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BIOSOLIDS AS A ROADSIDE SOIL AMENDMENT

BY

EDWIN M. FAVA III

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE

REQUIREMENTS FOR THE DEGREE OF

MASTER OF SCIENCE

IN

BIOLOGICAL AND ENVIRONMENTAL SCIENCE

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MASTER OF SCIENCE IN BIOLOGICAL AND ENVIRONMENTAL SCIENCE
THESIS
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ABSTRACT

Vegetation is a critical component of the roadside environment. It supplies services that include stabilizing soil, filtering runoff, trapping debris before it enters drains and water supplies, and providing visually appealing scenery for roadway users. These services are threatened when soil is unable to provide an environment suitable to the needs of perennial vegetation, leading to annual, often invasive, species that out-compete and thrive in dry, low nutrient and disturbed habitats dominating the environment. As a means of improving the availability of the macronutrient nitrogen, a limiting nutrient for many plants, we amended roadside soil in Saunderstown, Rhode Island with seven different products: five stabilized biosolids (products whose organic material consisted only of sewage sludge) and two composts (products whose organic material consisted either partially or completely of yard waste). The biosolids were applied at rates of 48 kg N/ha, 144 kg N/ha and 288 kg N/ha (nitrogen available in the first year) while the composts were applied at rates of 15%, 30% and 45% v:v of the first 15 cm of the soil. Control plots received no fertilization beyond the 95.2 kg/ha of 19-19-19 fertilizer included in the hydroseeding mixture. All plots were hydroseeded in September 2012 with a seed mixture of Kentucky bluegrass (*Poa pratensis*), perennial ryegrass (*Lolium perenne*) and red fescue (*Festuca rubra*). Quality of the vegetation within the plots amended with biosolids one year after planting indicated that soil would provide sufficient nitrogen without posing a significant leaching risk. However, results two years after planting indicated that the composts were a better source of long-term nitrogen and soil organic matter compared to biosolids. The vegetation on biosolids amended plots demonstrated a vulnerability to drought-

induced senescence due to low soil moisture associated with insufficient soil organic matter. By the end of the second year, no biosolids-amended plots had turfgrass quality significantly differing from the control plots, while all compost-amended plots had significantly better quality than the control. A combination of composts and biosolids products applied in a manner that increases soil organic matter levels to the already recommended 5% while providing 144 kg N/ha of first-year available nitrogen should provide sufficient short-term and long-term nitrogen to support persistent growth of planted perennial species.

Two surveys of the study area, conducted in June and September of 2014, measured how the relative coverage of planted species versus weed species and perennial species versus annual species varied based on amendment and, rate of amendment application, and distance from the road. With the exception of the WRB (anaerobically digested biosolids) amended plots monitored in September 2014 (33% relative planted coverage), all other amendments and rates assessed in June 2014 (39% - 61% relative planted coverage) and September 2014 (35% - 45% relative planted coverage) had significantly greater relative coverage of planted species than the control (June 2014 – 28%, September 2014 - 24% relative planted coverage). As for the relative coverage of perennial species, no individual rate of application in either June 2014 (72% - 79% relative perennial coverage) or September 2014 (55% - 60% relative perennial coverage) produced a relative perennial coverage significantly different than that of the control (June 2014 – 68%, September 2014 – 50% relative perennial coverage). In June 2014, individual biosolids amendments had significantly greater relative coverage of perennial species (RMI [wood-ash stabilized biosolids] –

83%, WW [aerobically composted biosolids] – 82% relative perennial coverage) than the control (68%). No other amendments in either June 2014 (79% - 67% relative perennial coverage) or September 2014 (46% - 64% relative perennial coverage) had relative coverage percentages significantly different from the control (June 2014 – 68%, September 2014 – 50% relative perennial coverage).

Distance from the road had a significant impact on the relative coverage of both planted and perennial species. The area within 1 meter of the road had significantly less planted coverage than the areas of the plots further from the road in all plots except the BBCC (biosolid cocompost) and control. Relative perennial coverage within the first meter from the road was significantly less than the rest of the area within the plots for both composts and biosolids. *Digitaria sp.* dominated that first meter, with the effect being especially pronounced on the side of the road where traffic was closer to the vegetation.

In order to promote the establishment and persistence of perennial species within Rhode Island highway roadsides, the use of composts that have both sufficient first-year plant-available nitrogen (144 kg n/ha) and high levels of organic matter (sufficient to raise soil levels to a minimum of 5% organic matter) are recommended. Regions of the roadside within one meter of the paved surface require the development and implementation of specific management techniques beyond amending the soil with organic materials.

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Casella Organics, The Town of Bristol, The City of West Warwick,

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CHAPTER 1

INTRODUCTION

It is easy to overlook the roadside due to its very ubiquity. With 1,102 miles of state roads and highways in Rhode Island alone, it is an environment that is easy to take for granted despite the variety of services it provides. According to the AASHTO *Guidelines for Vegetation Management* (American Association of State Highway and Transportation Officials Subcommittee on Maintenance 2011), the services provided by properly maintained roadside environments include: preserving visibility and sightlines for drivers, reducing highway maintenance costs, maintaining the integrity of the shoulder area, preventing guardrails from failing, preserving stream banks, preventing drains from clogging, preserving wetlands, improving runoff water quality, and keeping the roadside aesthetically pleasing. All of these services are threatened by degradation of the vegetation and soil adjacent to highway travel surfaces.

The vegetation community best suited to provide these critical services for the northeastern region of the United States is composed of native and regionally adapted perennial grass species (Booze-Daniels et al. 2000; RISCC 2014). These species have the benefits of tolerating mowing, rooting deeply, stabilizing soil, and staying green and attractive from spring through fall (Dunn et al. 2002). Mowing is necessary to prevent the succession to woody plants that is typical to the region (Parr and Way 1988). Mowing also preserves sightlines for drivers and decreases the attractiveness of the area as habitat for large mammals. The root systems of perennial grasses

consist of shorter, thicker and more lignified roots with lower nitrogen concentrations than those of annual grass species. The lower nitrogen and higher lignin content of the perennial vegetation means they decompose more slowly, leaving the soil less vulnerable to erosion (Roumet et al. 2006). Currently, the dominant species on Rhode Island roadsides are the annual grasses large and smooth crabgrass (*Digitaria sanguinalis* and *Digitaria ischaemum*). These warm-season annual grasses are alive only during the summer months, leaving roadsides bare and unattractive in the cooler months of the growing season (Brown and Sawyer 2012) and vulnerable to erosion.

The vegetation most commonly seeded along Rhode Island highways are perennial cool-season turf species chosen for their relatively low-price and wide availability. Despite being generally well adapted to the soils and climates of the Northeast, cool-season perennial turf grasses struggle with the unique challenges of the roadside environment (Dunifon et al. 2011). These include soils lacking in nutrients and organic matter, excessive drainage, irregular and potentially harmful mowing, traffic damage, competition from annual, invasive and opportunistic species, and exposure to road runoff that may contain harmful and herbicidal compounds (Haan et al. 2012).

As “disturbance specialists”, annual species are especially well suited for these high-stress areas. They are able to colonize low-nutrient and exposed ground, and propagate by setting massive amounts of seed rather than spreading vegetatively, allowing them to withstand the pressures of the environment better than perennial species that have been developed for more highly maintained sports fields and lawns (USDA 1935). The relative suitability of perennial and annual species is likely to be

affected by microhabitats within the roadside environment (Karim and Mallik 2008) and potentially by the distance from the travel surface (Spencer et al. 1988). As slope position and distance from vehicle traffic change, so do moisture patterns, organic matter accumulation, bulk density and opportunities for disturbance, impacting the ability of species to establish and persist.

Annual vegetation - particularly those species adapted to disturbed habitats - are better adapted to grow in the dry and coarse soil of roadsides. Annuals have the advantage of being able to seek out and acquire limited soil nutrients without committing significant resources to durable above-ground biomass or thick, persistent roots. Roadside soils, with their low cation exchange capacity and limited ability to retain water, place perennial species at a distinct disadvantage in the competition for nutrients. A number of explanations have been put forth for the difficulty that perennial and native species have persisting on roadsides. These include stress from the bulk density and particle size of soils (Haan et al. 2012), road salt (Friell et al. 2014), the speed at which annual species establish (Booze-Daniels et al. 2000), the timing of the emergence of annual vegetation (Stevens and Fehmi 2011), and disturbance from travel and construction (Hansen and Clevenger 2005) and other human activities. An additional possibility is that a lack of plant available nutrients, especially mineralize nitrogen, limits the ability of perennial cool-season species to persist and out-compete annual warm-season vegetation (Wakefield et al. 1974, Wakefield et al. 1981; Wakefield and Sawyer 1982; Brown and Gorres 2011; Boen and Haraldsen 2011).

If nutrients are the limiting factor, then the addition of nutrients in organic forms, particularly nitrogen, through the incorporation of organic amendments, should increase the coverage, quality and persistence of perennial species as compared to roadside soils lacking these amendments.

It is this theory that drives the hypotheses tested by this study:

Hypothesis 1: The addition of stabilized biosolids at a rate of 144 kg N/ha to roadside soil will significantly increase vegetation quality as compared to an unamended control for at least two years after seeding because of increased plant-available nitrogen in the soil.

Hypothesis 2: The addition of composts to roadside soil at a rate of 30% v:v will significantly increase vegetation quality scores as compared to an unamended control for at least two years after seeding because of increased plant-available nitrogen in the soil.

Hypothesis 3: The addition of stabilized biosolids at a rate of 144 kg N/ha to roadside soil prior to hydroseeding will significantly increase the coverage of perennial species in both June and September in the second year after seeding because of increased plant-available nitrogen in the soil.

Hypothesis 4: The addition of composts to roadside soil at a rate of 30% v:v prior to hydroseeding will significantly increase the coverage of perennial species in both June and September in the second year after seeding because of increased plant-available nitrogen in the soil.

CHAPTER 2

REVIEW OF LITERATURE

Review of Literature on Establishment of Vegetation

Conditions for the establishment of perennial grasses on roadsides

The importance of microhabitats for the competitiveness of native species is described by Karim and Mallik (2008). In studying random transects along 14 km of the Trans Canada Highway in the Terra Nova National Park in Newfoundland, Canada, they described four distinct microhabitats present between the edge of the road and the edge of the forest. These microhabitats -- the shoulder, the side slope, the ditch, and the back slope -- sustain significantly different plant communities. They attribute these differences in plant communities to gradients in soil moisture content, bulk density, organic matter depth and pH.

From the mid-1960s until the mid-1980s a number of trials testing seed mixes, mowing heights, the effects of mulches and the effects of fertilizers on the establishment and persistence of roadside vegetation were conducted through the agricultural experiment station at URI in conjunction with the RIDOT. These tests resulted in reports and recommendations that address the unique requirements of vegetation along Rhode Island highways. Wakefield, et al. (1974) provide a number of recommendations using data gathered from at least 8 years of tests. Regarding seed mixtures, they found fine-leaved fescues (*Festuca rubra*, *Festuca tenuifolia*) and

Colonial bentgrass (*Agrostis capillaris*) to be the best adapted to establishing in roadside areas, while Kentucky bluegrass (*Poa pratensis*) did not establish well in droughty soils and Perennial ryegrass (*Lolium perenne*) had the benefit of rapid germination but was short-lived and tended to reduce the establishment of other species. All species, however, showed improved performance when seeded in quality topsoil over a graveled base. This is a critical finding given the lack of quality topsoil along engineered roadsides. The study recommends a “Park Mix” of species for mowed areas, such as the seed mix included in this study, and a “Slope Mix” of species for unmowed areas, which are outside of the scope of this study. The recommended “Park Mix” is composed of 75% red fescue (*Festuca rubra*), 15% Kentucky bluegrass (*Poa pratensis*), 5% Colonial bentgrass (*Agrostis tenuis*) and 5% perennial ryegrass (*Lolium perenne*). Additionally, the report recommends that a chemical fertilizer be applied at rates of 112 kg N/ha, 179 kg P/ha and 156 kg N/ha at the time of seeding.

The current practices for the seeding of vegetation along Rhode Island highways are specified by the RIDOT and described in the *Rhode Island Department of Transportation Standard Specifications for Road and Bridge Construction* (2013), otherwise known as “The Bluebook”. It dictates:

- Suitable soil characteristics – “Plantable Soil” that should “consist of loose, friable topsoil free of refuse, brush, stumps, roots, rocks, cobbles, stones, noxious weeds, litter, and other materials which are longer than 1 inch in any dimension and which will prevent the formation of a suitable seed bed. Organic matter shall constitute not less than 4 percent nor more

than 20 percent of the plantable soil ... unless otherwise specified or directed. The plantable soil shall have an acidity range of approximately 5.5 pH to 7.5 pH.” These characteristics may be achieved through amending the soil with other materials. [There is a recommendation of 4 to 8 inches of topsoil that contains at least 5% organic matter in areas where turf is to be established contained within the *Rhode Island Soil Erosion and Sediment Control Handbook* (RISCC 2014)]

- Seeding mix – Creeping Red Fescue (70% by weight), Kentucky bluegrass (15% by weight) and Perennial ryegrass (15% by weight). All must be improved varieties.
- Fertilizer specifications and rates – 10-10-10 fertilizer applied at 850 lbs per acre. Fifty percent of the nitrogen in the fertilizer must be slow release.
- Seeding dates – Spring seeding from April 1 to May 31 and Fall seeding from August 15 to October 15.
- Seedbed preparation practices – a raked seedbed with sticks, litter, wire, weeds, cable, cobbles and stones larger than 1 inch removed. Compacted seedbeds are to be scarified to a depth of 5 inches. Soil should be limed at a rate of 1 ton per acre unless otherwise specified.
- Seeding rates and methods – 150 lbs per acre seeded either mechanically or hydroseeded
- Post-seeding mulching and watering practices – All new seeding is to be covered with a cellulose mulch. The cellulose much can be part of the

hydroseeding mixture. Watering is to occur within 72 hours of planting in a manner that ensure that water reaches the root zone without eroding the soil.

- Mowing practices – Vegetation should be mowed twice a year to a uniform height of three inches.

Use of composts and biosolids to improve establishment and persistence of perennial grasses

The usage of composts as fertilizers and amendments for residential, commercial and athletic turf applications is well documented (Henderson et al. 2012; Henry et al. 2002; Landschoot 1996). The goal is often to establish mowing tolerant turf stands that are green for a long part of the year, can withstand foot traffic and are free of non-planted species. In these applications, inorganic fertilizers are often preferred for their ease of storage and application and the precision with which they can be applied. Sometimes these fertilizers are “slow release”, though they are not meant to persist in the soil for more than a single season. They require regular, well-timed application and are not ideal for minimal management scenarios.

Under minimally managed conditions, biosolids are an attractive option as soil amendments because they are low-cost, plentiful and high in both nutrients and organic matter. A common practice has been to use them in reclaiming mining sites and other soils disturbed by industrial applications (Li et al. 2000). The use of biosolids as a soil amendment for the fertilization of grasses and vegetables is not a recent innovation Harper (1931) described their use in a number of experiments throughout the 1920s.

Following their experiments and publications in the 1970s, in 1981 and 1982 Wakefield et al. produced more comprehensive roadside vegetation management manuals. The experiments used to generate the data for these manuals took place both on Rhode Island highway roadsides and at the URI experiment station. Wakefield, et al. (1981) describe two experiments that involve the use of anaerobically digested sewage sludge as a fertilizer for existing roadside turf stands. The first test monitored the potential for heavy metal contamination of ground water as a result of runoff and leaching from anaerobically digested sewage sludge. Despite the sewage sludge containing heavy metals at a rate greater than what would be allowed for land application, the contamination of runoff by both nitrogen and heavy metals were highly mitigated by the presence of a turf buffer strip equal to the length of the area treated. Furthermore, turf in the treated plots showed considerably greater vegetative growth than in the untreated plots, leading the researchers to recommend the use of sewage sludge for further study. The second experiment focused on different seeding and fertilization methods for improving roadside turf. Among the fertilization methods were commercial water-soluble fertilizers, both fresh and aged sewage sludge and chlorine-stabilized and anaerobically-stabilized sludges. While none of the fertilization methods showed particular promise as a long-term solution to promoting perennial turf stands, the fresh sludge at a rate of 48 kg N/ha (1 lb N/1000 ft²) and aged sludge at a rate of 97 kg N/ha (2 lb N/1000 ft²) showed results similar to those of plots treated with 5-10-10 at a rate of 48 kg N/ha (1 lb N/1000 ft²).

URI's research into the effects of biosolids as a soil amendment on roadsides culminated in publishing a technical manual entitled *Use of Composted Sewage Sludge*

on *Roadside Vegetation* (Wakefield and Sawyer, 1986). This publication details three experiments that utilized composted sewage sludge, as opposed to anaerobically digested sewage sludge, in roadside applications. Two of these experiments focus on the use of composted sewage sludge on turf. The first experiment took place over a period of two years at the URI agricultural research station and measured the effects of a number of treatments and seeding methods on the improvement of deteriorated (60%) red fescue (*Festuca rubra*) turf. The results measured ground cover, plant growth and red fescue (*Festuca rubra*) and birdsfoot trefoil (*Lotus corniculatus*) establishment. The study concluded that compost at 27 T/A significantly improved ground cover, with higher levels (54 T/A) not resulting in further improved cover. Additionally, the use of glyphosphate prior to drop seeding and compost application led to the best results and the greatest establishment of improved species, with the theory that the herbicide application reduced competitive pressures and the alleopathic effects of established weeds. The results of these studies make a compelling case for the use of composted sewage sludge on roadsides. The fact that they took place in the controlled environment of the Agricultural Experiment Station with turf established on Enfield silt loam, as opposed to the harsh conditions and nutrient deficient engineered soils of the actual roadside, creates the justification for further studies. The second study, conducted at two locations in Kingston, Rhode Island, partially addressed the issue of existing roadside soil conditions by using plots that had soils with deteriorated topsoil in one location and removed topsoil in another. Field plots contained the following treatments: incorporation of composted sewage sludge to 13 cm at rates of 65 T/A, 130 T/A and 195 T/A, a 5 cm (2 in) surface application of composted sludge,

fertilized control and unfertilized control. The effects of the compost were tested on two roadside seed mixes and five individual turfgrass species. At both sites, the plots with incorporated or surface applied compost demonstrated “excellent establishment” of the two seed mixtures and the five individual turfgrass species. The two higher rates of incorporated sludge (130 T/A and 195 T/A) along with the surface applied sludge supported superior growth in low-grade soils. Additionally, the application of composted sewage sludge increased the moisture holding capacity of the soils it was applied to. While this study did not apply biosolids based on mineralizable nitrogen, it does demonstrate biosolids’ potential effectiveness in aiding in the establishment and persistence of perennial grasses on the poor soil of the roadside.

In a review of the potential benefits of compost for restoring soils disturbed by urban development, Cogger (2005) found that most research regarding the use of compost and its associated guidelines had been generated for agriculture. He noted a lack of literature regarding the use of composts as amendments for soils affected by urban development, recommending that more research take place. While extensive studies have been conducted on the use of biosolids in mine site reclamation (Jenness 2001; Daniels et al. 2002; Evanylo et al. 2005; Stehouwer et al. 2006), research concerning their use in engineered soils is less common. However, relevant to the establishment of grass on roadsides, he did find two studies (Tester 1990; Sullivan et al. 2003) that looked at the persistent benefits of a single compost application. Both studies, conducted in humid, temperate climates, used a single application of compost and found that the benefits of compost lasted for at least several years after application. He also examined the issue of over-application of compost. He describes

studies that found potential problems with elevated salt content within composts, excessive wetness and anaerobic conditions in poorly drained soils, and high rates of nitrate leaching in nitrogen-rich composts. These are all potential issues in roadside applications, where salt is often applied to roads, drainage must remain at a high level and, due to drainage patterns, leachate must be monitored for excessive nutrients. He also notes a study that found that high rates of application (50% or greater by volume) led to excessive settling and waterlogging in an urban soil. Craul (1999) recommends an application rate for degraded landscapes of 5 cm to 8 cm incorporated to 20 to 25cm deep (20%-40% v:v) for long-term improvement of the soil environment.

Loschinkohl and Boehm (2001) and Dunifon et al. (2011) both looked at the use of composts as a means of restoring fertility to disturbed soils. Loschinkohl and Boehm (2001) focused on the restoration of turf in a controlled plot scenario, while Dunifon et al. (2011) investigated the effectiveness of different compost application methods on existing roadsides. Loschinkohl and Boehm (2001) used established turf research plots and removed the first 20cm of existing topsoil, replacing it with nutrient-deficient subsoil. The plots were then amended with a 1:1; v/v mixture of two different composted biosolids. They found significantly ($P < 0.05$) greater turfgrass establishment in the compost-amended plots compared to subsoil plots. They credited the improved establishment to the plant-available nitrogen and phosphorus introduced with the compost.

Dunifon et al. (2011) compared the establishment of a 50:50 mix of tall fescue (*Festuca arundinacea* Schreb.) and chewing's fescue [*Festuca rubra* L. ssp. *fallax* (Thuill.) Nyman] when seeded either with standard hydromulch or a surface

application of compost. The study was performed between two road cuts in Virginia with silty clay loam soil that had a history of poor vegetation establishment and poor soil quality. The compost, a combination of poultry litter and woody waste, was applied at a rate of $235\text{m}^3 \text{ ha}^{-1}$. The hydromulch, a wood cellulose fiber, was applied at a rate of 112 kg ha^{-1} . The plots were mowed once per year to a height of 10 cm by Virginia DOT maintenance contractors using rotary mowers. Dunifon et al. (2011) concluded that a surface application of poultry litter and woody waste compost (C:N 17:1) increased important plant nutrients in disturbed roadside soils and significantly improved coverage of the intentionally planted tall and chewing's fescues relative to the hydromulched plots. However, they also concluded that these gains would be short-lived. They state that "any beneficial effects of the organic amendments would largely have been restricted to the soil surface". This was due to a lack of evidence of compost incorporation beyond 5 cm into the root zone after 2 years. While the compost amended plots outperformed the hydromulched plots in all regards, it was observed that by the second year of the study the fescues in the compost amended plots had declined and stands were dominated by spotted knapweed and horsenettle.

