage. This module covers the many advantages and potential disadvantages of sodding to establish turf on roadsides. Installation procedures and post-sodding care information are also provided. Activities include watching a presentation, reading an article on the best management practices for establishing salt-tolerant grasses on roadsides, reading about the Sod Quality Assurance Program on Minnesota Crop Improvement Association website, reading an article on how to establish a lawn from sod, and taking a quiz.

After completing this module, students should be able to:

- Discuss the advantages and disadvantages of planting sod on roadsides
- Describe the basic considerations prior to conducting a sodding project
- Demonstrate understanding of sod certification and the sod quality assurance program
- Discuss what to look for when assessing sod quality
- Describe sod installation guidelines
- Develop a post-sodding management program

5.1.6 Module 6: Mowing Principles and Practices

There are a variety of mowing strategies based on the site, turfgrass species, and roadside vegetation goals. In this module, students are provided with the principles of mowing practices for turfgrass, as well as an overview of the various mowing equipment available. Activities include watching a presentation, reading an article on benefits of recycling grass clippings, reading research on how to select turfgrasses and management practices to reduce mowing, reviewing how to develop improved mowing procedures, and taking a quiz.

After completing this module, students should be able to:

- Discuss the principles of mowing turfgrasses
- Describe the mechanical technology used for turfgrass mowing
- Establish a framework for the development of sustainable mowing strategies
- Demonstrate understanding of government regulations regarding mowing
- Develop a vegetation removal program for the maintenance of roadsides in temperate climates

5.1.7 Module 7: Irrigation

Irrigation of roadside turfgrasses is often necessary during the establishment process, whether utilizing sod or seed. In this module, students are provided with an overview of the important considerations when irrigating turfgrasses, as well as recommendations when irrigating roadside establishments. Activities include watching a presentation, reading articles on irrigation and turf water requirements, and taking a quiz.

After completing this module, students should be able to:

- Discuss soil moisture dynamics, including: soil water concepts, evapotranspiration, and replacement of water lost
- Discuss tools that can be used to effectively measure irrigation requirements
- Design a watering program for the successful establishment of roadside grasses
- Evaluate strategies to irrigate roadsides

5.1.8 Module 8: Fertilization of Roadsides

Fertilization is an important step for roadside turfgrass establishment and maintenance. This module will cover the basics of turf fertilization, including essential plant nutrients, common fertilizers and delivery mechanisms used, fertilization mathematics, and responsible fertilization practices. Activities include watching a presentation, watch a video on fertilizer calculations, reading an article on fertilizing lawns, and taking a quiz.

After completing this module, students should be able to:

- Identify proper and improper fertilization practices
- Describe the benefits of proper fertility on roadside turfgrass establishment and maintenance
- Demonstrate understanding of Minnesota's Phosphorus Law and how it relates to fertilizing roadsides
- Calculate the amount of fertilizer needed for a turf area
- Develop a fertility program for establishing a roadside area

5.1.9 Module 9: Weed Control for Roadsides

Weeds can negatively affect the maintenance and use of roadsides. This module will help students with understanding weed biology and ecology to help prevent their spread in turf stands. Activities include watching a presentation, reading an article on control of broadleaf weeds, learning to identify weeds, and taking a quiz.

After completing this module, students should be able to:

- Describe the importance of weed control on turfgrass establishment and maintenance
- Explain the effect of weed biology on weed control in turf
- Identify the ideal control method for particular problematic weeds on roadsides
- Develop a weed management program for maintaining a roadside area

5.1.10 Module 10: Diagnosing and Managing Problems

Roadsides often present many challenges, such as poor soils, a general lack of maintenance inputs, and many additional stresses such as deicing salts and areas the heat up due to impervious surfaces. In this module students will learn to diagnose and manage roadside turfgrass problems. Activities include watching a presentation, using a turfgrass identification tool, working through a checklist on diagnosing turf problems, reading an article on management of abiotic problems, and taking a quiz.

After completing this module, students should be able to:

- Discuss the common abiotic (non-living) and biotic (living) turfgrass problems experienced on roadsides
- Describe potential management strategies to overcome or reduce problems
- Establish a framework diagnosing both abiotic and biotic problems

5.1.11 Module 11: Case Study and Post Test

Once students have covered the many factors that go into a successful roadside turfgrass establishment, they will practice what they've learned. Activities include completing a case study, taking a post-course test, and completing a course evaluation.

After completing this module, students should be able to:

- Discuss the site conditions of a new roadside sod installation in case study site location/s
- Give recommendations to remedy issues of the site/s
- Demonstrate understanding of installation and management of roadside turfgrasses

5.2 COURSE STATISTICS

The online course “Installation and Management of Roadside Turfgrasses” has been accepting registrants since November 2018 (almost a year at the time of this writing). As of October 2019, 68 students have registered to take the course. Students have up to a year to complete the course. Certificates of course completion are provided to students if they request one and have a total score of 140 points (75%) or more in the course. Seven students have finished the course with the average final score of these students being 88%. Of the 14 students who have taken the pre-and post-course tests, the average score on the pre-test was 67% and the average post-test score was 81%, indicating a gain in knowledge. Our program will continue to offer this course with the goal of increasing roadside turfgrass establishment success in Minnesota and other northern regions.