Nitrate Mineralization

Nitrogen is often the limiting nutrient in turf production. It is commonly the nutrient that fertilizer application rates are based upon in landscape and athletic field management (Henry et al. 2002; Henderson et al. 2012). Nitrogen is commonly added to soil as synthetic fertilizers such as nitrate and ammonium salts or urea. In this form it is either plant available or quickly mineralized, but also very mobile and can be lost from soil through leaching, volatilization and denitrification. Synthetic nitrogen

fertilizers allow for precise and timely application, but requires that regular additions of fertilizer take place.

Mineralization of the nitrogen in organic amendments such as biosolids and composts into plant available forms depends on a number of microbial processes that are controlled by temperature, moisture, pH, soil texture and other physical and chemical soil properties. This creates a lack of precision in the application of nitrogen via organic amendments and requires that the amendments be applied at rates of nitrogen greater than those at which inorganic fertilizers are applied (Tian et al. 2008).

The current guidelines for the application of fertilizer along Rhode Island highways calls for the use of 10-10-10 (N-P-K) fertilizer, with fifty percent of nitrogen in slow release form (RIDOT 2013). These requirements are easy to meet when using synthetic fertilizers but almost impossible to control for when using organic amendments. A rate of application of 850 pounds of 10-10-10 per acre is specified for general highway seeding with 500 pounds per acre following the installation of sod (RIDOT 2013). Only recommendations and no specifications are available for the application of compost along Rhode Island highways (RIDOT 2013, RISCC 2014). Compost is suggested for use in increasing soil organic matter and not as a fertilizer.

Because biosolids and composts are comprised of complex organic compounds that require breakdown by microbes, the speed at which nutrients are released varies depending on factors such as the community of microbes present, the size and type of compounds present within the biosolids and composts, soil particle size, temperature, moisture, pH and other factors specific to a given location (Sylvia et al, 2005). All of

these variables impact the mineralization of the nitrogen present within the biosolids and composts and subsequently the availability of that nitrogen to vegetation.

Garau et al. (1986) looked at the problem of nitrogen mineralization rates from a multivariate perspective. Their study observed the impact that soil type, stabilization method (aerobic and anaerobic), amendment incorporation rate, leaching and time had on the rate of nitrogen mineralization for sewage sludge. They determined that soil was the most important factor in determining nitrogen mineralization rate, followed by application rate and then the properties of the sewage sludge. They also determined that organic nitrogen mineralized more quickly from aerobically treated sludges than from anaerobically treated sludges.

Claassen and Carey (2004) present a good demonstration of the mineralization dynamics that different organic amendments can present even when incorporated in the same soil. Their experiment measured the release of plant available nitrogen from six different composts to test the assumption that a lack of available N retards plant establishment in disturbed areas. Four yard waste composts (short curing time [17.04 g N/kg], typical process time [11.46 g N/kg], 18 month curing time [15.86 g N/kg], and highly processed [13.77 g N/kg]) and two co-composted biosolids/yard waste mixtures (windrow [15.77 g N/kg] and in-vessel [29.13 g N/kg]) were tested. The goal of the study was to characterize N mineralization and release patterns under long-term, aerobic conditions. These were then compared to the N release rates of native California soils. Compost treatments were mixed with a very low N content, sandy substrate of decomposed granite to facilitate soluble N extraction and to simulate a potential revegetation substrate. After aerobic incubation, the materials were regularly

extracted over a period of 586 days to measure N release rates. The chambers were maintained in aerated conditions at about 60% of field capacity at 30°C. Additionally, anaerobic incubation was used to measure available N using a one week, 40°C, waterlogged incubation. The two moderately-to-well-cured yard waste composts demonstrated the most immediate N mineralization. By the end of the incubation period the highly processed yard waste compost, while slower to initiate N mineralization, had a cumulative N mineralization similar to that of the moderately-to-well-cured yard waste composts as well as the low-fertility granitic subsoil (0.15 g N/kg) used as a reference. The least processed yard waste compost, which also contained what was thought to be the greatest proportion of woody materials, had an extended period of nitrogen immobilization and the lowest cumulative N mineralization. Far exceeding the N mineralization rates of the yard waste composts, the co-composted biosolids released twice as much N as the granite topsoil (1.17 g N/kg), and two-thirds that of the nutrient rich, sedimentary topsoil (2.14 g N/kg) used as a reference. The rate at which total available N was mineralized differed greatly between the yard waste composts and the biosolid co-composts. According to the study, 1% to 7% of the total N contained in the yard waste composts was released during the incubation period, while the co-composts released about 27% of total N. The yard waste composts provided a more gradual, long-term supply of N, though those with high levels of uncured and fibrous materials could initially slow plant establishment due to N immobilization, while the co-composts provided a more rapid source of N that might have less potential for continued N release.

To better understand the causes of these different mineralization rates it helps to view organic sources of nitrogen as parts of different “pools” that are released at different rates over time. The ratio of these pools in different sources of biosolids and composts will significantly impact their short-term and long-term effectiveness as sources of nitrogen for roadside turf.

Smith et al. (1998) state that stabilized (composted or air-dried) biosolids have up to five pools of mineralizable nitrogen to draw from, though these can be condensed into two pools for modeling and predictive purposes. The relative proportions of these “fast release” and “slow release” pools are determined by the process used to treat the biosolids. Digested biosolids had up to 60% of total N converted to nitrate within 4000 d°C (thermal time units), while dewatered undigested biosolids had only 15% mineralization to nitrate over the same 4000 d°C. Composted biosolids were the most stable, with only 10% of the N mineralizing to nitrate after 160 d of incubation at 25°C (4000 d°C). This stability indicates a minimal chance of leaching, though it appears to limit the utility of composted biosolids as a primary source of nitrogen. The study emphasizes the need for incubation tests for individual products and the importance of a centralized processing facility for biosolids so that product uniformity can be achieved. Furthermore, the thermal-time relationship between products and mineralization rates brings up the importance of considering climate when determining application rates.

An additional method of characterizing nitrogen (as well as carbon) pools in composted biosolids is presented by Doublet et al. (2010). Their study examined the role particle size plays in the mineralization of nitrogen and the sequestration of

carbon. They used a composite material comprised of a biosolids co-compost composed of aerobically-digested sewage sludge (13%), refuse from green waste compost screening (47%), stored yard trimmings (20%) and crushed wood pallets (21%). They then separated the finished material into seven particle size fractions: $[50-200\text{ }\mu\text{m}]_{\text{L}}$, $[200\text{ }\mu\text{m}-5\text{ mm}]_{\text{L}}$, $[5-20\text{ mm}]_{\text{L}}$, $[50-200\text{ }\mu\text{m}]_{\text{H}}$, $[200\text{ }\mu\text{m}-5\text{ mm}]_{\text{H}}$, $[5-20\text{ mm}]_{\text{H}}$ and $[0-50\text{ }\mu\text{m}]$. They found the $0-50\text{ }\mu\text{m}$ fraction to be the only fraction to contribute available N to the total compost, while other fractions decreased available N. This method of characterizing pools of mineralizable nitrogen further contributes to the complexity of determining application rates while increasing the importance of consistent analysis of organic soil amendments.

Mineralization rate is additionally impacted by the moisture present within soil. Hudson (1994) draws a link between increased soil organic matter and increased soil moisture. The addition of organic amendments should increase soil organic matter and lead to increased soil moisture which should then lead to increased mineralization of nitrogen containing compounds within the soil (Orchard and Cook 1983).

Potential for nitrogen surplus and leaching

Mineralized nitrogen in the soil that is in excess of what plants can immediately utilize is made unavailable to plants through either immobilization, volatilization, leaching, or denitrification. This over-application of a nitrogen is not only inefficient and costly, but leaching into groundwater can cause eutrophication and contaminated drinking water. Over-application of nitrogen in landscaping applications can also cause overly vigorous growth that can create the need for more frequent mowing.

Petrovic (1990) and Di and Cameron (2002) identified factors that influence the fate of nitrogen when it is applied as a turf fertilizer as well as in a variety of natural and agricultural systems. These factors include soil texture, nitrogen release rate, nitrogen storage, climate, vegetation harvesting, soil management and the type of vegetation being fertilized. The actual amount leached can vary widely and was determined to be controllable through management techniques.

While all fertilization runs the risk of leaching nutrients, Easton and Petrovic (2004) contend that the greatest risks of N and P leaching and runoff into ground water from turfgrass occur within the first 20 weeks following seeding. By the second year of the study there was no significant difference between plots fertilized with biosolids and the control in terms of nutrient leaching. The authors suggest, based on fertilized plots showing less leaching than the unfertilized control plots, that fertilization of turf that leads to greater rooting and tissue growth can provide a greater benefit to ground water than no fertilization.

This theory that turf serves as a sink for plant available nitrogen is further supported by the findings of Bushoven et al. (2000) and Jiang et al. (2000). They found that sudden turf death leads to increased nitrate leaching and that turf reestablishment significantly reduces the losses.

The source of the nutrients should be considered as well. King and Torbert (2007) state that land-applied organic sources of nutrients (composted animal manures) pose less of a runoff threat for nitrate and ammonium than inorganic sources. This is attributed to micro-organisms stabilizing nutrients in complex organic compounds during the composting process. These compounds lead to a slower and

steadier release of nutrients, more in sync with plant uptake. Further, they determined that ammonium is a much smaller runoff threat than nitrate. This is predicated, however, on NH_4^+ -N binding to clay particles in the soil. Very sandy soils and those soils with low cation exchange capacity are at a greater risk of leaching NH_4^+ -N, though most should volatilize.

Tian et al. (2008) demonstrate that while compost, is superior to peat for restoring soil microbial biomass in the sandy soil of golf course putting greens, biosolids offer greater potential for restoring N mineralizing bacteria that provide long-term plant mineralizable nitrogen. A caveat to this is that biosolids need to be applied at greater rates of total N than inorganic fertilizer in order to achieve similar levels of mineralized nitrogen. Since the nutrients are contained within organic compounds and decompose at a rate of approximately 10% per year (Tian et al. 2009), applying the product at the same N rate as inorganic fertilizers is likely to lead to N deficiency. The authors suggest that application rates for the biosolids products on turf be based on the annual mineralized nitrogen levels for the individual product.

Roadsides and engineered verges as grasslands, their vegetative composition and their suitability for perennial cool season grasses

As mentioned earlier, the roadside environment, including other transportation corridors such as verges adjacent to railroad tracks, has functional properties that create conditions which are less than optimal for the growth of perennial cool season grasses. These areas have long been thought to have little ecological value and their vegetative communities have been little studied. What has been found, however, is that these areas are home to a diverse array of annual and perennial grasses and forbs,

including rare native species. (Tikka et al. 2001) evaluated the role that roadside and railway verges play as hosts and dispersal corridors for grassland plant species. They found 78 grassland species within these unmanaged verges. Only three of the species found were of the sort that would have been sown. They conclude that these unmanaged verges could be important resources in the preservation of grassland species as natural grasslands disappear.

In their study of Rhode Island highway roadside vegetation, Brown and Sawyer (2012) identified 80 graminoid and forb species. Of these, 35 were native plant species and 4 were rare species. With little management beyond occasional mowing, these native and rare species can proliferate as niches develop within the roadside environment. Highways as habitats for both native and invasive species is further supported by Rentch et al. (2005). In their study of West Virginian highway roadsides, they identified a total of 538 vascular plant species. While they emphasize the impact of invasive species and the need to actively manage the threat they pose to native species, they do note that native species were often well-represented in the study plots.

While there is evidence to support these roadside areas as havens for native grass species there is also evidence that they can act as dispersal corridors for invasive and opportunistic species that colonize disturbed habitats. Hansen and Clevenger (2005) state that highway and railway corridors play host to a number of invasive species due to their high levels of disturbance and light. This impacts floral communities well beyond the corridors, leading to the spread of invasive species and the decline of

native species. They recommend reseeding corridors with native plants to prevent this.

There is also the theory that by applying composts and other amendments to roadsides the nutrients released will fertilize the weedy and annual species as much as they will the sown and perennial species. This would give the weedy species that are better adapted to disturbed environments a further advantage. This is stated succinctly by Dunifon et al. (2011) when they say, “the high nutrient rates can promote the growth of competing broadleaf weeds as well as that of the sown species.” If this holds true, then we should take actions that provide the greatest benefit to those species we would like to see dominate and persist. For instance, with crabgrass, a dominate species along Rhode Island roadsides, Turner and Van Acker (2014) contend that neither fall nor spring fertilization have an impact on the germination rates of smooth or large crabgrass. This means that if crabgrass is an issue, the fertilization regime most beneficial to cool season perennials should be the one used so as to allow them to compete with crab grass, without concern being given to the effect of fertilizing the crabgrass.

An additional concern regarding the suitability of roadsides as host environments for perennial grasses has been the perception that the use of road salt over the winter months leads to soil salinity levels that would damage common turf grasses. Rodgers and Anderson (1995) studied the impacts on soil salinity by the application of sewage sludge as an amendment and found that even though salinity increased to levels thought inhibit vegetation there was a linear increase in plant biomass. Research has shown that various factors influence soil salinity and that sensitivity to salinity varies

between plant species (Bernstein 1975). In the case of Rhode Island roadsides, the large particle size, low CEC and high levels of drainage that characterize the roadside soils do not allow salts to accumulate to levels detrimental to vegetation (Brown and Gorres 2012).

Karim and Mallik (2008) propose that by identifying the characteristics of substrates associated with the different microhabitats that comprise the roadside environment that native species can be selected for their ability to persist within those microhabitats. This adopts the strategy that rather than altering the conditions present on the roadside we should seed those native species best suited for the microhabitats created during road construction. The study further identifies particular native species suited for the four identified microhabitats. While they do not identify individual grasses, they did identify two low-growing herbaceous species that are native to both Eastern Canada and Rhode Island -- *Vaccinium angustifolium* and *Anaphalis margaritacea* -- and one introduced species that is present across all of North America -- *Trifolium repens*. To quote the study "...*Vaccinium angustifolium*, *Trifolium repens*, and *Anaphalis margaritacea* have desirable attributes to reduce soil erosion, ensure traffic visibility and regenerate naturally. These species have attributes, such as low stature, widespread above and below ground parts, perennial habit and drought and salt tolerant properties, which make them desirable plants for roadside revegetation." Of those three, only *T. repens* was identified by Brown and Sawyer (2012) in their survey of Rhode Island roadside vegetation. This method of roadside revegetation and slope stabilization could potentially be the most effective in terms of planted species persistence and lowest long-term cost of maintenance. However, it

would take a much larger upfront cost in researching local microhabitats, identifying the native species suited to those habits, developing targeted seeding methods for the roadside, and sourcing those native species that may have limited commercial availability. It would also shift management techniques from mowing grasses to managing forbs.

Ultimately, the future of roadside vegetation management is going to be determined by both biological and budgetary realities. Soils, plants and microbes have limits to what they can withstand and sustain and departments of transportation have limits on what they can afford. Maintaining roadside ecosystems comprised of desirable perennial grasses and forbs has been a challenge despite established best practices. Without adherence to those codified best practices and attention to current research, no effort will achieve consistent success in attaining the goal of safe, effective and attractive roadsides. The goal of this paper is to add to the body of knowledge that will inform future management guidelines and regulations for Rhode Island highways by investigating the potential of biosolids and composts to act as soil amendments that will support the physical and chemical needs of perennial species within roadside habitats.

CHAPTER 3

METHODOLOGY

Study site description and trial establishment and maintenance

I conducted the experiment at a single site within a highway median in Saunderstown, RI located at the intersection of US 1 and RI 138 (41°31'47.75"N, 71°28'1.65"W) ([Figure 1](#)). Both roads are limited access highways and the roadside vegetation is maintained by the Rhode Island Department of Transportation. The median is oriented east by north and west by south, with the width of the plots running parallel to the road. The median is approximately 14.25 m wide and its length continues beyond the designated plots. The first 50 cm of the soil profile is comprised of human transported material (HTM) with a loamy coarse sand texture ([Figure 2](#)). The study site was divided into 66 plots, each 2.1 m wide by 4.5 m long located within the shoulder slope of both sides of the median. Treatments were assigned using a randomized block design with three replications. The 66 individual plots were divided between the two sides of the median, with the second block split between the two sides. All amendment treatments utilized the same three unamended control plots ([Table 1](#)).

Figure 1. Aerial image of research site in Saunderson, RI with the area of study plots marked in white. The swale between the areas marked in white was not directly amended, though it may have received nutrients through runoff and leaching. It can be noticed that the study area in the north of the plots has a 3 to 5 meter shoulder between it and most vehicle traffic while the study area in the south of the plots directly abuts vehicle traffic.

Figure 2. Profile of soil within study plots 6/17/15. While horizonation is evident, the parent materials are not well defined due to the heavily engineered soils. Most of it is assumed to be HTM. Of note are the redoximorphic features within 30cm of the surface, indicating poor drainage or a perched water table for at least part of the year.

Table 1. Amendments, rates and locations for all treatments utilized in the study. Both sides run west to east with their plot layouts. * Rates for compost amendments based upon percent of the first 15 cm of soil. Rates for biosolid amendments based on first year mineralizable N

North side			South Side		
Plot	Amendment	Rate*	Plot	Amendment	Rate*
---Replication 1---					
1	RMI	48 kg N/ha	34	RIRRC	45% v:v
2	BBCC	15% v:v	35	RMI	144 kg N/ha
3	CRD	48 kg N/ha	36	CRD	288 kg N/ha
4	CRD	144 kg N/ha	37	BB	144 kg N/ha
5	BBCC	45% v:v	38	CRD	48 kg N/ha
6	BB	144 kg N/ha	39	BBCC	30% v:v
7	WWB	48 kg N/ha	40	BBCC	15% v:v
8	RMI	144 kg N/ha	41	RIRRC	30% v:v
9	RIRRC	30% v:v	42	WWB	144 kg N/ha
10	RIRRC	15% v:v	43	RIRRC	15% v:v
11	BB	48 kg N/ha	44	BB	48 kg N/ha
12	WRB	144 kg N/ha	---Replication 3---		
13	Control	-	45	BBCC	30% v:v
14	WRB	48 kg N/ha	46	RMI	48 kg N/ha
15	RMI	288 kg N/ha	47	BB	288 kg N/ha
16	RIRRC	30% v:v	48	BB	48 kg N/ha
17	WWB	144 kg N/ha	49	WRB	288 kg N/ha
18	WRB	288 kg N/ha	50	RIRRC	45% v:v
19	CRD	288 kg N/ha	51	Control	-
20	WWB	288 kg N/ha	52	WRB	144 kg N/ha
21	BBCC	30% v:v	53	RMI	144 kg N/ha
22	BB	288 kg N/ha	54	WWB	144 kg N/ha
---Replication 2---			55	WRB	48 kg N/ha
23	CRD	144 kg N/ha	56	RIRRC	30% v:v
24	BBCC	45% v:v	57	RIRRC	15% v:v
25	RMI	48 kg N/ha	58	RMI	288 kg N/ha
26	WRB	48 kg N/ha	59	BB	144 kg N/ha
27	WRB	144 kg N/ha	60	BBCC	15% v:v
28	BB	288 kg N/ha	61	CRD	48 kg N/ha
29	RMI	288 kg N/ha	62	CRD	288 kg N/ha
30	WWB	288 kg N/ha	63	CRD	144 kg N/ha
31	WWB	48 kg N/ha	64	WWB	48 kg N/ha
32	Control	-	65	WWB	288 kg N/ha
33	WRB	288 kg N/ha	66	BBCC	45% v:v

The trial was established in September 2012. No herbicide was used prior to establishment; the existing vegetation was predominately crabgrass. First, a tractor-mounted rototiller was used to till the soil to a depth of 7.6 cm, incorporating the existing vegetation and loosening the soil. Second, the amendments were applied by hand and raked evenly across the appropriate plots. Large rocks were removed at the same time. Third, the amendments were incorporated to a depth of 15 cm using a tractor-mounted rototiller. This step was done in three passes in the same direction in order to keep displacement of soil and amendments consistent across the plots. Soil profile analysis was conducted after the incorporation of the amendments. All plots (amended and control) were then hydroseeded using the RIDOT's "Park Mix" (70% *Festuca rubra* , 15% *Poa pratensis* and 15% *Lolium perenne*) at a rate of 168 kg/ha. The hydroseed mixture also contained 19-19-19 fertilizer (applied at a rate of 95.2 kg product/ha, equivalent to the 385.5 kg product/ha of 10-10-10 prescribed by RIDOT), hydrostraw and binder. No further fertilization or irrigation took place over the course of the study. RIDOT maintenance crews mowed the site occasionally using flail mowers.

Description of Amendments

The amendments included five stabilized biosolids and two compost products.

Boston Beans (BB)

"Boston Beans" is a heat-treated biosolids product similar to Milorganite; it is produced by passing anaerobically digested biosolids through a rotary drum drying and granulation process. The product is sold as a 4-3-0 +Iron fertilizer and is distributed by Casella Organics in both bulk and 40-lb bags. The product is listed as

US EPA Class A, Exceptional Quality, has Type I Approval of Suitability in Massachusetts and is fully approved for use in Massachusetts, Connecticut and Vermont (Casella Organics 2009).

RMI Biosolids (RMI)

RMI Biosolids is a wood-ash-stabilized biosolid product. It is produced and distributed by Resource Management, Inc. The product is manufactured by mixing “raw cake” (biosolids that have been dewatered at the wastewater treatment plant) with a biomass fly ash (wood ash) at a 1:1 v:v ratio. It is marketed as Heart + Soil Complete pH+Plus with an N-P-K of .008-.003-.0155 and 171 lbs of lime per ton. Analysis for the material used for the study is: Total Solids – 38.6%, TKN – 27 g/kg, Ammonium-N – 5.4 g/kg, Total K – 9.57 g/kg, Total P – 5.38 g/kg. The product is recognized as a Class A product under New Hampshire and federal regulations. Class A pathogen standards mean that the material is effectively sterile relative to pathogens and can be used on any type of crop with no waiting period necessary after application. Due to its lack of friability and objectionable appearance, it is only sold as a bulk commercial product. It is recommended that it be applied via a manure spreader or other commercial equipment (Charlie Hanson, pers. comm).

CRD Biosolids (CRD)

CRD Biosolids are alkaline stabilized biosolids produced by the city of Concord, NH. They are stabilized to Class A standards through a combination of heat and high pH. Analysis for the material used for the study is: Total Solids – 45.02%, TKN – 26 g/kg, Ammonium-N – 4.2 g/kg, Total K – 1.103 g/kg, Total P – 7.61 g/kg. (Andrew Carpenter, pers. comm.)

WRB Biosolids (WRB)

WRB Biosolids come from the Winnepesaukee River Basin Project in Franklin, NH. They are stabilized by anaerobic digestion to Class B standards. Class B pathogen standards mean that the level of pathogens has been reduced greatly (for instance, Class B biosolids have fewer pathogenic organics in them than cow manure or chicken manure), but there are still viable pathogens present and there is a required waiting period for harvesting some crops grown using the biosolids. Analysis for the material used for the study is: Total Solids – 22.04%, TKN – 58 g/kg, Ammonium-N – 12 g/kg, Total K – 1.421 g/kg, Total P – 19.1 g/kg (Andrew Carpenter, pers. comm.).

West Warwick Biosolids (WW)

The West Warwick Biosolids product is aerobically composted with an N-P-K of 0.8-1.26-0.05. It was produced by the Town of West Warwick Wastewater Treatment Facility and met Class A biosolid standards. The product utilized dewatered municipal sewage sludge. Due to a flood in 2010 and ongoing issues concerning smell and cost of operating the composting program, the product is no longer being produced.

Bristol Biosolids co-compost (BBCC)

The Bristol Biosolids co-compost is a Class A biosolid compost consisting of in-vessel aerated dewatered sewage sludge and ground yard waste. It is produced by the town of Bristol, Rhode Island and primarily marketed and distributed through Agresource Inc. Bristol residents can obtain BBCC directly from the facility. The biosolids are processed using Siemens-IPS in-vessel technology. The Bristol Compost Facility consists of four enclosed, 220-foot bays with five independent aeration zones and a mechanical turner. Undigested wastewater solids from belt filter presses (24%

solids) are combined with ground yard waste to make the compost. The ground yard waste is added to the sludge to adjust the moisture content of the mixture to approximately 35% to 40% solids. This ensures sufficient moisture content to sustain the composting process while retaining enough porosity to let air flow through the material. Once the active and curing phases have been completed, the compost is screened prior to distribution.

RIRRC yard waste compost (YWC)

The RIRRC yard waste compost is aerobic compost produced by Rhode Island Resource Recovery Corporation in Johnston, RI. Feedstock for this compost is comprised of chipped yard waste delivered from municipalities and contractors from around the state. The yard waste is composted in large windrows until it meets Rhode Island Class A standards for compost. The finished product is available either directly to consumers or through Casella Organics.

Rates of application

The RIDOT *Standard Specifications for Road and Bridge Construction* (2013) lists the specifications that an approved fertilizer must meet and the guidelines for applying approved fertilizers. The specifications are for synthetic fertilizers, which is to be formulated to provide 10% available N (50% of which is slow-release), 10% available phosphate, and 10% available potash (10-10-10), with significant trace elements and a salt index not exceeding 35 (M.18.06). RIDOT does not currently have specifications for the use of organic fertilizers, including biosolids. Biosolids do not contain equal amounts of nitrogen, phosphorous, and potassium, so the application rate in this study was based on nitrogen, as is standard in turfgrass management

(Henry et al. 2002). The biosolids were applied at rates of first-year available N of 48 kg N/ha (1 lb N/1000 ft²), 144 kg N/ha (3 lb N/1000 ft²) and 288 kg N/ha (6 lb N/1000 ft²). These rates are based upon a range of what is considered to be the low and high end of annual N turf fertilization rates (RISCC 2014; Henderson 2012, Henry et al. 2002). RIDOT has specifications for compost approved for use as a mulch but does not provide guidelines for its use as a soil amendment. Compost was applied based upon a percentage volume (v:v) of the first 15 cm (6 in) of soil, a common practice in the landscaping industry. The composts were applied at the rates of 15%, 30% and 45% v:v of the first 15 cm of the soil without consideration of first-year mineralizable nitrogen. The control plots did not receive any amendments or fertilizers beyond the equivalent of 385.5 kg 10-10-10 fertilizer/ha applied to all in the hydroseeding mixture.

Because the biosolids products and compost products were applied based on different parameters the total amount of material applied differed vastly between the two types of amendments. Total applied material ranged from 1 Mg product/ha to 48 Mg product/ha for biosolids and from 103 Mg product/ha to 523 Mg product/ha for composts. Carbon application ranged from <1 Mg C/ha to 14 Mg C/ha for biosolids and from 32 Mg C/ha to 109 Mg C/ha for composts (Table 2).

Table 2. List of treatment application rates based on Mg of product per ha and Mg of carbon per ha. Because the biosolids were applied based only upon first-year available nitrogen, the overall quantities were much lower as compared to the composts, which were applied based upon the percent volume of the soil to 15 cm. The effect of this is that the composts amended plots had much greater levels of organic matter applied.

Treatment (amendment and rate)	Application rate Mg product/ha	Application rate Mg C/ha
Biosolids		
BB 48 kg N/ha	1	<1
BB 144 kg N/ha	3	1
BB 288 kg N/ha	6	2
CRD 48 kg N/ha	8	2
CRD 144 kg N/ha	24	7
CRD 288 kg N/ha	48	14
WW 48 kg N/ha	7	2
WW 144 kg N/ha	22	7
WW 288 kg N/ha	44	14
WRB 48 kg N/ha	6	2
WRB 144 kg N/ha	19	7
WRB 288 kg N/ha	37	13
RMI 48 kg N/ha	7	2
RMI 144 kg N/ha	22	7
RMI 288 kg N/ha	44	15
Composts		
BBCC 15%	103	36
BBCC 30%	207	73
BBCC 45%	310	109
YWC 15%	174	32
YWC 30%	349	63
YWC 45%	523	95

Turf data collection methods

Turf quality was assessed in September 2012, May, June, August, September, October and November 2013 and May (early and late), June, July, August, September, October and November of 2014. The quality was assessed visually using a 0-5 scale, with 0 being bare ground and 5 being extremely lush and vigorous vegetation (Figure 3). Quality was based upon a combination of vegetation vigor, color, height, coverage and species composition (Morris and Shearman 1998).

Average height for each plot was measured in May 2013 (prior to the first mowing) by placing a ruler at three random points within each plot and recording the tallest single grass.

Biomass for the plots was measured in May 2013. An 0.093 m² quadrat was placed randomly within each plot and the vegetation within the quadrat harvested to a height of approximately 3 cm using scissors. The samples were stored in paper bags, dried and weighed in order to obtain a dry biomass total.

Figure 3. Examples of turf with visual rating of 1-5. Turf with a rating of 0 would be bare ground.

Soil sampling and analysis

Soil samples were collected in September 2012, May, June, August, September, October and November 2013 and May (early and late), June, July, August, September, October and November of 2014. Samples were collected using a 3.2 cm-diameter soil core sampler. During each sampling period each plot was sampled in five locations distributed in an “X” pattern. Individual cores were taken down to 15cm below the soil surface. Depth was often limited by compacted and gravelly soil. Fresh samples were placed in resealable plastic bags and stored at 4°C until analysis. Samples were prepared for ammonium and nitrate analysis within 5 days of collection. Soil samples were sieved at field moisture conditions through a 2 mm-mesh screen prior to chemical and physical analysis. Nitrate and ammonium were determined using the method described by Gugino et al. (2009) and analyzed using a BioTek PowerWave 340 running KCJunior software version 1.41.8 (BioTek, Winooski, VT). Soil pH and EC were determined using a 1:1 soil water mixture and analyzed with a Denver Instruments UB-10 Ultra Basic pH/mV Meter (Denver Instruments Inc., Bohemia, NY). Soil moisture content was determined by drying and reweighing a 20g samples of field-condition sieved soil. Organic matter was determined by loss-on-ignition at 550°C for 5 hours. The C/N ratio of amendments was determined by the URI Graduate School of Oceanography using the protocol set by the manufactures of the Costech 4010 Elemental Analyzer (Costech Analytical Technologies Inc., Valencia, CA).

Vegetation survey methods

We conducted the vegetation survey in the early summer over a 14-day period (June 11, 2014 to June 24, 2014), and again in late summer over a 13-day period (September 5, 2014 to September 17, 2014). A 1-m² quadrat, subdivided into a grid of 100 sections, each 100 cm², was randomly placed within each of three distinct areas of each plot. The areas were designated as Location 1 (0 m – 1.5 m from the road), Location 2 (1.5 m – 3 m from the road), and Location 3 (3 m – 4.5 m from the road). Species coverage was determined by counting the number of sections that contained above-ground vegetation of a particular species utilizing the methods of Brown and Sawyer (2102). All plants were identified to genus, and to species when possible.

In June the eight most common non-planted species (minimum coverage of 500 units) and in September the nine most common non-planted species (minimum coverage 250 units) from the respective vegetation surveys were compared.

Statistical analysis

Statistical analysis was conducted in SAS v.9.2. Repeated measures ANOVA was utilized for analyzing vegetation quality ratings, soil moisture, and soil organic matter data. Factorial ANOVA was utilized for soil nitrate, soil ammonium, vegetation survey, pH, and electrical conductivity data. Least Squared Means testing within the Factorial ANOVA function was conducted using Fischer's LSD.

Main effects for all analyses were the specific amendment and the rate of application. Interaction terms were tested and further analyzed if they were significant. For the analysis of the vegetation survey, location was also used as a main

effect. Biosolids and compost amendments were analyzed separately to account for their differing application rates.

CHAPTER 4

RESULTS AND DISCUSSION

Vegetation Quality

Over the 26 months following hydroseeding, the turf quality in plots amended at any rate of biosolids products (no significant difference between products) and the turf quality in plots amended with either compost product (no significant difference between rates) was significantly better than the turf quality in the unamended control plots. The generally superior performance of the vegetation within the amended plots over the two-year study agrees with the results reported by numerous other studies and management guides that have investigated the effects of amending disturbed soil with biosolids and compost (Byju et al. 2015; RISCC 2014; Dunifon et al. 2011; Wright et al. 2008; Cogger 2005; Claassen and Carey 2004; Loschinkohl et al. 2001; Landschoot 1996; Sikora and Yakovchenko 1996; Wakefield and Sawyer 1984; Wakefield et al. 1981; Wakefield et al. 1974).

Turf Quality in Biosolids-Amended Plots

Turf in plots amended with biosolids, as a class, performed well at all application rates in the 2013 season (year one), only to steadily degrade in quality over the 2014 season (year two) ([Figure 4](#)). In year one, the turf in plots at all three rates of application of the biosolids amendments outperformed the control ($P < 0.0001$) while having an average quality score within the acceptable range. The method of biosolids stabilization did not have an effect on turf performance. Overall quality increased

with N application rate (48 kg N/ha – 2.44, 144 kg N/ha – 2.96, 288 kg N/ha – 3.40). The control averaged 1.29 over the same time period, which was below the acceptable range. In year two, there was a substantial difference in performance in the biosolids-amended plots between the time period from May 2014 to June 2014 and the time period from July 2014 to November 2014. The period stretching from the end of July 2014 to the beginning of November 2014 marked a period of below average rainfall ([Figure 5](#)). This lack of rain negatively impacted the turf in the study. Close to average rainfall occurred during the first three sampling periods of year two (May 2014 to June 2014). During the first three observations of year two the turf within the plots amended at the 288 kg N/ha rate averaged a quality score of 2.68 and were significantly ($P < 0.05$) better than the turf within the plots amended at 144 kg N/ha (average score 2.15), 48 kg N/ha (average score 2.00) and the control (average score 1.67). There were no significant differences between the two lower rates and the control. From July 2014 to November 2014, no significant differences (all P for LSM > 0.1) were observed between either the individual biosolids amendments or the individual application rates and the control. Over that time period the turf had quality score that averaged 1.89 (44 kg N/ha), 1.95 (144 kg N/ha) and 1.91 (288 kg N/ha) while the control averaged 1.60. While the turf within the plots amended with biosolids at all three application rates had acceptable average quality scores (between 2 and 4) throughout the first year, the turf quality of all rates fell below 2 during the end of the year two. These results are contrary to those reported by Wakefield et al. (1986), who over three years of annual observations saw that performance of vegetation in their turf plots amended with composted biosolids exceeded that of their

control plots. This difference is likely due to Wakefield et al. (1986) applying much greater rates of product (145 Mg/ha, 291 Mg/ha and 437 Mg/ha) than used in this study (between 1 Mg/ha and 44 Mg/ha).

Figure 4. Year 1 and Year 2 Turf Visual Ratings for biosolids amendments by rate of application. Individual products are not shown because no significant differences were detected between them. The rate of application had a significant effect on the quality of the turf in the first year of the study, with all three rates producing results better than the control. In the second year, these differences disappear with little significant difference between any of the rates and the control. By the end of the second year, all of the rates of biosolids application dropped below the lower limit of acceptable turf quality. Error bars represent standard error of the control.

Figure 5. April to November 2014 daily, monthly and monthly-historic precipitation for Kingston, RI. While the rainfall totals from April 2014 through July 2014 are close to historical averages, there is a period of below average rainfall that extends from August 2014 until November 2014 that led to drought-induced senescence within the biosolids amended plots. The compost amended plots were also negatively impacted, but remained within acceptable levels of quality over that time

Compost Amended Plots

The quality of the turf in the plots amended with BBCC was significantly better ($P < 0.05$) than the plots amended with YWC ([Figure 6](#)) while also demonstrating the best performance among all amendments. In the first year of the study the turf within the compost-amended plots failed to demonstrate consistently acceptable performance due to an over-application of quickly-mineralizable nitrogen in the case of the BBCC, and an under-application of quickly-mineralizable nitrogen in the case of YWC. The high level of woody material within the YWC likely led to nitrogen immobilization within the first year, a process that did not occur within the BBCC amended plots due to the presence of easily mineralized biosolids. On average, the amendments did produce quality scores within the acceptable range of between 2 and 4. The BBCC turf within the amended plots averaged a quality score of 2.51 which was significantly greater ($P = 0.0185$) than the turf within the YWC amended plots that averaged 2.01. Both amendments performed significantly better ($P < 0.001$) than the control, which averaged a quality score of 1.29. In year two, both products produced more consistently acceptable results. This is likely due to nitrogen mineralization rates stabilizing as the slower-to-mineralize forms of nitrogen in the organic matter fraction of both products began to be utilized by the soil microbes. Significant differences were not identified between the two products, with the turf within the BBC-amended plots averaging a score of 2.65 and the turf within the YWC-amended plots averaging a score of 2.60. The turf in the plots amended with either products performed significantly better ($P < 0.01$) than the control, which averaged a score of 1.63. There was no significant difference between rates of compost application in either year. In

2013 the average score for the 15%, 30% and 45% rates were 2.63, 2.55, and 2.57, respectively. In 2014 average score for the 15%, 30% and 45% rates were 2.85, 3.15 and 2.88 respectively. A key comparison, due to their diverging quality scores, between the biosolids and compost plots is their performance over the July 2014 to November 2014 period. While the biosolids plots regressed towards the control over that time period, the compost amended plots remained within the range of acceptable quality. During that time period no significant difference was noticed between the quality of the turf based on the amendment products (BBCC – 2.60, YWC – 2.50) or between rates of application (15% v:v – 2.7, 30% v:v – 3.03, 45% v:v – 2.9) but all were significantly greater ($P < .03$) than the average control plot score of 1.60. Turf within the BBCC-amended plots also demonstrated the best performance across both the biosolids-amended (48 kg N/ha – 2.20, 144 kg N/ha – 2.51, 288 kg N/ha – 2.76, control – 1.46) and compost-amended (BBCC – 2.97, YWC – 2.52, control – 1.46) plots over the full two year period.

The sudden decline in quality observed in August of year one within the BBCC-amended plots follow the first mowing of the season in July. The vegetation within the BBCC-amended plots grew vigorously early in year one (Figure 6 and Figure 7), and when it was cut the clippings smothered the remaining vegetation. This initial vigorous growth is likely due to the rapid mineralization of the nitrogen present within the biosolids portion of the amendment (Smith et al. 1998).

Claassen and Carey (2004) reported that biosolid/yard waste cocomposts, such as BBCC, initially mineralize nitrogen at a greater rate than yardwaste composts such as YWC, but the long-term mineralization rates of the two products are similar, and both

provide steady sources of mineralized N over time. The early season vigor of the BBCC-amended plots in the first and second year, as well as the early season vigor of the YWC in the second year, agree with the findings of Sullivan et al. (2003), who observed strong, early season biomass production over a seven-year study of tall fescue (*Festuca arundinacea* Schreb. ‘A.U. Triumph’) grown in plots that received a heavy one-time application of food waste compost. Additionally, the results observed within the compost-amended plots more closely agree with those of Li et al. (2000), Tester (1990), and Wakefield et al. (1986) who saw improvements in vegetation using composted amendments.

Figure 6. Year 1 and Year 2 Turf Visual Ratings for compost amendments based upon type of amendment applied. Rates are not shown due to no significant difference appearing between them. Despite an early spike followed by a massive drop in quality by the BBCC, the two compost products largely produced similar results, especially in the second year. They consistently remained within the acceptable limits for turf quality while performing significantly better than the control. Error bars represent standard error of the control.

Figure 7. Vegetation Height and Biomass for all treatments (amendment/rate) May 2013. A strong direct relationship between vegetation height and biomass is visible within the graph. The BBCC plots outproduced all other plots. Measuring the tallest vegetation within a plot can give an good overall picture of the productivity of the soil.

Soil Quality

Plant-available Nitrogen

Nitrate and ammonium levels present within the soil at the time of sample collection (Day 0) were combined and analyzed as total nitrogen. Both forms of mineralized nitrogen are equally available to plants and our analysis did not distinguish whether one form was being utilized by vegetation more than the other. Monthly averages for the control ranged from 53 $\mu\text{g N/kg}$ (May 2013) to 1989 $\mu\text{g N/kg}$ (August 2014).

Within the biosolid-amended plots, type of amendment and rate had a significant effect on total nitrogen present in the soil in May 2013, August 2013 and September 2013 ([Table 3](#) and [Table 4](#)). Only type of amendment had a significant effect on total nitrogen in August 2014 ([Table 3](#)). Neither rate nor type of amendment was significant in any other month and no significant interactions between rate and amendment occurred.

Compost-amended plots had significant differences between type of amendment and between rates in August and October of 2013 ([Table 5](#) and [Table 6](#)). Only the type of amendment was significant in early and late May and July 2014 ([Table 5](#)). Significant interactions between rate and type of amendment occurred in May, June and September 2013 and October 2014 ([Tables 7-10](#)). Neither rate nor type of amendment was significant in any other month.

Table 3. Total Day 0 extractable nitrogen ($\mu\text{g kg}$) present within the soil for months when significant differences were present between types of biosolids amendment and no significant interaction effect was present. Different letters within the row indicate a significant difference between soils amended with those products.

Sample period	Control	BB	CRD	RMI	WW	WRB	LSD
May 2013	53 bc	58 bc	142 a	90 ab	56 bc	21 c	50
August 2013	431 b	1190 a	1222 a	1323 a	540 b	1190 a	547
September 2013	171 c	407 ab	506 a	426 a	396 ab	272 bc	145
August 2014	1989 a	1257 ab	1096 b	1198 ab	1208 ab	1336 ab	843

Table 4. Total Day 0 extractable nitrogen ($\mu\text{g kg}$) present within the soil for months when significant differences were present between rates of application of biosolids amendments and no significant interaction effect was present. Different letters within the row indicate a significant difference between soils amended at those rates.

Sample period	Control	48 kg N/ha	144 kg N/ha	288 kg N/ha	LSD
May 2013	53 b	35 b	80 ab	112 a	50
August 2013	431 c	940 b	1096 ab	1465 a	446
September 2013	171 c	331 b	495 a	455 a	119

Table 5. Total Day 0 extractable nitrogen ($\mu\text{g kg}$) present within the soil for months when significant differences were present between types of compost amendment and no significant interaction effect was present. Different letters within the row indicate a significant difference between soils amended with those products.

Sample period	Control	BBCC	YWC	LSD
August 2013	431 c	1875 a	1115 b	620
October 2013	335 b	752 a	723 a	269
Early May 2014	416 b	631 ab	777 a	261
Late May 2014	385 b	491 b	831 a	310
July 2014	631 b	829 ab	1207 a	468

Table 6. Total Day 0 extractable nitrogen ($\mu\text{g kg}$) present within the soil for months when significant differences were present between rates of application of compost amendments and no significant interaction effect was present. Different letters within the row indicate a significant difference between soils amended at those rates.

Sample period	Control	15%	30%	45%	LSD
August 2013	431 b	1157 a	1173 a	1800 a	716
October 2013	335 b	610 ab	600 ab	868 a	310

Table 7. Total Day 0 extractable nitrogen ($\mu\text{g kg}$) present during May 2013 within soil amended with BBCC. A significant interaction effect ($p>0.05$) was present between product and rate. Different letters within the row indicate a significant difference between soils amended at those rates.