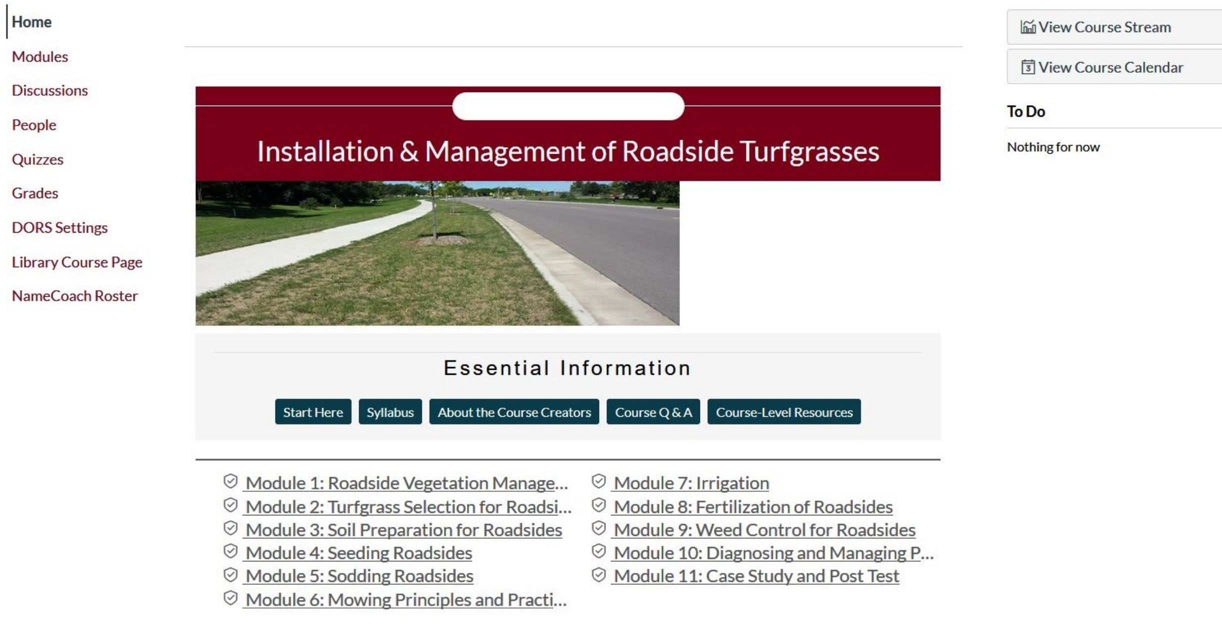

Figure 5.1 Canvas site with Installation and Management of Roadside Turfgrasses online course.

CHAPTER 6: DEVELOPMENT OF EDUCATIONAL AND WEBSITE CONTENT FOR PRIVATE OWNERS

Communicating research is an important aspect of our work. To convey the MnDOT research and outreach materials our team has developed, we have created a dedicated roadside turf website (http://roadsideturf.umn.edu) as part of our now completed Regional Roadside Turfgrass Testing Program project (http://www.cts.umn.edu/Publications/ResearchReports/reportdetail.html?id=2872).

For this latest project we have added a link, the Online Professional Education tab on the main menu (Figure 6.1), that leads to the roadside turfgrass management course (see Chapter 5 of this report). We have also added an entirely new section to the website specifically for homeowner roadside turfgrass education, which is described in more detail below.

6.1 HOMEOWNER EDUCATIONAL CONTENT

When homeowners are tasked with maintaining newly installed roadside turf, it may be overwhelming, particularly for those without basic plant knowledge. Common mistakes include improper watering, mowing, fertilizing and weed control. We developed a section called Homeowner Education (http://roadsideturf.umn.edu/homeowner-education) to address these issues on our Roadside Turf website. Homeowners can follow each of the lessons sequentially to learn many aspects of turfgrass management or they can go to individual lessons when they have questions on a single topic. The lessons consist of overviews of the topics, numerous videos and other resources. The lesson on maintaining boulevard turfgrass includes a video developed by The Minnesota Local Road Research Board and SRF Consulting called *Growing Green Grass Along Your Street: How To Maintain Residential Boulevard Turfgrass*. The lessons are:

1. Introduction - http://roadsideturf.umn.edu/homeowner-education
2. Maintaining boulevard turfgrass - an overview - http://roadsideturf.umn.edu/homeowner-education/maintaining-boulevard-turfgrass-overview
3. Grasses used in roadsides - http://roadsideturf.umn.edu/homeowner-education/grasses-used-roadsides
4. Managing a newly established roadside - http://roadsideturf.umn.edu/homeowner-education/managing-newly-established-roadside
5. Fertilizing a roadside lawn - http://roadsideturf.umn.edu/homeowner-education/fertilizing-roadside-lawn
6. Mowing a roadside lawn - http://roadsideturf.umn.edu/homeowner-education/mowing-roadside-lawn
7. Watering a roadside lawn - http://roadsideturf.umn.edu/homeowner-education/watering-roadside-lawn
8. Weeds in the roadside lawn – http://roadsideturf.umn.edu/homeowner-education/weeds-roadside-lawn

9. What if the turf that was installed fails? - http://roadsideturf.umn.edu/homeowner-education/what-if-turf-was-installed-fails

6.2 CONCLUSION

We will continue to maintain and add roadside turf content to this website to benefit both researchers and homeowners. We will also monitor the number of website visits via Google Analytics.