May 2013	Control	15%	30%	45%	LSD
BBCC	54 b	688 b	2491 b	7095 a	3860
YWC	54 a	24 a	106 a	147 a	218

Table 8. Total Day 0 extractable nitrogen ($\mu\text{g kg}$) present during June 2013 within soil amended with BBCC. A significant interaction effect ($p<0.05$) was present between product and rate. Different letters within the row indicate a significant difference between soils amended at those rates.

June 2013	Control	15%	30%	45%	LSD
BBCC	332 b	1029 b	1674 ab	2685 a	1488
YWC	332 a	721 a	776 a	793 a	600

Table 9. Total Day 0 extractable nitrogen ($\mu\text{g kg}$) present during September 2013 within soil amended with BBCC or YWC. A significant interaction effect ($p<0.05$) was present between product and rate. Different letters within the row indicate a significant difference between soils amended at those rates

September 2013	Control	15%	30%	45%	LSD
BBCC	171 b	891 a	762 ab	835 a	595
YWC	171 b	586 ab	994 a	842 a	496

Table 10. Total Day 0 extractable nitrogen ($\mu\text{g kg}$) present during October 2014 within soil amended with BBCC or YWC. A significant interaction effect ($p<0.05$) was present between product and rate. Different letters within the row indicate a significant difference between soils amended at those rates.

October 2014	Control	15%	30%	45%	LSD
BBCC	519 b	589 b	708 b	2177 a	899
YWC	519 b	772 b	640 b	1772 a	595

Potentially Mineralizable Nitrogen

The amount of ammonium (NH_4^+) produced by a soil sample over a 7-day waterlogged incubation represents the amount of potentially mineralizable nitrogen (PMN) (ammonium + nitrite + nitrate) within a soil (Waring and Bremner 1964). All of the plots associated with the study were sampled and subsequently tested for anaerobic ammonium production.

For the biosolid-amended plots, rate of application significantly affected potentially mineralizable nitrogen ($P<0.05$) during six sampling periods (Table 12). During those months the PMN in the amended plots never significantly exceeded that of the control plots, suggesting that differences were due to background variation in the soil. In all other months, differences based on rate were not significant for the plots amended with biosolids.

Among the biosolids-amended plots, amendment significantly affected levels of PMN during seven of the sampling periods (Table 11). Only in November 2014 did any of the amendments have a PMN significantly greater than the control. Significant differences were present between individual amendments, with certain amendments often producing greater PMN levels than others. The soil amended with BB and WRB most often produced the greatest PMN levels while soil amended with WW, RMI and CRD most often produced the least PMN. The BB and WRB amendments, both anaerobically digested products, were applied at the lowest volumes, among all amendments, and therefore would have had the least impact on the physical characteristics of the soil. The RMI and CRD products were alkaline stabilized with either wood ash or lime. The application of such highly alkaline amendments may have negatively impacted the soil microbial community, which likely is adapted to the acidic soils of the region. The minimal impact of the BB and WRB products may have preserved or had little effect on that microbial community, allowing PMN to remain within the range of the control.

Among the compost-amended plots, amendment application rate significantly affected PMN during only two months (Table 14) and product significantly affected potentially mineralizable nitrogen during 5 months (Table 13), with a significant interaction effect between rate and product occurring in November 2013 (Table 15).

Consistently greater levels of PMN in the control plots than in the biosolids-amended plots indicate that the addition of biosolids as an amendment at the three rates utilized either has no impact or an inhibitory effect on nitrogen mineralization in soil. Tian et al. (2008) found the opposite was true in their multiyear study of sandy

putting greens that had been amended with biosolids, compost and peat. The biosolids and compost-amended soils in their study increased both soil microbial activity and PMN in comparison to the control. The difference in our results can be attributed to the range of conditions that impact the presence of soil microbial life, as well as the differences between individual composts and biosolids. Putting greens are highly-managed and regularly-watered environments that would have very different microbial dynamics from a minimally-managed roadside.

The differences in both total soil nitrogen and PMN between the different amendments and rates, despite being significant ($P < .05$) in some months, do not explain the differences in turf performance. Furthermore, we were not able to draw a relationship between the mineralized nitrogen in the soil and the quality of the vegetation observed in the plots. The fate of the nitrogen within turf stands is difficult to determine since nitrogen can leach, be taken up by plants, be microbially immobilized, or be volatilized (Petrovic 1990). Nitrogen is also deposited via precipitation in substantial amounts over the eastern United States (Keene et al. 2002) in amounts substantial enough to impact carbon cycling in forest systems (Townsend et al. 1996). In crops such as corn, pre-planting and pre-sidedress soil nitrate tests have been shown to be a significant indicator of crop performance (Ma and Wu 2008). These nitrogen tests, however, have been established in monocropped agricultural soils with improved and standardized crop varieties and the ability to control for factors such as soil moisture and competition from weeds. The variability and diversity of the soil and flora of the roadside makes it impractical to forecast future turf quality based only on the current and potential mineralized nitrogen within the

soil. The mineralization of nitrogen within soil is impacted by a range of variables (e.g. organic matter, soil moisture, temperature, disturbance, particle size), as is the quality of vegetation growing within those soils (e.g. vegetation management, sunlight, competition). Simply having the potential to mineralize nitrogen does not mean it will mineralize at rates that will positively impact vegetation. Measurements other than monthly soil nitrate extractions appear to be better indicators of future vegetation quality in roadside soils.

Table 11. Potentially mineralizable nitrogen of soil as measured by total NH_4^+ ($\mu\text{g kg}$) released after a 7-day waterlogged incubation. The months listed are for when significant differences were present between biosolids amendments, and without a significant interaction effect between type of product and rate of application. Different letters within the row indicate a significant difference between soils amended with those products.

Sample period	Control	BB	CRD	RMI	WW	WRB	LSD
June 2013	965 a	711 ab	36 d	225 cd	375 bcd	473 bc	371
September 2013	1097 a	574 bc	321 c	447 c	546 bc	837 ab	369
October 2013	1408 a	1140 ab	573 c	699 bc	785 bc	1232 ab	535
November 2013	1062 a	1179 a	509 b	597 b	786 ab	933 ab	450
Early May 2014	1670 a	1328 ab	729 b	844 b	796 b	1119 ab	603
October 2014	651 a	748 a	-145 c	139 bc	404 ab	436 ab	496
November 2014	-265 bc	431 a	-303 bc	-614 c	114 ab	20.5 abc	645

Table 12. Potentially mineralizable nitrogen of soil as measured by total NH_4^+ ($\mu\text{g kg}$) released after a 7-day waterlogged incubation. The months listed are for when significant differences were present between the rates of application of biosolids amendments, and without a significant interaction effect between type of product and rate of application. Different letters within the row indicate a significant difference between soils amended at those rates.

Sample period	Control	48 kg N/ha	144 kg N/ha	288 kg N/ha	LSD
June 2013	965 a	278 b	205 b	409 b	303
September 2013	1097 a	550 b	453 b	449 b	301
October 2013	1408 a	966 b	647 b	872 b	436
Early May 2014	1670 a	1043 b	817 b	795 b	492
September 2014	2033 a	1201 b	1027 b	993 b	803
October 2014	651 a	219 bc	46 c	572 ab	405

Table 13. Potentially mineralizable nitrogen of soil as measured by total NH_4^+ ($\mu\text{g kg}$) released after a 7-day waterlogged incubation. The months listed are for when significant differences were present between compost amendments, and without a significant interaction effect between type of product and rate of application. Different letters within the row indicate a significant difference between soils amended with those products.

Sample period	Control	BBCC	YWC	LSD
May 2013	1054 ab	2016 a	600 b	1045
September 2013	1097 a	1215 a	360 b	467
June 2014	505 b	1094 a	373 b	586

Table 14. Potentially mineralizable nitrogen of soil, as measured by total NH_4^+ ($\mu\text{g kg}$) released after a 7-day waterlogged incubation, during June 2013 within soil amended with BBCC or YWC. A significant interaction effect ($p < 0.05$) was present between product and rate. Different letters within the row indicate a significant difference between soils amended at those rates.

Product	Control	15%	30%	45%	LSD
BBCC	966 b	492 bc	66 c	1940 a	555
YWC	996 a	-86	-490	-697	960

Table 15. Potentially mineralizable nitrogen of soil, as measured by total NH_4^+ ($\mu\text{g kg}$) released after a 7-day waterlogged incubation, during November 2013 within soil amended with YWC. A significant interaction effect ($p<0.05$) was present between product and rate. Different letters within the row indicate a significant difference between soils amended at those rates.

November 2013	Control	15%	30%	45%	LSD
BBCC	1062 ab	886 b	627 b	2143 a	1230
YWC	1062 a	333 ab	-222 b	784 a	752

Comparisons between Biosolids and Composts

I cannot make direct comparisons between the compost and biosolids products used in this study because different parameters were used to determine application rates. Application rates were based on expected first-year mineralizable nitrogen for the biosolids and on product volume for the composts. Furthermore, due to the differing kinetics of nitrogen mineralization between stabilized biosolids and composts (Smith et al. 1998), and the role of particle size in the release and immobilization of both carbon and nitrogen (Doublet et al. 2010), we can only compare these two products within their own classifications.

The effects of the different application rates on the quality of the vegetation quality within the study plots for the biosolids and composts were observed over the course of the two years of the study. Applying the organic biosolids amendments at the same rates of first-year plant-available nitrogen that inorganic fertilizer is typically applied appears to have been insufficient for sustaining vegetation quality over the second year of growth. First-year results for the biosolids-amended plots were generally acceptable throughout the year, with manageable growth throughout. Though this method provided sufficient first-year nitrogen to the vegetation, it did not address other physical properties of the soil that are critical for sustained perennial vegetation, such as soil bulk density, cation exchange capacity, organic carbon and plant-available soil moisture. This became evident in year two when the overall quality of the biosolids-amended plots began to decline. The rates at which the biosolids amendments were applied did not account for second-year availability of

nitrogen and were determined based upon the methods recommended for standard inorganic fertilizers. Tian et al. (2009) states that applying biosolids at the same rate of nitrogen as inorganic fertilizers is likely to lead to nitrogen deficiency. Moreover, considering the coarse, gravelly texture of the roadside soil, along with its low organic matter content, the sustained release of nitrogen from the biosolids remains unlikely.

In contrast to the first-year available nitrogen metric used to determine application rates for the biosolids amendments, the compost amendments were applied based on a percent volume of the existing soil. Applying organic amendments based upon either volume (v:v of soil to a certain depth) or mass (Mg/ha) has been the method often utilized by studies investigating their impact in agricultural, remediation, and revegetation. Three studies that investigated the impacts of the one-time application of amendments, the method desired by the RIDOT, used application rates of 60 Mg/ha, 120 Mg/ha, and 240 Mg/ha (Tester 1990), 155 Mg/ha (Sullivan et al. 2003), and 145 Mg/ha, 291 Mg/ha and 437 Mg/ha (Wakefield and Sawyer 1986). For comparison, the biosolids amendments were applied at rates that ranged from 1 Mg/ha to 44 Mg/ha, while the composts were applied at rates that ranged from 103 Mg/ha to 523 Mg/ha (Table 2). The far greater volume of compost material applied, in comparison to the biosolids, along with the amount of total carbon present within the composts (35% for BBCC and 18% for YWC) resulted in a far greater addition of organic matter to the soil and a much larger reserve of organic nutrients that could be mineralized over time.

Organic Matter

Soil organic matter levels ranged from 5.15% to 6.09% for plots amended with biosolids. No significant differences were observed between either products or rates. Plots amended with composts had organic matter percentages that averaged 9.29% in BBCC amended plots and 7.50% in YWC amended plots. Organic matter level increased significantly with increasing application rate for both composts. Control plots averaged 5.68%.

Figure 8. Year 1 and Year 2 soil organic matter percentage for biosolid treatments (amendment/rate). The error bars represent standard error.

Figure 9. Year 1 and Year 2 soil organic matter percentage for compost treatments (amendment/rate). The error bars represent standard error.

Soil Moisture

Over the course of the entire study, none of the biosolids amended soils had a soil moisture percentage significantly different from the control, while soils amended with either compost amendment had soil moisture percentages significantly greater than the control (Figure 17). This trend also occurred during the period of low rainfall from August 2014 through November 2014 (Figure 18) (URI Experiment Station). During that time the compost-amended soils had soil moisture levels significantly greater than all the biosolids-amended soils ($P < 0.05$) (except for WW) and the control ($P < 0.10$). The significantly greater levels of soil moisture help to explain the superior performance of the turf within the compost-amended soil during the second year, especially during the period of below-average rainfall. The WW product is an aerobically composted biosolid product, giving it physical characteristics similar to the composts used in the study. This is potentially why the soil it was amended with had moisture levels not significantly different than the compost-amended soils.

Organic matter and soil moisture data obtained from both the biosolids-amended and compost-amended plots had strong correlations to each other (biosolids $r = 0.655$ $P < 0.001$, composts $r = 0.774$ $P < 0.001$). This is in line with the determination of Hudson (1994) that a soil's available water content increases with its organic matter content. Following this reasoning, increased soil moisture likely led to increased microbial nitrogen mineralization in the compost amended plots (Orchard and Cook 1983), further increasing turf quality. The difficulty of comparing soil organic matter among different soils and results obtained through different measurement techniques

is describe by Hoskins (2002). The soil organic matter values obtained in this study should only be used to compare between the treatments utilized in this study and should not be used for the purpose of comparing organic matter levels to results obtained by other research.

Figure 10. Year 1 and Year 2 soil moisture percentage for all amendments. Error bars represent standard error. Only the two compost products, BBCC and YWC, have soil moisture percentages that are significantly greater than the control. This is due to the greater soil organic matter percentages of the compost amended soils.

Figure 11. August 2014 to November 2014 soil moisture percentage for all amendments. This is the period of time that had below average rainfall during the second year. Error bars represent standard error. The compost-amended plots had soil moisture levels significantly greater than all of the biosolids-amended plots except for those amended with the West Warwick biosolids.

Soil pH and EC

Two chemical properties, pH and electrical conductivity (EC), were measured over the course of the study. Monitoring of pH is important due to its impact on the availability of nutrients critical to the health of vegetation. Monitoring of EC in the application of biosolids is important since they can contain high levels of dissolved salts (8800 Microsiemens/centimeter² [$\mu\text{S}/\text{cm}^2$]) (Rodgers and Anderson 1995), and in some climates repeated applications can lead to soil salinity levels that can negatively impact vegetation.

The soil pH of samples collected in September 2012 and October 2014 from all treatments were within the pH range of 6.0 to 8.0 recommended by Landschoot (1996) for good turf root growth (Tables 16 - 19). In September 2012, the soil amended with CRD (7.44), RMI (7.17) and WW (7.58) biosolids products and the YWC (7.02) compost product had soil pH levels that differed significantly from the control (6.11) (Table 16). Rate of application was not significant for either biosolids-amended or compost-amended soils (Tables 17 & 19). In October 2014, soil amended with CRD (7.63) and RMI (7.27) biosolids products had soil pH levels that differed significantly from the control (6.54) (Table 16). Product was not significant for compost-amended soils. Rate was significant for the biosolids-amended soils with the 288 kg N/ha application rate (7.09) differing significantly from the 48 kg N/ha application rate (6.60). Rate was not significant for the compost-amended soils. No significant interactions occurred between product type and rate for either sampling period.

In September 2012, the EC levels of soil amended with biosolids at a rate of 288 kg N/ha ($1145 \mu\text{S}/\text{cm}^2$) differed significantly from the plots amended at rates of 48 kg N/ha ($703 \mu\text{S}/\text{cm}^2$) and 144 kg N/ha ($772 \mu\text{S}/\text{cm}^2$). Product type was not significant for biosolids-amended soils. Soils amended with BBCC ($3183 \mu\text{S}/\text{cm}^2$) compost had significant differences from soils amended with YWC ($823 \mu\text{S}/\text{cm}^2$) and the control ($528 \mu\text{S}/\text{cm}^2$). Rate was not significant for compost amended soils. In October 2014 neither type of product nor rate was significant for biosolids amended soils (control – $127 \mu\text{S}/\text{cm}^2$) (Tables 16 & 17). Type of product was significant for compost amended soils. YWC amended soils ($391 \mu\text{S}/\text{cm}^2$) were significantly different from the control ($127 \mu\text{S}/\text{cm}^2$) (Table 18). Rate was not significant for compost amended soils (Table 19). No significant interactions occurred between product type and rate for either sampling period.

The addition of biosolids and compost amendments did not have a negative effect upon the pH levels of the soil. The two products (CRD [7.63] and RMI [7.27]) with pH levels significantly greater than the control (6.54) after 26 months were both stabilized with alkaline substances.

Table 16. September 2012 and October 2014 pH levels of soils amended with biosoilds, by product type. No significant interaction between product type and rate was observed. Different letters within rows indicate a significant difference between types of products.

Sample period	Control	BB	CRD	RMI	WW	WRB	LSD
September 2012	6.11 b	6.39 b	7.44 a	7.17 a	7.58 a	6.19 b	.60
October 2014	6.54 cd	6.44 d	7.63 a	7.27 ab	6.99 bc	6.41 d	.54

Table 17. September 2012 and October 2014 pH levels of soils amended with biosolids, by rate. Rate was only significant ($P < 0.05$) in October 2014. Different letters within rows indicate a significant difference between rates of application.

Sample period	48 lb/N	144 lb/N	288 lb/N	LSD
September 2012	6.56 b	6.83 ab	7.05 a	.43
October 2014	6.60 b	6.94 ab	7.09 a	.38

Table 18. September 2012 and October 2014 pH levels of soils amended with composts, by product type. Type of product was significant ($P < 0.05$) only in September 2012. No significant interaction between product type and rate was observed. Different letters within rows indicate a significant difference between types of products.

Sample period	Control	BBCC	YWC	LSD
September 2012	6.11 b	6.61 ab	7.02 a	.50
October 2014	6.54 a	6.55 a	6.86 a	.58

Table 19. September 2012 and October 2014 pH levels of soils amended with composts, by rate. Rate was not significant ($P < 0.05$) during either sampling period. Different letters within rows indicate a significant difference between rates of application.

Sample period	15%	30%	45%	LSD
September 2012	6.49 a	6.71 a	6.54 a	.50
October 2014	6.56 a	6.89 a	6.50 a	.58

Over the same time period, all of the soil in the study had EC levels below the 2000 $\mu\text{S}/\text{cm}^2$ concentration (Tables 20-23) considered to inhibit the growth of very sensitive vegetation (Bernstein 1975). The low initial levels for all biosolids-amended soils are probably due to the small quantities that were applied. In this study no more than 48 Mg/ha of product were applied. For comparison, when Rodgers and Anderson (1995) applied biosolids to soil at 56 Mg/ha they observed a soil an EC of 900 $\mu\text{S}/\text{cm}^2$. The BBCC product, applied at rates of 103, 207 and 310 Mg/ha, had an average initial EC of $2519 \mu\text{S}/\text{cm}^2 \pm 837 \mu\text{S}/\text{cm}^2$. Those values are similar to the ones obtained by Rodgers and Anderson (1995) when they amended soil with sewage sludge at rates of 111, 222 and 333 Mg/ha (1400, 2900 and 3400 $\mu\text{S}/\text{cm}^2$, respectively). Despite these initial elevated concentrations, all treatments dropped to levels well below those considered harmful to most plants. This is due to the combined factors of the generally mesic climate and the low cation exchange capacity of the soil providing few exchange sites to retain Ca^+ and Na^+ , and the gravelly soil providing high levels of drainage that leach out the soluble Ca^+ and Na^+ .

Table 20. September 2012 and October 2014 electrical conductivity (EC) levels for soils amended with biosolids, by product type. Values are in $\mu\text{S}/\text{cm}^2$. Type of product was not significant ($P < 0.05$) during either sampling period. Different letters within rows indicate a significant difference between types of products.

Sample period	Control	BB	CRD	RMI	WW	WRB	LSD
September 2012	528 b	827 ab	1094 a	865 ab	1023 ab	904 ab	509
October 2014	127 a	260 a	220 a	229 a	215 a	272 a	161

Table 21. September 2012 and October 2014 electrical conductivity (EC) levels for soils amended with biosolids, by rate of application. Values are in $\mu\text{S}/\text{cm}^2$. Rate of application was not significant ($P < 0.05$) in October 2014. Different letters within rows indicate a significant difference between rates of application.

Sample period	48 lb/N	144 lb/N	288 lb/N	LSD
September 2012	703 b	772 b	1146 a	360
October 2014	244 a	202 a	215 a	114

Table 22. September 2012 and October 2014 electrical conductivity (EC) levels for soils amended with composts, by product type. Values are in $\mu\text{S}/\text{cm}^2$. Different letters within rows indicate a significant difference between types of products.

Sample period	Control	BBCC	YWC	LSD
September 2012	528 b	3183 a	823 b	924
October 2014	127 b	283 ab	391 a	195

Table 23. September 2012 and October 2014 electrical conductivity (EC) levels for soils amended with composts, by rate of application. Values are in $\mu\text{S}/\text{cm}^2$. Rate of application was not significant ($P < 0.05$) during either sampling period. Different letters within rows indicate a significant difference between rates of application.

Sample period	15%	30%	45%	LSD
September 2012	1250 a	1612 a	1673 a	924
October 2014	321 a	241 a	239 a	195

Vegetation Survey

The roadside is host to wide array of flora, ranging from noxious and invasive annual weeds to rare and endangered native perennials. The reasons for the presence or absence of individual species can include soil conditions, slope orientation, traffic patterns and microclimates (Forman and Deblinger 2000). Within the Rhode Island climate, cool season perennial grasses have been identified as affordable, mowing tolerant species able to stabilize roadside soil while remaining green from spring through fall. While the species chosen for planting will hopefully dominate the ecosystem, they are not expected to be the only species present. The roadside is an open environment that can be colonized by an array of vegetation (Tikka, Högmander and Koski 2001; Rentch et al. 2005; Brown and Sawyer 2012). In amending the soil to provide for the physical and chemical needs of perennial turf grasses, the goal is to help them outcompete annual species that specialize in colonizing very sunny, warm and disturbed habitats while also promoting conditions favorable to the establishment of other perennial species, particularly native species. The vegetation survey sought to characterize the vegetation present within the study plots and determine how amending the soils of the berm/slope region of the roadside influences the plant populations within the plots and the adjacent swale. Species counts were analyzed based upon the specific amendments, the rate of application of the amendments and location within the plot (Location 1 [0 m – 1.5 m from the paved surface], Location 2 [1.5 m – 3 m from the paved surface], and Location 3 [3 m – 4.5 m from the paved surface]).

Amendment and rate – Planted vs. Weed

Both the biosolids and the compost amendments significantly increased coverage by planted species and decreased weedy/volunteer species (all non-planted species). Relative coverage was calculated using the count of instances of planted species as a percentage of the total instances of all species. In June (Table 24), all plots amended with biosolids had significantly higher relative coverage of planted species than the control, with the product averages ranging from 49.1% (WRB) to 60.5% (RMI). Compost-amended plots also had significantly more planted species coverage than the control, averaging 56.0% for BBCC and 39.9% for YWC. Control plots averaged 27.8% (Table 25). In September (Table 24), the range of averages for relative coverage of planted species within plots amended with biosolids was from 33.1% (WRB) to 43.8% (CRD). Compost-amended plots averaged 44.7% for BBCC and 39.7% for YWC (Table 25). Control plots averaged 24.5%, significantly less relative coverage of planted species than all products except WRB (Table 24 and Table 25).

In general percent coverage of planted species demonstrated very little difference between rates in both June and September. Significant differences between rates occurred only for the biosolids amendments in June where the 288 kg N/ha rate produced significantly greater coverage with planted species than the 48 kg N/ha rate and 144 kg N/ha rate (Table 26). Relative coverage of biosolids-amended plots in June ranged from 45.3% at 48 kg N/ha to 58.2% at 288 kg N/ha (Table 26). In September relative coverage of biosolids-amended plots ranged from 35.9% at 48 kg N/ha to 39.9% at 288 kg N/ha (Table 26). Compost-amended plots, by application

rate, had average relative coverages between 39.2% at 15% v:v and 42.4% at 30% v:v in June and between 35.7% at 30% v:v and 36.6% at 45% v:v in September (Table 27). Control plots in June averaged 27.8% and in September averaged 24.5% (Table 26 and Table 27).

Table 24. June and September 2014 percent coverage of planted species within biosoils-amended plots, by product type. Different letters within rows indicate a significant difference between product types.

Sample Period	Control	BB	CRD	RMI	WW	WRB	LSD
June 2014	27.8% b	50.5% a	56.9% a	60.5% a	54.85 a	49.1% a	12.1%
September 2014	24.5% c	38.1% ab	43.8% a	43.4% a	42.7% a	33.1% bc	9.1%

Table 25. June and September 2014 percent coverage of planted species within compost-amended plots, by product type. Different letters within rows indicate a significant difference between product types.

Sample Period	Control	BBCC	YWC	LSD
June 2014	27.8% c	56.0% a	39.9% b	10.3%
September 2014	24.5% b	44.7% a	39.7% a	10.3%

Table 26. June and September 2014 percent coverage of planted species within biosoils-amended plots, by application rate. Different letters within rows indicate a significant difference between rates of application.

Sample Period	48 lb/N	144 lb/N	288 lb/N	LSD
June 2014	46.3% b	45.3% b	58.2% a	8.6%
September 2014	37.1%	35.9%	39.9%	6.4%

Table 27. June and September 2014 percent coverage of planted species within compost-amended plots, by application rate. Different letters within rows indicate a significant difference between rates of application.

Sample Period	15%	30%	45%	LSD
June 2014	39.2% a	42.4% a	42.1% a	10.3%
September 2014	36.6% a	35.7% a	36.6% a	10.3%

Amendment and rate – Perennial vs Annual

In addition to observing the coverage of planted species relative to weed species, I analyzed the plant community based upon the broader categories of perennial and annual species. This acknowledges that many of the naturally occurring species are potentially desirable perennials. While some perennial species are considered noxious weeds, they will still provide greater benefits to the roadside than annuals which will die over the winter.

During the June survey of the biosolids amended plots, the type of product had a significant effect on the coverage of perennial species (Table 28). In that survey, RMI at 83.3% and WW at 81.9% had a percentage of perennial species coverage significantly different than the control at 68.3%. Type of product was not significant for the compost-amended plots (Table 29). In September, none of the plots amended with any of the biosolids or compost products had perennial species coverage significantly different than the control at 50.3% (Table 28 and Table 29). Application rate did not significantly impact the coverage of perennial species relative to annual species within any of the amended plots in either June or September. For biosolids amended plots, coverage ranged from 74.9% at 144 kg N/ha to 78.0% at 288 kg N/ha for June and from 55.2% at 288 kg N/ha to 57.1% at 144 kg N/ha for September. Compost amended plots had coverage ranging from 71.6% at 15% v:v to 79.3% at 45% v:v for June and from 58.5% at 15% v:v to 60.2% at 45% v:v in September.

The lack of a significant difference in perennial species coverage between amended and control plots can be explained by significantly greater instances of

individual weedy/volunteer perennial species within the control plots. This compensated for the significantly fewer instances of planted species, all of which are perennial, within the control plots. With similar counts of annuals appearing in both control and amended plots, a significant difference in the ratio of annuals to perennials did not emerge.

Although I observed a similar annual:perennial ratio across treatments, this did not account for total plot coverage of vegetation, as many plots had areas of bare ground. To better compare the actual coverage and vigor of the vegetation within the plots I examined differences in the species counts themselves. In June and September, the type of product significantly affected the counts per quadrat, as opposed to the coverage, of planted species (Tables 34,35, 37 and 39). Control plots had an average count of planted species of 56.7 per quadrat in June and 48.8 per quadrat in September. This was significantly less than all of the biosolids amended plots in June, ranging from WRB at 86.5 per quadrat to RMI at 107.1 per quadrat, and significantly less than all of the biosolids plots except WRB in September, ranging from BB at 81.4 per quadrat to CRD at 89.9 quadrat. Control counts were also significantly less than the counts within the compost-amended plots, ranging from YWC at 90.3 to BBCC at 109.4 in June and BBCC at 83.3 to YWC at 88.0 in September.

In both June and September, neither product nor rate had a significant effect on either the total annual or perennial counts in either the biosolids-amended or compost-amended plots (Tables 30 – 33). Control counts for June were 68.1 for total annuals and 154.0 for total perennials. In September, control counts were 73.1 for total

annuals and 109.9 for total perennials. In June, while product was not significant to $p < 0.05$ across the overall main effect, individual treatments were significant in certain biosolids-amended plots. Both RMI at 32.3 and WW at 36.9 had significantly fewer annuals than the control and WRB at 121.7 had significantly fewer perennials than the control. These values were not significantly different than other biosolids-amended plots. Average values in June were 42.9 for annuals and 145.0 for perennials within biosolids-amended plots and 47.4 for annuals and 166.0 for perennials within compost-amended plots. In September, plots amended with WRB had average perennial counts of 86.8. This was significantly lower than all other biosolids-amended plots, but not significantly different from the control. Average values in September were 77.6 for annuals and 120.3 for perennials within biosolids-amended plots and 67.8 for annuals and 132.0 for perennials within compost-amended plots. It should be noted that while counts of annuals within amended plots in June were only significantly different from the control for two of the amendments, the control plots had 30 – 50% more annuals than most of the plots. While not statistically significant in most cases, it could be practically significant as the relationship between early-season perennial to annual species is explored.

Other perennial species, in addition to the planted species, that were affected by type of amendment were *Trifolium repens* (white clover), in June (Table 34 and Table 35) and September (Table 37 and Table 39), and *Juncus tenuis* (path rush), in June (Table 34). White clover counts in June were significantly greater in the control plots at 32.4 than in all biosolids amended plots except WW, ranging from WRB at 4.4 to CRD at 15.6. Within compost-amended plots, YWC-amended plots had

significantly more clover than the control at 52.9 while BBCC-amended plots had significantly less at 7.0. In September, the control, at 31.6, had significantly more clover than all biosolids amended plots except WW, ranging from WRB at 1.2 to RMI at 13.1. Among compost-amended plots, the control had significantly more clover than BBCC at 4.2, but not YWC. Path rush counts in June were significantly greater in the control plots at 34.7 than in all biosolids-amended plots, ranging from CRD at 4.8 to BB at 12.9, and all compost-amended plots from BBCC at 2.7 to YWC at 8.7.

Type of amendment also affected the most common annual species, *Digitaria* sp. (crabgrass). Crabgrass counts in June (Table 34 and Table 35), at 42.4 for the control, were significantly higher than in plots amended with the biosolids products RMI at 16.5, CRD at 20.4 and WW at 22.9, and the compost products BBCC at 15.3 and YWC at 21.9. In September the control, at 68.1, was not significantly different from any biosolids or compost products (Table 37 and Table 39).

It appears that the perennial plants that would have naturally established were replaced with the seeded species. No substantial increase in the soils' favorability to perennial species was observed, aside from the RMI and CRD plots in June. The turf within the plot amended with these products had the lowest crabgrass counts and the greatest planted species counts among the biosolids-amended plots. These impact, however did not carry over into the September survey. While perennial species in general did not appear to benefit from the addition of the amendments, the planted species did. Future observations will establish if this trend allows for the long-term establishment and spread of the planted species within the amended plots.

Table 28. June and September 2014 percent coverage of perennial species within biosolids-amended plots, by product type. Different letters within rows indicate a significant difference between product types.

Sample Period	Control	BB	CRD	RMI	WW	WRB	LSD
June	68.3% b	78.6% ab	77.0% ab	83.3% a	81.9% a	67.0%	12.7%
September	50.3% ab	59.1% a	59.3% a	61.0% a	61.3% a	46.6% b	12.2%

Table 29. June and September 2014 percent coverage of perennial species within compost-amended plots, by product type. Different letters within rows indicate a significant difference between product types.

Sample Period	Control	BBCC	YWC	LSD
June	68.3% a	78.9% a	79.0% a	13.4%
September	50.3% a	63.8%	63.3% a	15.1%

Table 30. June 2014 total counts of annual and perennial species within biosolids-amended plots, by product type. Different letters within rows indicate a significant difference between product types.

Vegetation Type	Control	BB	CRD	RMI	WW	WRB	LSD
Annual	68.1 a	40.3 ab	46.0 ab	32.3 b	36.9 b	59.0 ab	27.9
Perennial	154.0 a	152.0 ab	145.6 ab	152.2 ab	153.7 ab	121.7 b	32.1

Table 31. June 2014 total counts of annual and perennial species within compost-amended plots, by product type. Different letters within rows indicate a significant difference between product types.

Vegetation Type	Control	BBCC	YWC	LSD
Annual	68.1 a	44.9 a	49.8 a	33.0
Perennial	154.0 a	153.9 a	178.0 a	33.9

Table 32. September 2014 total counts of annual and perennial species within biosolids-amended plots, by product type. Different letters within rows indicate a significant difference between product types.

Vegetation Type	Control	BB	CRD	RMI	WW	WRB	LSD
Annual	73.1 a	76.9 a	80.0 a	75.0 a	73.5 a	82.8 a	17.3
Perennial	109.9 ab	129.7 a	123.7 a	125.2 a	135.9 a	86.8 b	36.5

Table 33. September 2014 total counts of annual and perennial species within compost-amended plots, by product type. Different letters within rows indicate a significant difference between product types.

Vegetation Type	Control	BBCC	YWC	LSD
Annual	73.1 a	65.2 a	73.3 a	20.2
Perennial	109.9 a	120.7 a	143.3 a	40.4

Table 34. Coverage of most common species within biosolids-amended plots during June 2014 vegetation survey. Different letters indicate significant differences between plots amended with different biosolids products.

June most common species	Control	BB	CRD	RMI	WW	WRB	LSD
Planted	56.7 b	94.0 a	106.0 a	107.1 a	93.4 a	86.5 a	21.7
<i>Digitaria sp.</i>	42.4 a	28.0 abc	20.4 bc	16.5 c	22.9 bc	32.7 ab	15.9
<i>Trifolium repens</i>	32.4 a	12.9 c	15.6 bc	11.3 c	28.1 ab	4.4 c	14.2
<i>Agrostis sp.</i>	18.3 a	17.7 a	6.6 a	12.1 a	16.9 a	11.0 a	13.9
<i>Elymus repens</i>	6.1 a	5.2 a	9.3 a	5.0 a	2.4 a	3.8 a	7.0
<i>Juncus tenuis</i>	34.7 a	12.9 b	4.8 c	5.6 bc	5.6 bc	11.1 bc	7.7
<i>Medicago lupulina</i>	0.3 a	0.6 a	3.4 a	1.4 a	2.6 a	2.7 a	3.3
<i>Chamaesyce aculate</i>	20.4 a	6.7 b	7.3 b	5.5 b	5.8 b	12.1 ab	10.8
<i>Plantago major</i>	0.2 b	3.5 a	1.5 ab	3.9 a	1.3 ab	0.6 b	2.9

Table 35. Coverage of most common species within compost-amended plots during June 2014 vegetation survey. Different letters indicate significant differences between plots amended with different compost products.

June most common species	Control	BBCC	YWC	LSD
Planted species	56.7 b	109.4 a	90.3 a	20.6
<i>Digitaria sp.</i>	42.4 a	15.3 b	21.9 ab	17.8
<i>Trifolium repens</i>	32.4 b	7.0 c	52.9 a	17.1
<i>Agrostis sp.</i>	18.3 a	6.3 a	12.8 a	12.5
<i>Elymus repens</i>	6.1 b	17.9 a	3.0 b	10.0
<i>Juncus tenuis</i>	34.7 a	2.7 b	8.7 b	9.0
<i>Spergularia rubra</i>	20.4 a	10.6 a	11.1 a	13.1
<i>Plantago major</i>	0.2 b	5.9 a	5.4 a	4.7

Table 36. Coverage of most common species within compost-amended plots during June 2014 vegetation survey for which there was a significant interaction between amendment and rate . Different letters indicate significant differences between plots amended with compost at different rates.

BBCC June	Control	15%	30%	45%	LSD
<i>Medicago lupulina</i>	0.3 b	5.9 a	0.0 b	0.8 b	4.2
YWC June					
<i>Medicago lupulina</i>	0.3 b	0.0 b	22.6 a	0.0 b	16.3

Table 37. Coverage of most common species within biosolids-amended plots during September 2014 vegetation survey. Different letters indicate significant differences between plots amended with different biosolids products.

Sept. most common species	Control	BB	CRD	RMI	WW	WRB	LSD
Planted species	48.8 b	81.4 a	89.9 a	88.0 a	89.0 a	59.4 b	20.7
<i>Digitaria sp.</i>	68.1 a	69.0 a	66.4 a	62.8 a	69.1 a	75.6 a	14.7
<i>Trifolium repens</i>	31.6 a	12.2 b	11.6 b	13.1 b	27.6 a	1.2 b	14.4
<i>Agrostis sp.</i>	11.6 ab	21.4 a	5.7 b	10.0 ab	9.2 b	14.8 ab	11.8
<i>Elymus repens</i>	5.3 a	6.8 a	10.1 a	9.3 a	4.8 a	3.1 a	8.2
<i>Spergularia rubra</i>	4.8 a	2.3 ab	2.0 ab	1.9 ab	0.4 b	2.8 ab	3.8
<i>Echinochloa crus-galli</i>	0.2 a	0.4 a	1.2 a	0.7 a	0.8 a	0.1 a	1.4

Table 38. Coverage of most common species within biosolids-amended plots during September 2014 vegetation survey for which there was a significant interaction between amendment and rate. Different letters indicate significant differences between plots amended with biosolids at different rates.

BB Sept	Control	48 lb/N	144 lb/N	288 lb/N	LSD
<i>Chamaesyce aculate</i>	0.0 b	0.0 b	9.2 a	0.0b	6.9
<i>Juncus tenuis</i>	3.6 a	8.0 a	0.8 a	0.7 a	7.4
<i>Plantago major</i>	0.0 b	2.8 a	1.8 ab	0.0 b	2.6
CRD Sept					
<i>Chamaesyce aculate</i>	0.0 b	5.0 ab	0.8 b	12.2 a	9.1
<i>Juncus tenuis</i>	3.6 a	0.0 a	4.8 a	3.7 a	6.3
<i>Plantago major</i>	0.0 b	0.6 b	0.7 b	3.2 a	2.4
RMI Sept					
<i>Chamaesyce aculate</i>	0.0 b	0.6 b	17.8 a	0.0 b	9.8
<i>Juncus tenuis</i>	3.6 a	1.1 a	0.2 a	2.3 a	3.4
<i>Plantago major</i>	0.0 a	1.6 a	1.0 a	0.2 a	2.3
WRB Sept					
<i>Chamaesyce aculate</i>	0.0 a	0.6 a	7.6 a	0.0 a	9.3
<i>Juncus tenuis</i>	3.6 ab	1.9 b	12.6 a	5.7 ab	10.1
<i>Plantago major</i>	0.0 a	0.0 a	0.0 a	0.1 a	0.2
WW Sept					
<i>Chamaesyce aculate</i>	0.0 a	0.0 a	1.8 a	0.0 a	2.6
<i>Juncus tenuis</i>	3.6 ab	0.1 b	5.3 a	0.0 b	4.2
<i>Plantago major</i>	0.0 b	0.0 b	2.1 a	0.0 b	1.5

Table 39. Coverage of most common species within compost-amended plots during September 2014 vegetation survey. Different letters indicate significant differences between plots amended with different compost products.

Sept most common species	Control	BBCC	YWC	LSD
Planted species	48.8 b	74.7 a	78.2 a	19.2
<i>Digitaria sp.</i>	68.1 a	60.6 a	61.5 a	15.3
<i>Trifolium repens</i>	31.5 a	11.1 b	31.5 a	15.9
<i>Agrostis sp.</i>	11.6 a	7.0 a	11.8 a	9.9
<i>Elymus repens</i>	5.3 b	18.6 a	4.7 b	9.5
<i>Juncus tenuis</i>	3.6 a	1.4 b	1.1 b	1.7
<i>Spergularia rubra</i>	4.8 a	1.7 a	3.1 a	4.2
<i>Plantago major</i>	0.0 b	1.6 ab	2.3 a	1.9

Table 40. Coverage of most common species within compost-amended plots during September 2014 vegetation survey for which there was a significant interaction between amendment and rate. Different letters indicate significant differences between plots amended with compost at different rates.

BBCC September	Control	15%	30%	45%	LSD
<i>Chamaesyce aculate</i>	0.0 b	4.0 a	1.7 ab	0.0 b	3.9
<i>Echinochloa crus-galli</i>	0.2 b	1.0 b	7.8 a	0.0 b	4.9
YWC September					
<i>Chamaesyce aculate</i>	0.0 b	0.2 b	0.0 b	17.3 a	10.6
<i>Echinochloa crus-galli</i>	0.2 a	3.4 a	3.9 a	1.9 a	4.5

Location relative to the road

I analyzed the areas 0 - 1.5 m from the paved surface (Location 1), 1.5-3 m from the paved surface (Location 2), and 3-4.5 m from the paved surface (Location 3) independently of each other to determine if coverage of planted and perennial species changed significantly, as compared to the control, as distance from the road changed. Different coverage based on distance from the road could suggest that different management techniques would be needed for the different areas.

Planted coverage by location

In Location 1, in both June and September (Tables 41 – 44), I observed no significant difference in the coverage of planted species between the turf in the control plots and the plots amended with either biosolids or compost. In June, the turf within the control plots had planted coverage of 31.5% and in September had planted coverage of 30%. In June, coverage of planted species within all amended plots ranged from YWC at 29.7% to BBCC at 48.2%. In September, the coverage of planted species within all amended plots ranged from WRB at 28.4% to CRD at 35.0%.

In Location 2, for all amended plots in June (Table 41 and Table 42) and all amended plots, except those amended with WRB, in September (Table 43 and Table 44), I observed significant differences in the coverage of planted species in the turf compared to the turf within the control plots. In June, the turf within the control plots had planted coverage of 25.9%. Turf within the plots amended with biosolids had planted species coverage ranging from BB at 57.4% to RMI at 69.5%. Turf within

plots amended with compost had planted species coverage of 45.8% for YWC and 61.7% for BBCC. In September, the turf within the control plots had planted species coverage of 27.3%. Turf within the plots amended with biosolids that were significantly different from the control had planted species coverage ranging from BB at 43.3% to RMI 49.6%. Turf within the plots amended with compost had planted species coverage of 47.2% for YWC and 50.1% for BBCC.

In Location 3, in both June and September (Tables 41 – 44), I observed significant differences in the coverage of planted species between the turf in the control plots and all of the plots amended with either biosolids or compost. In June, the turf within the control plots had planted coverage of 25.9%. Turf within the plots amended with biosolids had planted species coverage ranging from WRB at 48.8% to RMI at 59.7%. Turf within plots amended with compost had planted species coverage of 44.1% for YWC and 58.0% for BBCC. In September, the turf within the control plots had planted species coverage of 16.2%. Turf within the plots amended with biosolids that were significantly different from the control had planted species coverage ranging from WRB at 32.5% to CRD and WW at 47.7%. Turf within the plots amended with compost had planted species coverage of 42.3% for YWC and 49.8% for BBCC.