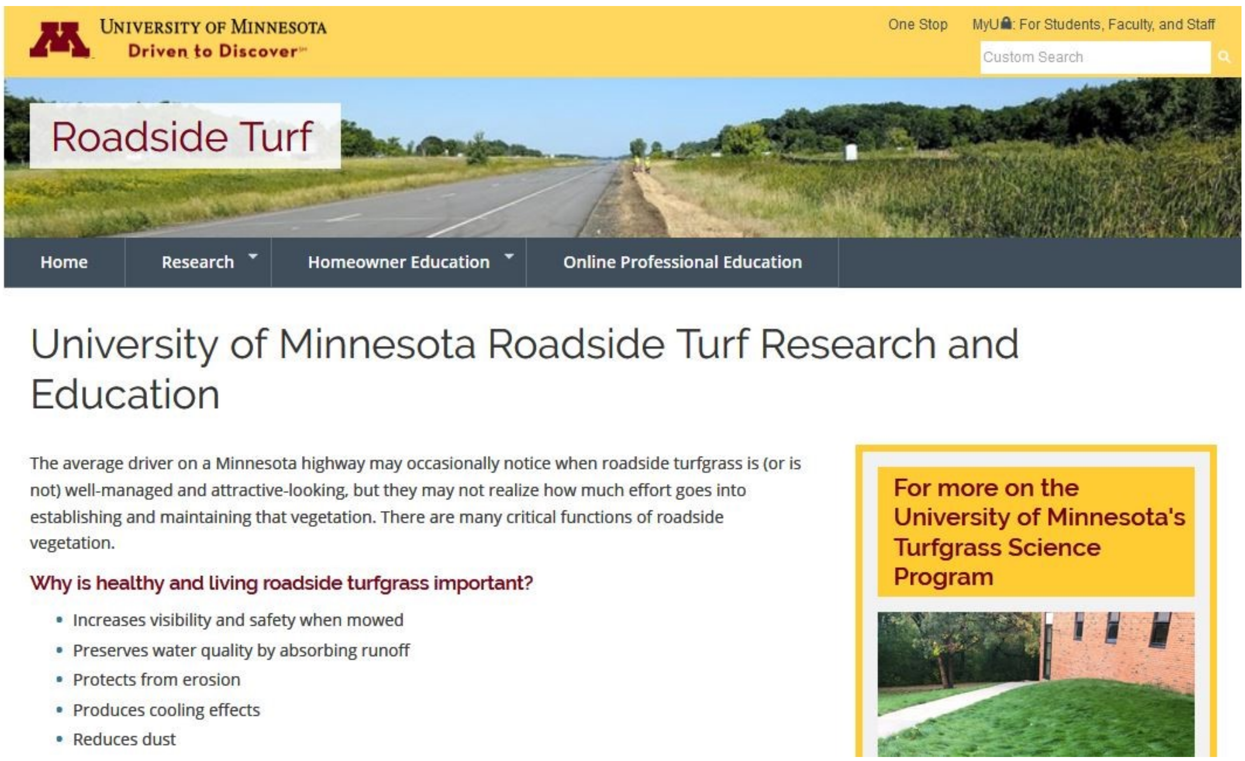

Figure 6.1 The University of Minnesota's Roadside Turf website.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

Our project was based on the need to water new roadside installations more efficiently to ensure that the turfgrasses, especially the new salt-tolerant mixes, establish more successfully without wasting water.

We found that a non-permanent irrigation system using water from a fire hydrant was the ideal approach for watering roadside turfgrass. We tested a number of different options for this type of system and found few differences in germination rates, coverage, or turf quality between the 12-inch (30.5-cm) and 18-inch (45.7-cm) irrigation tape or when the tape was laid above the sod or germination blanket or below. Should contractors choose to use a hydrant adapter with a programmable irrigation system, 18-inch (45.7-cm) irrigation tape laid above the germination blanket (when seeding) or above sod is recommended. The use of an 18-inch (45.7-cm) irrigation tape placed above the turf surface was easier and cheaper to install, could be removed and possibly reused after establishment, and will result in reduced water use.

If an irrigation system is not viable for a site, we found that for water trucks, the two nozzles that show the most promise for efficiently irrigating roadsides are the Niece fan nozzle and the Pancake adjustable nozzle.

We developed unique educational materials on roadside turfgrass management for both installers and homeowners. We recommend that MnDOT personnel and professionals involved in roadside management use and promote these materials to further the goals of better roadside establishment by installers and better roadside maintenance by homeowners.

We have provided a workable alternative for watering roadside turfgrass installations. Continued innovation by those using this system should result in even better efficiency with reduced costs. Public agencies will need to consider changes to the contracting process if this type of system is to become commonplace for new installations.

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