Table 41. June 2014 coverage of planted species within different locations of the turf of plots amended with biosolids, by type of product. Different letters indicate a significant difference in planted coverage between types of product.

Location	Control	BB	CRD	RMI	WW	WRB	LSD
1	31.5% a	42.5% a	49.2% a	52.4% a	49.9% a	39.8% a	30.1%
2	25.9% b	57.4% a	66.0% a	69.5% a	61.8% a	58.7% a	15.9%
3	25.9% b	51.5% a	55.6% a	59.7% a	52.6% a	48.8% a	21.1%

Table 42. June 2014 coverage of planted species within different locations of the turf of plots amended with compost by type of product. Different letters indicate a significant difference in planted coverage between types of product.

Location	Control	BBCC	YWC	LSD
1	31.5% a	48.2% a	29.7% a	26.8%
2	25.9% c	61.7% a	45.8% b	15.7%
3	25.9% b	58.0% a	44.1% a	15.0%

Table 43. September 2014 coverage of planted species within different locations of the turf of plots amended with biosolids by type product. Different letters indicate a significant difference in planted coverage between types of product.

Location	Control	BB	CRD	RMI	WW	WRB	LSD
1	30.0% a	31.1% a	35.0% a	33.3% a	34.2% a	28.4% a	20.7%
2	27.3% b	43.3% a	48.8% a	49.6% a	46.3% a	38.5% ab	13.7%
3	16.2% c	39.9% ab	47.7% a	47.3% ab	47.7% a	32.5% b	15.2%

Table 44. September 2014 coverage of planted species within different locations of the turf of plots amended with compost by type of product. Different letters indicate a significant difference in planted coverage between types of product.

Location	Control	BBCC	YWC	LSD
1	30.0% a	34.4% a	29.6% a	25.6%
2	27.3% b	50.1% a	47.2% a	14.3%
3	16.2% b	49.8% a	42.3% a	17.0%

Perennial coverage by location

In Location 1, in both June and September (Tables 45 – 48), I observed no significant difference in the coverage of perennial species between the turf in the control plots and the plots amended with either biosolids or compost. In June, the turf within the control plots had perennial coverage of 61.2% and in September had perennial coverage of 51.2%. In June, coverage of perennial species within all amended plots ranged from WRB at 47.9% to RMI at 68.5%. In September, the coverage of perennial species within all amended plots ranged from WRB at 35.9% to WW at 48.2%.

In Location 2, in June (Table 45 and Table 46) for plots amended with either biosolids or compost, only the turf within the plots amended with RMI, at 88.3%, and WW, at 89.9%, were significantly different than the control at 73.0%. In September (Table 47 ad Table 48), I observed no significant difference in the coverage of perennial species between the turf in the control plots and the plots amended with either biosolids or compost. The turf within the control plots had perennial coverage of 54.2%. Turf within all amended plots had perennial coverage that ranged from WRB at 50.9% to BBCC at 70.0%.

In Location 3, in June, only the turf within the plots amended with RMI, at 93.8% (Table 45), had perennial coverage significantly different from the control, at 70.7%. Turf in all other amended plots (Table 45 and Table 46) had perennial coverage ranging from WRB at 79.8% to BBCC at 90.5%. In September (Table 47 ad Table 48), I observed significant differences in the coverage of perennial species

between the turf in the control plots and all of the plots amended with either biosolids or compost, except for those plots amended with WRB. The turf within the control plots had perennial coverage of 45.5%. Turf within the plots amended with biosolids had perennial species coverage ranging from BB at 67.8% to RMI at 75.3%. Turf within plots amended with compost had perennial species coverage of 77.7% for YWC and 79.7% for BBCC.

I also analyzed the total counts of both perennial and annual species within plots, as opposed to their relative coverage within those plots. I did this to determine if amending the soil increased total plant coverage and not just the ratio of perennials to annuals. When all locations were included in the models for June and September of 2014 for turf amended with either biosolids or compost, neither product nor rate had a significant ($P < 0.05$) effect on total counts of annual or perennial species, but location did. When only Locations 2 and 3 were included in the model, product had a significant effect in some of the models, but location did not. Rate was not significant in any model and no significant interaction were detected.

In June 2014, excluding Location 1 from the model, type of product had a significant effect on the total count of annual species within the turf of biosolids and compost amended plots (Table 49 and Table 50). Biosolids amended plots with counts significantly less than the control ranged from RMI at 17.3 instances per quadrat to BB at 27.8 instances per quadrat. The turf of the plots amended with WRB at 45.1 instances per quadrat were not significantly different from the control at 66.5 instances per quadrat. The turf within compost amended plots had significantly fewer instances of annual species than the control for both BBCC at 22.3 instances per

quadrat and the YWC at 25.7 instances per quadrat. Product did not have a significant effect on total perennial counts for either biosolids or composts. No product produced counts of perennial species that significantly differed from the control at 168.3 instances per quadrat. Within the biosolids amended plots the turf in the WW amended plots at 175.7 instances per quadrat did significantly differ from the WRB amended plots at 145.3 instances per quadrat.

In September 2014 excluding Location 1 from the model, type of product had no significant effect on the total count of annual species within the turf of biosolids-amended and compost-amended plots (Table 51 and Table 52). No product produced counts of annual species that significantly differed from the control at 72.2 instances per quadrat. Product did have a significant effect on the total counts of perennial species in both biosolids-amended and compost-amended plots. Only plots amended with WW, at 167.4 instances per quadrat, had counts significantly greater than the control at 114.3 instances per quadrat. All other biosolids products, except for WRB at 105.9 instances per quadrat, produced counts greater than the control, but not significantly so. The turf within YWC compost-amended plots had significantly greater instances of perennial species than the control at 169.7 instances per quadrat, but the BBCC at 144.2 did not.

In all cases the area nearest the road was less able to support perennial species. This area was at the greatest risk of disturbance from vehicles leaving the paved travel surface and causing soil compaction, erosion and destruction of vegetation. Perennial species require resources (water, nutrients, stored energy) to recover from damage

where annual species may regenerate from large soil seedbanks, giving them an advantage in highly disturbed soils such as those nearest the road.

The increase in perennial species as distance from the road increased is in keeping with the findings of Brown and Sawyer (2012). Their study looked at mowed, yet unamended areas along Rhode Island highways. They noticed this trend on a larger scale, with their three zones (Zone 1 0-3.3m from the pavement, Zone 2 3.3-6.6 m from the pavement, Zone 3 6.6-10 m from the pavement) being the same size as an entire plot in this study. Karim and Mallik (2008) observed that all four of the microhabitats that they surveyed along the Trans Canada highway were dominated by perennial species. They, however, did not identify individual grass species, making their study and this one difficult to compare. The regions they surveyed were relatively undisturbed for 10 to 15 years, allowing for a degree of succession to take place and trees and shrubs to establish. This natural succession may not be an option along Rhode Island highways where woody vegetation poses unacceptable safety risks.

Table 45. June 2014 coverage of perennial species within the turf of plots amended with biosolids, by type of product. Different letters indicate a significant difference in planted coverage between types of product.

Location	Control	BB	CRD	RMI	WW	WRB	LSD
1	61.2% a	65.0% a	65.1% a	68.5% a	65.8% a	47.9% a	30.4%
2	73.0% c	87.0% abc	81.3% abc	88.3% ab	89.9% a	74.6% bc	14.2%
3	70.7% b	84.9% ab	84.8% ab	93.8% a	90.2% ab	79.8% ab	20.0%

Table 46. June 2014 coverage of perennial species within the turf of plots amended with compost, by type of product. Different letters indicate a significant difference in planted coverage between types of product.

Location	Control	BBCC	YWC	LSD
1	61.2% a	61.8% a	61.1% a	31.7%
2	73.0% a	86.2% a	85.4% a	15.4%
3	70.7% a	90.5% a	90.4% a	24.0%

Table 47. September 2014 coverage of perennial species within the turf of plots amended with biosolids, by type of product. Different letters indicate a significant difference in planted coverage between types of product.

Location	Control	BB	CRD	RMI	WW	WRB	LSD
1	51.2%	45.6% a	47.7% a	42.9% a	48.2% a	35.9% a	21.2%
2	54.2% a	64.1% a	58.3% a	65.1% a	61.7% a	50.9% a	23.1%
3	45.5% c	67.8% ab	72.5% ab	75.3% a	73.9% ab	52.9% bc	21.3%

Table 48. September 2014 coverage of perennial species within the turf of plots amended with compost, by type of product. Different letters indicate a significant difference in planted coverage between types of product.

Location	Control	BBCC	YWC	LSD
1	51.2% a	42.8% a	45.1% a	27.2%
2	54.2% a	70.0% a	67.4% a	31.0%
3	45.5% b	79.7% a	77.7% a	25.5%

Table 49. June 2014 total count (instances per quadrat) of annual and perennial species within Locations 2 and 3 of the turf of plots amended with biosolids, by type of product. Different letters indicate a significant difference in instances per quadrat of annual or perennial species between types of products.

Species type	Control	BB	CRD	RMI	WW	WRB	LSD
Annual	66.5 a	27.8 bc	29.1 bc	17.3 c	20.8 c	45.1 ab	23.0
Perennial	168.3 ab	170.2 ab	154.5 ab	169.9 ab	175.7 a	145.3 b	29.8

Table 50. June 2014 total count (instances per quadrat) of annual and perennial species within Locations 2 and 3 of the turf of plots amended with composts, by type of product. Different letters indicate a significant difference in instances per quadrat of annual or perennial species between types of products.

Species type	Control	BBCC	YWC	LSD
Annual	66.5 a	22.3 b	25.7 b	28.1
Perennial	168.3 a	167.5 a	188.0 a	32.1

Table 51. September 2014 total count (instances per quadrat) of annual and perennial species within Locations 2 and 3 of the turf of plots amended with biosolids, by type of product. Different letters indicate a significant difference in instances per quadrat of annual or perennial species between types of products.

Species type	Control	BB	CRD	RMI	WW	WRB	LSD
Annual	72.2 a	73.6 a	70.1 a	64.5 a	71.3 a	81.2 a	17.9
Perennial	114.3 bc	153.8 ab	134.6 abc	149.0 ab	167.4 a	105.9 c	41.1

Table 52. September 2014 total count (instances per quadrat) of annual and perennial species within Locations 2 and 3 of the turf of plots amended with composts, by type of product. Different letters indicate a significant difference in instances per quadrat of annual or perennial species between types of products.

Species type	Control	BBCC	YWC	LSD
Annual	72.2 a	52.4 a	62.4 a	24.3
Perennial	114.3 b	144.2 ab	169.7 a	46.8

CHAPTER 5

CONCLUSIONS

The primary conclusion drawn from this study is one that was not addressed in the initial hypotheses. Two years after amending roadside soils with biosolids and compost products, the most significant factor in predicting the quality of the turf within those plots is the volume at which these organic amendments were applied. Applying the products at greater volume increased the soil organic matter and the soil's ability to retain moisture.

I utilized two different forms of organic soil amendments (biosolids and composts) and based their application rates on different characteristics (nitrogen expected to be mineralized in the first year [biosolids] and percent of the first 15 cm of soil [composts]). This led to vastly different amounts (Mg/ha) of material being applied. This also led to vastly different rates of organic carbon being applied. These rates of application for both the total amount of material (1 to 48 Mg/ha for biosolids and 103 to 523 Mg/ha for composts) and total carbon applied (<1 to 15 Mg/ha for biosolids and 32 to 109 Mg/ha for composts) had a substantial impact on the soil organic matter and soil moisture levels. The much greater rates of total compost material applied brought the application rates closer to those of previous studies (60-437 Mg/product/ha) that saw success in improving vegetation utilizing biosolids amendments (Wakefield and Sawyer 1986, Tester 1990, Sullivan et al. 2003).

The large amounts of organic matter present within the composts likely changed the mineralization dynamics and long-term biology of the soil rather than just

providing immediate fertilization. This increase in soil organic matter led to significantly greater soil moisture levels within the compost amended plots. The increased soil moisture likely led to increased nitrogen mineralization, greater buffering of soil temperature levels and the prevention of drought-induced senescence. Despite the biosolids products appearing to providing sufficient first-year mineralizable nitrogen, they did not significantly increase soil organic matter or soil moisture. The difference in organic matter was likely the key factor in the declining performance of the biosolid-amended plots in the second year of the study as compared to the sustained performance of the compost-amended plots over the same time. In order for roadside amendments to successfully supply the needs of cool-season perennial grasses and native perennials, greatest consideration should be given to the physical properties of the soil and how it will support the microbiological functions necessary for acceptable vegetation quality and persistence.

This initial conclusion provides good reasoning for the rejection of the first hypothesis: *The addition of stabilized biosolids at a rate of 144 kg N/ha to roadside soil prior to hydroseeding will significantly increase vegetation quality scores as compared to an unamended control two years after seeding because of increased plant available nitrogen in the soil.* The addition of stabilized biosolids at a rate of 144 kg N/ha did not improve the quality of vegetation as compared to the control two years after incorporation. Effects lasted approximately 20 months. Addition at rates of 48 kg N/ha and 288 kg N/ha did not improve the quality of the vegetation over that period either. The quality of the turf, as signified by quality scores, within the biosolids-amended soils were significantly better than those given to the control in the first year

of growth while in the second year the quality steadily declined until it was no longer significantly different from that of the turf within the unamended plots.

These trends in quality are attributed to two factors. First, the biosolids products were applied at rates that controlled for expected first-year mineralizable nitrogen and were applied at rates commonly associated with synthetic fertilizers. The nitrogen mineralization rates of the following years were not addressed. Second, the relatively small amounts of biosolids amendments that were applied did not improve the soil organic matter and its ability to retain plant-available moisture, leaving it prone to droughty conditions and low rates of nitrogen mineralization. The rates at which the biosolids amendments were applied are not recommended for a one-time application if the goal is to promote the persistence of perennial species. The rate of amendment application did, however, appear to effectively promote the early establishment of planted species and could potentially be used to amend annually fertilized soils.

The primary conclusion also provides reasoning for the support of the second hypothesis: *The addition of composts to roadside soil at a rate of 30% v:v prior to hydroseeding will significantly increase vegetation quality scores as compared to an unamended control two years after seeding because of increased plant available nitrogen in the soil.* The addition of composts at a rate of 30% v:v to the first 15 cm of soil did significantly improve the quality of vegetation as compared to the control. This improvement was also observed at the 15% and 45% v:v rates. The turf grown in the soil amended by the both of the composts performed well over the two year study, though differences existed in their performance in the first year. The BBCC appeared to provide sufficient first and second year mineralized nitrogen while both products

improved the soil organic matter and water holding capacity of the soil. The 15% v:v application rate of the BBCC can be recommended due to its ability produce turf of acceptable quality throughout the study. The YWC demonstrated the ability to consistently produce turf of acceptable quality in the second year and could benefit from the addition of a more quickly mineralizing source of nitrogen such as one of the biosolids products. Creating conditions conducive to the long-term mineralization of organic nitrogen appears to be an effective strategy for improving the persistence of perennial species within the roadside environment.

Overall, the products utilized in the study appeared to impact the vegetation in a manner consistent with the findings of previous studies. Smith et al. (1998) observed digested biosolids, such as BB, mineralizing nitrogen at a rate six times faster than composted biosolids, such as the WW product. This is reflected in the application rates by mass of the two products, with WW being applied at approximately seven times the rate of the BB. Furthermore, the compost products reacted in a manner generally consistent with the findings of Claassen and Carey (2004) who observed far greater release of nitrogen from biosolid co-compost than from yard waste composts. That same study, however, also demonstrated the variability in nitrogen release rates between similar organic products. Four different yard waste compost (short curing time, typical curing time, 18 month curing time, and highly processed) had initial nitrogen rates that varied by as much as 48% between products and nitrogen release rates that ranged from 1% to 7%. Just basing application rates on broad categories such as biosolids and composts is not sufficient for effectively predicting the mineralization rates of organic amendments.

This complexity is compounded when we add in the findings of Doublet et al. (2010) and Garau et al. (1986) who demonstrated that a range of factors that include particle size, soil type, and incorporation rate impact the rate of nitrogen mineralization. By acknowledging the influence of these variables, it becomes imperative that individual products be bench tested in soils and conditions (e.g. moisture, temperature, pH, EC) similar to those they will be used in in order to effectively model their impacts on vegetation. It will then fall on regulators to ensure that guidelines are established and adhered to in order to ensure the successful utilization of these products. Mentioned earlier was the dual challenge of biological and budgetary constraints. Unless the resources are present to test products and monitor their use, any knowledge concerning their impacts on soils, microbes and vegetation will likely only have short-lived positive effects.

Due to the differences in the establishment and persistence of vegetation within different areas of the plots based on distance from the road, I can neither fully support nor reject the third and fourth hypotheses: *The addition of stabilized biosolids at a rate of 144 kg N/ha to roadside soil prior to hydroseeding will significantly increase the coverage of perennial species in both June and September in the second year after seeding because of increased plant available nitrogen in the soil. The addition of composts to roadside soil at a rate of 30% v:v prior to hydroseeding will significantly increase the coverage of perennial species in both June and September in the second year after seeding because of increased plant available nitrogen in the soil.* Based on a relative coverage of perennial versus annual species, the RMI amended plots had significantly greater perennial coverage than the control in both June and September

2014 in the area of the plot 1.5 m to 4.5 m from the paved surface. In September 2014, within the area 3 m to 4.5 m from the paved surface, all turf, except that in plots amended with WRB, had perennial coverage significantly greater than the control. Also, most turf in that same region of the plot, whether in soil amended by biosolids or composts, had perennial coverage greater than the control, just not significantly so.

This brings us to an additional conclusion that was not previously hypothesized as part of this research. The factor that had the greatest effect on the coverage of planted and perennial species was the location in the plot relative to the roadside.

When the plots were divided into three distinct areas, differences in the composition of the turf emerged. Within Location 1 (0 - 1.5 m from the road) no amendment had the ability to significantly change the percent coverage of either planted or perennial species or the total instances of either annual or perennial species in the turf.

As distance increased from the road, so did significant differences between the amended plots and the control. Within Location 2 (1.5 - 3 m from the road) and location 3 (3 - 4.5 m from the road), product significantly affected the coverage of planted species within the turf. In both June and September 2014, all amended plots, except for the Location 2 WRB-amended plots in September, had coverage of planted species within the turf significantly greater than that of the unamended control plots. In June 2014, only plots amended with RMI had turf with relative coverage of perennial species that was significantly greater than the control in both Location 2 and 3. By September 2014, relative perennial coverage within Location 3 for all biosolids

and compost amended plots, except for those amended with WRB, was significantly greater than the control. Total perennial counts in September within Locations 2 and 3 were only significantly greater in plots amended with WW and YWC.

Since this study did not track or classify stresses on the turf, either on the whole plot or on specific locations within the plot, we can only hypothesize as to the cause of the differences between locations. The location closest to the road would have been more likely to have been damaged by vehicles, be more exposed to increased heat radiated from the road surface and intercept more runoff and particulates. As distance increased, the risk of disturbances should have decreased, allowing for better survival of planted and perennial species.

The stress applied by the proximity to the travel surface and the proximity to vehicles was observed during data collection, but not classified. This stress was especially notable when the two sides of study area were compared. The side with vegetation closer to vehicle traffic, not just a paved surface, had noticeably poorer vegetation and greater coverage of *Digitaria sp.* within one meter of the paved surface. Not only was the region within a meter of the paved surface significantly more disturbed than the areas further away, but the level of disturbance was different based on the soil's proximity to vehicle traffic. This is also the region of greatest importance to the structural integrity of the roadside where gullying and the erosion of soil would have the greatest negative impact. I encourage further study of this region of the roadside, with consideration being given to both vegetative and non-vegetative options for construction and management practices that preserve the services of the roadside while excluding invasive and noxious plant species.

A further observation is that *Trifolium repens* should be considered as an addition to the RIDOT Park mix of seeds due to its success in establishing in plots with no or little added nitrogen. Within otherwise poor plots, the areas with populations of *T. repens* supported stands of seeded species while maintaining noticeably greater soil moisture. The design of this study did not allow for the consideration of the effects of smaller stands of vegetation within the plots, but the observation of the investigators leads us to recommend the effects of this species, or another nitrogen fixing species, for further study within non-slope roadside environments.

Recommendations for future studies

With the expectation that the results from this study will justify the future investigation of the use of organic amendments within roadside soils, the following recommendations are presented.

- Future amendment studies should control for a single property among the amendments used. It is recommended that organic matter be explored as a critical factor in the amending of roadside soils. The effectiveness of different compost/biosolids combinations in improving vegetation and soil quality would be a worth investigation.
- Use fewer amendments with larger study plots. By using 21 different treatments along with a control, the ability to make specific observations was limited due to there being only three replications of each treatment. Furthermore, the great deal of variability within individual plots, along with the regular damage caused by vehicles disturbing large sections of

soil, made the small plots poor indicators of larger trends. The use of larger plots would allow for more randomized sampling procedures as well as minimizing the potential impacts of variability.

- Perform random soil profiles prior to amending and seeding and then again at the conclusion of the study in order to assess the impacts of amendments on the physical properties of existing soils while also documenting variability within the soils.
- Future studies should refrain from splitting replications between physically distinct areas. By splitting a replication in this study between two sides of the study area, a direct comparison of the effects of the two sides was not possible.
- Future roadside studies should control for the distance not only from the paved surface, but also from vehicle traffic. Utilizing an area that is less prone to vehicular damage is recommended as well.

APPENDICES

Appendix A

Interesting observations warranting further research

Effect of distance from vehicle travel

I have not come across a study that analyzes roadside vegetation as a function of distance from traffic as opposed to just the distance from the paved travel surface. Spencer et al. (1988) addresses the effects distance from the roadside had on plant growth and nitrogen availability, determining that positive nitrogen effects were derived from being closer to the road. However, they conducted these experiments using potted plants, as opposed to *in situ* vegetation, removing the effects of vehicle damage, run off, sand particles and other stress factors. Karim and Mallik (2008) looked at roadside vegetation *in situ*, observing the changes in species presence based on slope position, but made no mention of paved shoulder space between the travel lane and the vegetation. These studies indicate that there are engineering and design factors aside from soil, amendments and planted vegetation, such as vegetation's distance from a paved surface and from vehicle traffic, that significantly impact the establishment and persistence of planted and perennial species along the roadway. Further study of the impact of paved surface and vehicle distance from vegetation and methods to mitigate any negative effects they cause is highly recommended.

In observing the amended plots, the area closest to the road on the southern side of the study area (plots 34-66) was more heavily and uniformly dominated by *Digitaria sp.* and appeared to be under much more stress than the equivalent area on

the northern side of the study area (plots 1-33). When viewed from above (Figure 1) it can be seen that the southern side directly abuts the traffic lanes while on the northern side there is a paved shoulder that ranges in width from 2 m to 5 m and is guarded with posts. We conducted a two sample t-test for means on the coverage of both planted and perennial species, for both the June and September surveys, that compared the equivalent zones on the two sides of the road without consideration of amendment or rate. When compared, the area close to the road on the southern side has significantly ($P < .0001$) less coverage of both planted and perennial species than the northern side in both June and September.

This significant difference does not appear to negatively impact the other two zones. There is no significant difference noticed between the areas in the middle of plots in either month for either planted or perennial coverage. The area near the swale even performs better on the southern side, with significantly greater planted ($P = .0076$) and perennial ($P = .00002$) coverage in June and perennial coverage ($P = .0441$) in September. The poor turf within the area nearest the road could potentially have leached nitrate, contributing to the improved performance of the vegetation lower on the slope.

Amendment effects on adjacent environments

The swale was surveyed using a 10 x 100 cm quadrat with a 100 cm² grid. The quadrat was placed every 1.8 meters starting at the point where the swale met the drain for the median and continuing for 54 m until the swale no longer had treatment plots on both sides of it. As a control for the swale survey, we surveyed 54 m of swale from

a nearby unamended region of the median that utilized the same drain as that of the amended swale.

Fertilizer can impact flora beyond that area which it was directly applied to (Di and Cameron 2002). In order to observe the effects that applying organic amendments would potentially have on downslope vegetation we conducted a vegetation survey of the swale adjacent to the two blocks of study plots. A nearby swale was surveyed in the same manner and used as a control. All measurements were taken based upon distance from the drain utilized by the swales.

Thirty-eight species (some only identified to genus due to age or mowing) were identified between the two regions. Twenty-one species were identified in the study area while 32 species were identified in the control area. Of these species, 17 had counts that varied significantly between the two areas (Table 3). There was no significant difference in the presence of annual or perennial species between the two areas.

Soil moisture appears to have the greatest impact on the speciation within the two swales. Significantly greater coverage of *Cyperus esculentus* and *Persicaria maculosa*, two species common within cultivated soils indicate greater soil moisture. The USDA also classifies *Cyperus esculentus* as a facultative wetland species in the Northeast. It is difficult to ascribe the significantly greater coverage of *Elymus repens* and *Plantago major* to moisture differences since they were both common within the amended plots. The greater coverage of *Poa pratensis* is likely due to it having been seeded within the amended plots. The significantly greater presence of *Aster sp.*, *Andropogon virginicus*, *Dichanthelium acuminatum*, *Dichanthelium sphaerocarpon*

and *Digitaria sanguinalis* within the control swale indicate a lower soil moisture percentage. These species are associated with dry and disturbed soils (Uva et al. 1997). Other species with significantly greater coverage within the control swale are *Plantago aristata*, described as “found in sandy drought-prone sites”(Uva et al. 1997), *Rumex acetosella*, described as “often found on, but not limited to, acid soils and area with poor drainage, low nitrogen, and little competition” (Uva et al. 1997), and *Potentilla recta* which is generally found on dry soil in the Northeast (Uva et al. 1997). While both areas were predominately populated with native and naturalized weed species, the addition of organic amendments appears to have altered the moisture dynamics of the soil and led to the differences in individual species coverage. We theorize that differences in moisture dynamics between the two swales can be attributed to both greater organic matter within the swale adjacent to the amended soils, due to the movement of OM as runoff from the amended plots, and greater biomass due to the leaching of nitrate contributing to increased fertility within that swale. How this would impact the overall flora of the roadside is not yet evident. However, greater levels of moisture within the swale could lead to increased denitrification and carbon sequestration, which are a services often provided by wetlands. Increased vegetation would also help serve as a buffer to take up and filter heavy metals and contaminants that might occur in elevated levels within biosolids products (Wakefield et al. 1981) and road surface runoff.

Appendix B

Ap^	0 cm -12 cm; 7.5 YR 2.5/1 coarse sandy loam; many fine roots; moderate fine granular structure; 10% fine gravel
C1^	12 cm – 17 cm, sandy loam, massive, 10 YR 2/1
C2^	17 cm – 22 cm, gravelly sandy loam, massive, 10 YR 2/1
C3^	22 cm – 28 cm, very gravelly loamy coarse sandy, single grain, few masses 5YR 5/8, 10 YR 3/3
Cd^	28 cm – 38 cm, gravelly loamy coarse sand, stones and channers present, common masses 7.5YR 5/8, massive 10 YR 3/3
2C^	38 cm – 50+ cm, stoney loamy sand, single grain, 10YR 2/2

Appendix B. Soil profile description for study area June 2015. It is difficult to distinguish the native soil from HTM. Soil may have been brought in from offsite while soil from on site may have been screen and replaced. Stones larger than those allowed in the roadside construction guidelines were present. Redoximorphic features may have occurred either due to compacted soils and a perched water table or may have been previously present in the HTM used in the soil's construction.

Appendix C

Latin Name	Common Name	Perennial, Biennial, Annual (P/B/A)	Total Instances
Planted Species			
<i>Festuca Rubra</i> var. <i>rubra</i>	Red Fescue	P	226
<i>Lolium</i> sp.	Ryegrass	P	14715
<i>Poa pratensis</i>	Kentucky Bluegrass	P	4056
Non-Planted Species			
<i>Digitaria</i> sp.	Crabgrass	A	4640
<i>Trifolium repens</i>	White Clover	P	3858
<i>Agrostis</i> sp.	Bentgrass	P	2420
<i>Spergularia rubra</i>	Sandspurry	A	1780
<i>Juncus tenuis</i>	Path Rush	P	1699
<i>Elymus repens</i>	Quackgrass	P	1310
<i>Plantago major</i>	Broadleaf Plantain	P	596
<i>Medicago Lupulina</i>	Black Medick	A	554
<i>Vicia tetrasperma</i>	Vetch	A	269
<i>Matricaria discoidea</i>	Pineapple Weed	A	267
<i>Cyperus esculentus</i>	Yellow Nutsedge	P	228
<i>Crepis capillaris</i>	Smooth Hawksbeard	A	222
<i>Cerastium vulgatum</i>	Mouse-ear Chickweed	A	180
<i>Veronica persica</i>	Persian Speedwell	A	147
<i>Lactuca serriola</i>	Prickley Lettuce	A	134
<i>Nuttallanthus canadensis</i>	Oldfield Toadflax	A	131
<i>Polygonum aviculare</i>	Prostrate Knotweed	A	116
<i>Paspalum</i>	<i>Paspalum</i>	P	102
<i>Euphorbia maculata</i>	Spotted Spurge	A	87
<i>Rumex acetosella</i>	Sheep Sorrel	P	81
<i>Aster</i> sp.	Aster sp.	P	80
<i>Trifolium aureum</i>	Yellow Hop Clover	B	79
<i>Conyza canadensis</i>	Horseweed	A	76
<i>Plantago aristata</i>	Bracted Plantain	A	76
<i>Holcus lanatus</i>	Velvet Grass	P	67
<i>Artemisia vulgaris</i>	Mugwort	P	63
<i>Rumex crispus</i>	Curly Dock	P	58
<i>Ambrosia</i> sp.	Ragweed	A	57
<i>Taraxacum officinale</i>	Dandelion	P	56
<i>Festuca arundinacea</i>	Tall Fescue	P	54
<i>Schizachyrium scoparium</i>	Little bluestem	P	52
<i>Vulpia myuros</i>	Rat's-tail Fescue	A	50

<i>Setaria viridis</i>	Green foxtail	A	48
<i>Erigeron sp.</i>	Fleabane	A	44
<i>Dichanthelium</i>	Dichanthelium	P	40
<i>sphaerocarpon</i>	Sphaerocarpon		
<i>Hypochaeris radicata</i>	Cat's Ear	P	34
<i>Persicaria maculosa</i>	Lady's Thumb	A	30
<i>Trifolium pratense</i>	Red Clover	B	30
<i>Spurgularia</i>			
<i>canadensis</i>	Canadian sandspurry	A	28
<i>Daucus carota</i>	Wild Carrot	B	27
<i>Andropogon</i>			
<i>virginicus</i>	Broomsedge	P	19
<i>Dichanthelium</i>	Dichanthelium	P	18
<i>acuminatum</i>	acuminatum		
<i>Juncus canadensis</i>	Canadian Rush	P	18
<i>Potentilla recta</i>	Sulfur Cinquefoil	P	16
<i>Juncus effusus</i>	Soft Rush	P	10
<i>Plantago lanceolata</i>	Lanceleafed plantain	P	10
<i>Lotus corniculatus</i>	Birdsfoot Trefoil	P	9
<i>Alopecurus sp.</i>	Foxtail sp.	A	8
<i>Panicum virgatum</i>	Switchgrass	P	8
<i>Eragrostis spectabilis</i>	Purple Lovegrass	P	7
<i>Oxalis Stricta</i>	Yellow Woodsorel	P	7
<i>Scleranthus annuus</i>	Knawel	A	6
<i>Convolvulus arvensis</i>	Field bindweed	P	5
<i>Chenopodium album</i>	Lambsquarters	A	4
<i>Krigia virginica</i>	Dwarf Dandelion	A	3
<i>Lepidium campestre</i>	Field Pepperweed	A	3
<i>Hieracium sp.</i>	Hawkweed sp.	P	2
<i>Phleum pratense</i>	Timothy	P	2
<i>Eragrostis sp.</i>	Lovegrass	P	1
<i>Fragaria vesca</i>	Wild Strawberry	P	1
<i>Polygonum</i>			
<i>hydropiperoides</i>	Smartweed	P	1
<i>Verbascum thapsus</i>	Common Mullein	B	1

Appendix C. List of species present within quadrats placed inside study plots during the June 2014 vegetation survey, whether they are perennial, biennial or annual in Rhode Island and their total counted instances.

Appendix D

Latin Name	Common Name	Perennial, Biennial, Annual (P/B/A)	Total Instances
Planted Species			
<i>Festuca sp.*</i>	Fescue	P	1580
<i>Lolium sp.</i>	Ryegrass	P	13397
<i>Poa pratensis</i>	Kentucky Bluegrass	P	1100
Non-Planted Species			
<i>Digitaria sp.</i>	Crabgrass	A	13042
<i>Trifolium repens</i>	White Clover	P	3021
<i>Agrostis sp.</i>	Bentgrass	P	2224
<i>Elymus repens</i>	Quackgrass	P	1711
<i>Chamaesyce aculate</i>	Spotted Spurge	A	708
<i>Juncus tenuis</i>	Path Rush	P	482
<i>Spergularia rubra</i>	Sandspurry	A	381
<i>Plantago major</i>	Broadleaf Plantain	P	265
<i>Echinochloa crus-galli</i>	Barnyard Grass	A	251
<i>Polygonum aviculare</i>	Common Knotgrass	A	184
<i>Cyperus esculentus</i>	Yellow Nutsedge	P	160
<i>Setaria pumila</i>	Yellow Foxtail	A	126
<i>Conyza canadensis</i>	Horseweed	A	93
<i>Artemisia vulgaris</i>	Mugwort	P	87
<i>Paspalum</i>	Paspalum	P	84
<i>Panicum virgatum</i>	Switchgrass	P	48
<i>Holcus lanatus</i>	Velvet Grass	P	35
<i>Rumex crispus</i>	Curly Dock	P	23
<i>Ambrosia sp.</i>	Ragweed	A	22
<i>Plantago lanceolata</i>	Lanceleafed plantain	P	22
<i>Medicago lupulina</i>	Black Medic	B	21
<i>Taraxacum officinale</i>	Dandelion	P	21
<i>Lotus corniculatus</i>	Birdsfoot Trefoil	P	20
<i>Lactuca serriola</i>	Prickly Lettuce	A	19
<i>Cerastium fontanum.</i>	Mouse-ear Chickweed	A	14
<i>Trifolium pratense</i>	Red Clover	B	14
<i>Erigeron sp.</i>	Fleabane	A	13
<i>Rumex acetosella</i>	Sheep Sorrel	P	13
<i>Andropogon virginicus</i>	Broomsedge	P	12
<i>Oxalis stricta</i>	Wood Sorrel	P	11
<i>Portulaca oleracea</i>	Common Purslane		9

<i>Dichanthelium acuminatum</i>	Tapered Rosette Grass	P	8
<i>Trifolium arvense</i>	Rabbit's Foot Clover	A	7
<i>Portulaca oleracea</i>	Purslane	A	6
<i>Veronica persica</i>	Persian Speedwell	A	6
<i>Aster sp.</i>	Aster sp.	P	6
<i>Hypochaeris radicata</i>	Cat's Ear	P	5
<i>Mollugo verticillata</i>	Carpetweed		5
<i>Schizachyrium scoparium</i>	Little Bluestem	P	5
<i>Dichanthelium depauperatum</i>	Starved Panic Grass	P	4
<i>Trifolium campestre</i>	Yellow Hop Clover	B	4
<i>Hieracium sp.</i>	Hawkweed	P	4
<i>Daucus carota</i>	Wild Carrot	B	3
<i>Centaurea stoebe</i>	Spotted Knapweed	B	2
<i>Chenopodium album</i>	Lambsquarters	A	2
<i>Crepis tectorum</i>	Narrow-leaf Hawksbeard	A	2
<i>Raphanus raphanistrum</i>	Wild Radish	A	2
<i>Scleranthus annuus</i>	Knawel	A	1
<i>Convolvulus arvensis</i>	Bindweed	P	1
<i>Bromus sp.</i>	Brome Grasses		1
<i>Setaria faberi</i>	Giant Foxtail	A	1

* Fescue only identified to genus due to mowing.

Appendix D. List of species present within quadrats placed inside study plots during the September 2014 vegetation survey, whether they are perennial, biennial or annual in Rhode Island and their total counted instances.

Appendix E

ANOVAs

Vegetation Quality Compost July 2014 to November 2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	3	16.2	3.66	.0346
Rate	2	14.3	5.58	.0162
Product x Rate	6	20.5	2.00	.1118
Date	4	150	32.19	<.0001

Vegetation Quality Compost 2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	2	14.7	8.21	.0041
Rate	3	16.3	5.49	.0085
Product x Rate	6	20.3	2.61	.0484
Date	7	255	23.57	<.0001

Vegetation Quality Biosolids July 2014 to November 2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	5	33	1.03	.4171
Rate	3	31.5	.17	.9182
Product x Rate	15	38.4	.46	.9486
Date	4	300	25.65	<.0001

Vegetation Quality Biosolids May 2014 to June 2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	5	34.8	1.23	.3147
Rate	3	31	3.81	.0197
Product x Rate	15	44.3	1.14	.3482
Date	2	158	23.52	<.0001

Vegetation Quality Biosolids 2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	5	33	1.15	.3566
Rate	3	31.6	.71	.5551
Product x Rate	15	38.2	.63	.8338
Date	7	513	22.49	<.0001

Vegetation Quality Compost 2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	2	22.4	14.13	.0001
Rate	3	36.1	5.86	.0023
Product x Rate	6	53	2.58	.0288
Date	6	224	4.81	.0001

Vegetation Quality Biosolids 2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	5	39.9	8.70	<.0001
Rate	3	29.8	23.82	<.0001
Product x Rate	15	56.6	2.58	.0053
Date	6	445	7.18	<.0001

Vegetation Quality Compost 2013-2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	2	16.7	15.86	.0001
Rate	3	20.3	8.77	.0006
Product x Rate	6	28.5	3.86	.0061
Date	14	501	10.33	<.0001

Vegetation Quality Biosolids 2013-2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	5	34.9	3.14	.0192
Rate	3	31.5	7.68	.0005
Product x Rate	15	45	1.40	.1901
Date	14	1010	13.60	<.0001

Total Day 0 N 05/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	50555948.62	25277974.31	17.95	<0.0001
Rate of application	3	31309909.18	10436636.39	7.41	0.0011
Rate of application x product	6	597757197.37	9962532.90	7.07	0.0002
Error	24	33804135.8	1408505.7		
Corrected Total	35	175445190.9			

Total Day 0 N Early 05/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	790289.9824	395144.9912	4.10	0.0295

Rate of application	3	595382.1687	198460.7229	2.06	0.1326
Rate of application x product	6	539167.6517	89861.2753	0.93	0.4905
Error	24	2315138.687	96464.112		
Corrected Total	35	4239978.490			

Total Day 0 N Late 05/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	1303825.072	651912.536	4.81	0.0175
Rate of application	3	577574.625	192524.875	1.42	0.2610
Rate of application x product	6	540104.399	90017.400	0.66	0.6788
Error	24	3250885.088	135453.545		
Corrected Total	35	5672389.184			

Total Day 0 N 06/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	7644209.642	3822104.821	15.03	<.0001
Rate of application	3	4207217.982	1402405.994	5.52	0.0050
Rate of application x product	6	5224428.890	870738.148	3.42	0.0138
Error	24	6101753.15	254239.71		
Corrected Total	35	23177609.66			

Total Day 0 N 06/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	2298447.105	1149223.553	1.37	0.2721
Rate of application	3	4262230.665	1420743.555	1.70	0.1937
Rate of application x product	6	4636625.383	772770.897	0.92	0.4951
Error	24	20060860.13	835869.17		

Corrected Total	35	31258163.29			
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Total Day 0 N 07/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	2056483.983	1028241.991	3.33	0.0531
Rate of application	3	1689892.974	563297.658	1.82	0.1701
Rate of application x product	6	1312240.490	218706.748	0.71	0.6469
Error	24	7421157.48	309214.90		
Corrected Total	35	12479774.93			

Total Day 0 N 08/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	12527808.46	6263904.23	11.56	0.0003
Rate of application	3	8461956.61	2820652.20	5.21	0.0065
Rate of application x product	6	6775515.10	1129252.52	2.08	0.0930
Error	24	13002278.77	541761.62		
Corrected Total	35	40767558.93			

Total Day 0 N 08/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	4391597.456	2195798.728	1.43	0.2587
Rate of application	3	2594576.327	864858.776	0.56	0.6442
Rate of application x product	6	2787316.494	464552.749	0.30	0.9293
Error	24	36824968.01	1534373.67		
Corrected Total	35	46598458.29			

Total Day 0 N 09/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	1885439.359	942719.679	16.60	<.0001

Rate of application	3	1297186.793	432395.598	7.61	0.0010
Rate of application x product	6	867101.016	144516.836	2.54	0.0474
Error	24	1362964.934	56790.206		
Corrected Total	35	5412692.102			

Total Day 0 N 09/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	2262979.044	1131489.522	2.78	0.0823
Rate of application	3	2279310.256	759770.085	1.86	0.1625
Rate of application x product	6	1628892.377	271482.063	0.67	0.6775
Error	24	9778908.71	407454.53		
Corrected Total	35	15950090.38			

Total Day 0 N 10/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	1303051.928	651525.964	6.39	0.0060
Rate of application	3	1280902.860	426967.620	4.19	0.1625
Rate of application x product	6	883509.744	147251.624	1.44	0.2394
Error	24	2447289.162	101970.382		
Corrected Total	35	5914753.695			

Total Day 0 N 10/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	1601990.320	800995.160	5.43	0.0113
Rate of application	3	5531619.512	1843873.171	12.50	<.0001
Rate of application x product	6	3037443.074	506240.512	3.43	0.0137
Error	24	3539833.61	147493.07		

Corrected Total	35	13710886.52			
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Total Day 0 N 11/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	1347606.945	673803.473	2.59	0.0956
Rate of application	3	1788234.257	596078.086	2.29	0.1035
Rate of application x product	6	1742124.733	290354.122	1.12	0.3817
Error	24	6236312.36	259846.35		
Corrected Total	35	11114278.30			

Total Day 0 N 11/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	1740509.754	870254.877	1.97	0.1620
Rate of application	3	1909830.477	636610.159	1.44	0.2564
Rate of application x product	6	1790035.629	298339.272	0.67	0.6719
Error	24	10626402.10	442766.75		
Corrected Total	35	16066777.96			

Total Day 0 N 05/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	103900.1050	20780.0210	3.60	0.0076
Rate of application	3	60491.8703	20163.9568	3.49	0.0226
Rate of application x product	15	105852.4041	7056.8269	1.22	0.2890
Error	48	277192.4910	5774.8436		
Corrected Total	71	547436.8704			

Total Day 0 N Early 05/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	129335.0132	25867.0026	0.41	0.8409

Rate of application	3	14528.4642	4842.8214	0.08	0.9724
Rate of application x product	15	329049.8442	21936.6563	0.35	0.9861
Error	48	3042892.461	63393.593		
Corrected Total	71	3515805.782			

Total Day 0 N Late 05/14 Biosoilds Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	403847.7414	80769.5483	1.46	0.2218
Rate of application	3	130119.2740	43373.0913	0.78	0.5099
Rate of application x product	15	710978.8392	47398.5893	0.85	0.6156
Error	48	2662694.804	55472.808		
Corrected Total	71	3907640.659			

Total Day 0 N 06/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	1173023.053	234604.611	1.80	0.1299
Rate of application	3	767824.306	255941.435	1.97	0.1313
Rate of application x product	15	1136504.221	75766.948	0.58	0.8737
Error	48	6241656.169	130034.504		
Corrected Total	71	9319007.749			

Total Day 0 N 06/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	1243875.537	248775.107	0.67	0.6517
Rate of application	3	1967031.717	655677.239	1.75	0.1688
Rate of application x product	15	3321257.896	221417.193	0.59	0.8665
Error	48	17954540.95	374052.94		

Corrected Total	71	24486706.10			
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Total Day 0 N 07/14 Biosoilds Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	522723.857	104544.771	0.38	0.8590
Rate of application	3	1569596.665	523198.888	1.91	0.1407
Rate of application x product	15	4027530.707	268502.047	0.98	0.4901
Error	48	13155349.18	274069.77		
Corrected Total	71	19275200.41			

Total Day 0 N 08/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	9121989.37	1824397.87	4.11	0.0003
Rate of application	3	9925078.30	3308359.43	7.44	0.0003
Rate of application x product	15	11558471.00	770564.73	1.73	0.0756
Error	48	21331422.47	444404.63		
Corrected Total	71	51936961.14			

Total Day 0 N 08/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	6295068.17	1259013.63	1.19	0.3277
Rate of application	3	10205555.90	3401851.97	3.22	0.0308
Rate of application x product	15	3537433.65	235828.91	0.22	0.9987
Error	48	50743345.51	1057153.03		
Corrected Total	71	70781403.24			

Total Day 0 N 09/13 Biosoilds Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	870924.385	174184.877	5.51	0.0004

Rate of application	3	1148125.612	382708.537	12.10	<.0001
Rate of application x product	15	705235.440	47015.696	1.49	0.1485
Error	48	1518438.721	31634.140		
Corrected Total	71	4242724.158			

Total Day 0 N 09/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	632643.792	126528.758	0.51	0.7669
Rate of application	3	738310.293	246103.431	0.99	0.4041
Rate of application x product	15	1217161.754	81144.117	0.33	0.9894
Error	48	11894923.05	247810.90		
Corrected Total	71	14483038.89			

Total Day 0 N 10/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	245089.2747	81696.4249	1.63	0.1954
Rate of application	3	738310.293	246103.431	0.99	0.4041
Rate of application x product	15	596689.7943	39779.3196	0.79	0.6797
Error	48	2410076.429	50209.926		
Corrected Total	71	3772241.434			

Total Day 0 N 10/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	354597.0069	70919.4014	0.45	0.8128
Rate of application	3	28819.8357	9606.6119	0.06	0.9802
Rate of application x product	15	953996.3138	63599.7543	0.40	0.9719
Error	48	7603653.538	158409.449		

Corrected Total	71	8941066.694			
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Total Day 0 N 11/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	356108.1456	71221.6291	0.57	0.7251
Rate of application	3	121184.5945	40394.8648	0.32	0.8099
Rate of application x product	15	309420.7143	20628.0476	0.16	0.9998
Error	48	6033987.119	125708.065		
Corrected Total	71	6820700.574			

Total Day 0 N 11/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	189643.794	37928.759	0.10	0.9925
Rate of application	3	175095.601	58365.200	0.15	0.9312
Rate of application x product	15	1424386.248	94959.083	0.24	0.9980
Error	48	19070546.15	397303.04		
Corrected Total	71	20859671.80			

PMN 05/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	654423.572	218141.191	0.57	0.6375
Product	5	4025259.801	805051.960	2.10	0.0811
Rate of application x product	15	4883829.356	325588.624	0.85	0.6194
Error	48	18368996.00	382687.42		
Corrected Total	71	27932508.72			

PMN 06/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
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Rate of application	3	6408865.167	2136288.389	10.26	<.0001
Product	5	6730033.660	1346006.732	6.46	0.0001
Rate of application x product	15	3074647.617	204976.508	0.98	0.4857
Error	48	9996390.30	208258.13		
Corrected Total	71	26209936.74			

PMN 08/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	904308.765	301436.255	0.89	0.4535
Product	5	1254551.804	250910.361	0.74	0.5971
Rate of application x product	15	3464822.851	230988.190	0.68	0.7893
Error	48	16270594.43	338970.72		
Corrected Total	71	21894277.85			

PMN 09/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	5191982.660	1730660.887	9.87	<.0001
Product	5	4797355.818	959471.164	5.47	0.0005
Rate of application x product	15	4472634.967	298175.664	1.70	0.0830
Error	48	8416999.70	175354.16		
Corrected Total	71	22878973.15			

PMN 10/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	5502452.667	1834150.889	5.04	0.0041
Product	5	6647856.779	1329571.356	3.66	0.0070
Rate of application x product	15	9655377.494	643691.833	1.77	0.0683
Error	48	17458279.53	363714.16		

Corrected Total	71	39263966.47			
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PMN 11/13 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	2001779.397	667259.799	2.16	0.1048
Product	5	4131516.138	826303.228	2.68	0.0326
Rate of application x product	15	4394079.214	292938.614	0.95	0.5199
Error	48	14815830.74	308663.14		
Corrected Total	71	25343205.49			

PMN Early 05/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	9010657.139	3003552.380	5.17	0.0035
Product	5	8048967.189	1609793.438	2.77	0.0281
Rate of application x product	15	6565835.482	437722.365	0.75	0.7193
Error	48	27890968.93	581061.85		
Corrected Total	71	51516428.74			

PMN Late 05/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	443567.782	147855.927	0.41	0.7444
Product	5	2648138.544	529627.709	1.48	0.2140
Rate of application x product	15	8834609.503	588973.967	1.65	0.0966
Error	48	17182015.93	357958.67		
Corrected Total	71	29108331.76			

PMN 06/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
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Rate of application	3	2062458.456	687486.152	2.07	0.1163
Product	5	1942421.306	388484.261	1.17	0.3373
Rate of application x product	15	3202626.332	213508.422	0.64	0.8237
Error	48	15926411.23	331800.23		
Corrected Total	71	23133917.32			

PMN 07/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	2100288.639	700096.213	1.52	0.2221
Product	5	1238865.765	247773.153	0.54	0.7473
Rate of application x product	15	8122668.759	541511.251	1.17	0.3237
Error	48	22152238.10	461504.96		
Corrected Total	71	33614061.26			

PMN 08/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	785653.172	261884.391	0.77	0.5186
Product	5	2529094.974	505818.995	1.48	0.2139
Rate of application x product	15	5985424.463	399028.298	1.17	0.3282
Error	48	16406562.35	341803.38		
Corrected Total	71	25706734.96			

PMN 09/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	12863527.91	4287842.64	2.89	0.0449
Product	5	12974906.96	2594981.39	1.75	0.1415
Rate of application x product	15	20540783.66	1369385.58	0.92	0.5456
Error	48	71203700.6	1483410.4		

Corrected Total	71	117582919.1			
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PMN 10/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	4468596.971	1489532.324	4.54	0.0070
Product	5	6568991.290	1313798.258	4.01	0.0041
Rate of application x product	15	7594650.885	506310.059	1.54	0.1272
Error	48	15737309.64	327860.62		
Corrected Total	71	34369548.79			

PMN 11/14 Biosolids Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	2333889.956	777963.319	1.17	0.3307
Product	5	8098710.976	1619742.195	2.44	0.0478
Rate of application x product	15	7423346.463	494889.764	0.74	0.7279
Error	48	31899872.10	664580.67		
Corrected Total	71	49755819.49			

PMN 05/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	4437559.10	1479186.37	0.93	0.4416
Product	2	12551455.32	6275727.66	3.94	0.0330
Rate of application x product	6	9617067.67	1602844.61	1.01	0.4437
Error	24	38190308.91	1591262.87		
Corrected Total	35	64796391.01			

PMN 06/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
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Rate of application	3	3127156.849	1042385.616	5.61	0.0046
Product	2	7944713.094	3972356.547	21.39	<.0001
Rate of application x product	6	7623271.481	1270545.247	6.84	0.0003
Error	24	4456350.00	185681.25		
Corrected Total	35	23151491.43			

PMN 08/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	566578.373	188859.458	0.30	0.8278
Product	2	1667659.015	833829.507	1.31	0.2890
Rate of application x product	6	1617809.795	269634.966	0.42	0.8564
Error	24	15303498.83	637645.78		
Corrected Total	35	19155546.01			

PMN 09/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	950123.006	316707.669	1.10	0.3689
Product	2	5156556.232	2578278.116	8.94	0.0013
Rate of application x product	6	2581706.922	430284.487	1.49	0.2230
Error	24	6918315.91	288263.16		
Corrected Total	35	15606702.07			

PMN 10/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	2848084.744	949361.581	1.86	0.1626
Product	2	1656785.696	828392.848	1.63	0.2175
Rate of application x product	6	3273705.155	545617.526	1.07	0.4067
Error	24	12222584.48	509274.35		

Corrected Total	35	20001160.08			
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PMN 11/13 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	3588688.156	1196229.385	5.64	0.0045
Product	2	3274713.670	1637356.835	7.72	0.0026
Rate of application x product	6	3244911.650	540818.608	2.55	0.0472
Error	24	5093220.65	212217.53		
Corrected Total	35	15201534.13			

PMN Early 05/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	3163019.311	1054339.770	1.20	0.3303
Product	2	3177877.591	1588938.795	1.81	0.1851
Rate of application x product	6	2390684.638	398447.440	0.45	0.8348
Error	24	21054166.81	877256.95		
Corrected Total	35	29785748.35			

PMN Late 05/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	1404501.490	468167.163	1.39	0.2699
Product	2	1494313.949	747156.974	2.22	0.1306
Rate of application x product	6	2450175.704	408362.617	1.21	0.3340
Error	24	8081816.63	336742.36		
Corrected Total	35	13430807.77			

PMN 06/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
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Rate of application	3	1047506.725	349168.908	0.76	0.5280
Product	2	3529769.336	1764884.668	3.84	0.0358
Rate of application x product	6	4382161.248	730360.208	1.59	0.1939
Error	24	11039012.47	459958.85		
Corrected Total	35	19998449.78			

PMN 07/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	136612.3980	45537.4660	0.07	0.9743
Product	2	466112.0151	233056.0075	0.37	0.0358
Rate of application x product	6	787780.5104	131296.7517	0.21	0.9708
Error	24	15149996.73	631249.86		
Corrected Total	35	16540501.65			

PMN 08/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	5027061.099	1675687.033	1.66	0.2016
Product	2	745095.262	372547.631	0.37	0.6949
Rate of application x product	6	9135924.835	1522654.139	1.51	0.2172
Error	24	24191499.35	1007979.14		
Corrected Total	35	39099580.55			

PMN 09/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	9339269.050	3113089.683	1.09	0.3710
Product	2	2492385.981	1246192.991	0.44	0.6506
Rate of application x product	6	7854647.513	1309107.919	0.46	0.8309
Error	24	68330234.08	2847093.09		

Corrected Total	35	88016536.62			
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PMN 10/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	568435.893	189478.631	0.53	0.6661
Product	2	643716.095	321858.048	0.90	0.4198
Rate of application x product	6	2725148.921	454191.487	1.27	0.3079
Error	24	8582626.60	357609.44		
Corrected Total	35	12519927.51			

PMN 11/14 Composts Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate of application	3	215289.764	71763.255	0.09	0.9668
Product	2	1363212.790	681606.395	0.82	0.4520
Rate of application x product	6	7135599.356	1189266.559	1.43	0.2435
Error	24	19926599.19	830274.97		
Corrected Total	35	28640701.10			

Organic Matter Compost Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	2	13.7	13.21	.0006
Rate	2	17.6	11.67	.0006
Product x Rate	4	18.8	5.80	.0033
Date	3	114	7.38	.0001

Organic Matter Biosolids Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	5	32.2	1.66	0.1734
Rate	2	34	0.06	0.9378
Product x Rate	10	36.3	0.87	0.5707
Date	3	229	25.56	<.0001

Soil Moisture Compost Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
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Product	2	13.4	2.13	0.1574
Rate	2	47.1	2.69	0.0786
Product x Rate	4	42.4	1.07	0.3840
Date	12	427	124.38	<.0001

Soil Moisture All Amendments August 2014 to November 2014 Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Treatment	6	171	2.97	.0088
Date	3	270	635.48	<.0001

Soil Moisture Biosolids Repeated Measures ANOVA

Effect	Num DF	Den DF	F Value	Pr>F
Product	5	35.1	0.92	0.4787
Rate	2	68.5	0.27	0.7608
Product x Rate	10	63.9	0.21	0.9946
Date	12	867	351.35	<.0001

pH Compost September 2012 factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.24800741	0.12400370	0.49	0.6227
Product	2	3.73742963	1.86871481	7.33	0.0047
Rate x product	4	1.14241481	0.28560370	1.12	0.3779
Error	18	4.58973333	0.25498519		
Corrected Total	26	9.71758519			

pH Compost October 2014 factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.78486667	0.39243333	1.14	0.3406
Product	2	0.59628889	0.29814444	0.87	0.4362
Rate x product	4	1.67591111	0.41897778	1.22	0.3365
Error	18	6.17420000	0.34301111		
Corrected Total	26	9.23126667			

pH Biosolids September 2012 factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	2.08213333	1.04106667	2.79	0.0747
Product	5	19.59415000	3.91883000	10.50	<.0001

Rate x product	10	5.15686667	0.51568667	1.38	0.2276
Error	36	13.43060000	0.37307222		
Corrected Total	53	40.26375000			

pH Biosolids October 2014 factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	2.23067037	1.11533519	3.635.35	0.0367
Product	5	11.24974815	2.24994963	7.32	<.0001
Rate x product	10	3.67128519	0.36712852	1.19	0.3267
Error	36	11.06346667	0.30731852		
Corrected Total	53	28.21517037			

EC Compost October 2014 factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	3	171247.1922	57082.3974	1.48	.2454
Product	2	237586.1267	118793.0633	3.08	.0646
Rate x product	6	108481.2711	18080.2119	.47	.8248
Error	24	926285.480	38595.228		
Corrected Total	35	1443600.070			

EC Compost September 2012 factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	3	7467600.56	2489200.19	2.97	.0518
Product	2	28591843.39	14295921.69	17.08	<.0001
Rate x product	6	10158117.28	1693019.55	2.02	.1019
Error	24	20093512.00	837229.67		
Corrected Total	35	66311073.22			

EC Biosolids October 2014 factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	3	133629.2460	44543.0820	1.62	.1970
Product	5	87700.6607	17540.1321	.64	.6718

Rate x product	15	183562.0932	12237.4729	.45	.9558
Error	48	1319647.607	27492.658		
Corrected Total	71	1724539.607			

EC Biosolids September 2012 factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	3	3648669.056	1216223.019	4.71	.0058
Product	5	1305482.611	261096.522	1.01	.4216
Rate x product	15	3395479.611	226365.307	.88	.5929
Error	48	12395863.33	258247.15		
Corrected Total	71	20745484.61			

Planted Coverage Biosolids June 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.55373551	0.27686775	5.46	0.0052
Product	5	1.82645919	0.36529184	7.20	<.0001
Rate x product	10	0.69953075	0.06995308	1.38	0.1957
Error	144	7.30691976	0.05074250		
Corrected Total	161	10.38664521			

Planted Coverage Biosolids September 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.04600962	0.02300481	0.81	0.4489
Product	5	0.78570889	0.15714178	5.50	0.0001
Rate x product	10	0.21734374	0.02173437	0.76	0.6661
Error	144	4.11340958	0.02856534		
Corrected Total	161	5.16247183			

Planted Coverage Composts June 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.01596495	0.00798247	0.22	0.8000
Product	2	1.08111107	0.54055553	15.16	<.0001

Rate x product	4	0.03661418	0.00915355	0.26	0.9047
Error	72	2.56796896	0.03566624		
Corrected Total	80	3.70165916			

Planted Coverage Composts September 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00147194	0.00073597	0.02	0.9796
Product	2	0.59953732	0.29976866	8.39	0.0005
Rate x product	4	0.00516660	0.00129165	0.04	0.9974
Error	72	2.57320678	0.03573898		
Corrected Total	80	3.17938264			

Perennial Coverage Biosoilds June 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	5	0.03243736	0.01621868	0.29	0.7478
Product	2	0.64008458	0.12801692	2.30	0.0481
Rate x product	10	0.14081137	0.01408114	0.25	0.9897
Error	144	8.01876335	0.05568586		
Corrected Total	161	8.83209666			

Perennial Coverage Biosolids September 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	5	0.01019835	0.00509918	0.10	0.9061
Product	2	0.52742457	0.10548491	2.04	0.0764
Rate x product	10	0.10190879	0.01019088	0.20	0.9962
Error	144	7.44386691	0.05169352		
Corrected Total	161	8.08339862			

Perennial Coverage Composts June 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.08115306	0.04057653	0.67	0.5147
Product	2	0.20458039	0.10229019	1.69	0.1918

Rate x product	4	0.19280754	0.04820188	0.80	0.5315
Error	72	4.35849572	0.06053466		
Corrected Total	80	4.83703670			

Perennial Coverage Composts September 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00487626	0.00243813	0.03	0.9691
Product	2	0.31962304	0.15981152	2.06	0.1349
Rate x product	4	0.02337977	0.00584494	0.08	0.9895
Error	72	5.58474234	0.07756587		
Corrected Total	80	5.93262140			

Annual Total Count Biosolids June 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	2122.30864	1061.15432	0.39	0.6754
Product	5	25721.51235	5144.30247	1.91	0.0966
Rate x product	10	7203.39506	720.33951	0.27	0.9873
Error	144	388368.0000	2697.0000		
Corrected Total	161	423415.2160			

Perennial Total Count Biosolids June 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	2507.93827	1253.96914	0.35	0.7042
Product	5	21293.53086	4258.70617	1.19	0.3151
Rate x product	10	21396.65432	2139.66543	0.60	0.8120
Error	144	513616.2222	3566.7793		
Corrected Total	161	558814.3457			

Annual Total Count Composts June 2014 Factorial ANOVA

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	2934.246914	1467.123457	0.40	0.6743
Product	2	8112.320988	4056.160494	1.10	0.3399

Rate x product	4	5671.604938	1417.901235	0.38	0.8201
Error	72	266586.8889	3702.5957		
Corrected Total	80	283305.0617			

Perennial Total Count Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	3633.35802	1816.67901	0.46	0.6302
Product	2	10448.32099	5224.16049	1.34	0.2693
Rate x product	4	11058.49383	2764.62346	0.71	0.5897
Error	72	281481.7778	3909.4691		
Corrected Total	80	306621.9506			

Annual Total Count Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	1411.901235	705.950617	0.68	0.5064
Product	5	2000.919753	400.183951	0.39	0.8567
Rate x product	10	7393.950617	739.395062	0.72	0.7083
Error	144	148688.0000	1032.5556		
Corrected Total	161	159494.7716			

Perennial Total Count Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	4652.16049	2326.08025	0.51	0.6038
Product	5	42604.71605	8520.94321	1.85	0.1060
Rate x product	10	13991.39506	1399.13951	0.30	0.9791
Error	144	661640.2222	4594.7238		
Corrected Total	161	722888.4938			

Annual Total Count Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	906.000000	453.000000	0.33	0.7215
Product	2	1152.666667	576.333333	0.42	0.6605

Rate x product	4	5278.000000	1319.500000	0.96	0.4374
Error	72	99457.3333	1381.3519		
Corrected Total	80	106794.0000			

Perennial Total Count Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	916.24691	458.12346	0.08	0.9207
Product	2	15683.13580	7841.56790	1.42	0.2495
Rate x product	4	20070.12346	5017.53086	0.91	0.4654
Error	72	398947.1111	5540.9321		
Corrected Total	80	435616.6173			

Common Species Planted Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	45770.27778	9154.05556	5.57	0.0001
Rate	2	6575.81481	3287.90741	2.00	0.1391
Rate x product	10	12978.85185	1297.88519	0.79	0.6391
Error	144	236783.5556	1644.3302		
Corrected Total	161	302108.5000			

Common Species Crabgrass Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	11963.95679	2392.79136	2.60	0.0275
Rate	2	1731.64198	865.82099	0.94	0.3920
Rate x product	10	1649.54321	164.95432	0.18	0.9975
Error	144	132286.0000	918.6528		
Corrected Total	161	147631.1420			

Common Species White Clover Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	15391.51235	3078.30247	4.51	0.0008
Rate	2	10453.56790	5226.78395	7.65	0.0007

Rate x product	10	9833.91358	983.39136	1.44	0.1684
Error	144	98329.1111	682.8410		
Corrected Total	161	134008.1049			

Common Species Bentgrass Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	2934.790123	586.958025	0.86	0.5083
Rate	2	865.641975	432.820988	0.64	0.5310
Rate x product	10	5582.876543	558.287654	0.82	0.6099
Error	144	98037.5556	680.8164		
Corrected Total	161	107420.8642			

Common Species Quackgrass Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	746.6419753	149.3283951	0.84	0.5238
Rate	2	623.7160494	311.8580247	1.75	0.1769
Rate x product	10	780.5802469	78.0580247	0.44	0.9253
Error	144	25618.00000	177.90278		
Corrected Total	161	27768.93827			

Common Species Path Rush Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	17481.51235	3496.30247	17.51	<.0001
Rate	2	734.97531	367.48765	1.84	0.1625
Rate x product	10	3078.95062	307.89506	1.54	0.1303
Error	144	28752.66667	199.67130		
Corrected Total	161	50048.10494			

Common Species Black Medick Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	212.9444444	42.5888889	1.17	0.3274
Rate	2	179.1481481	89.5740741	2.46	0.0892

Rate x product	10	531.2962963	53.1296296	1.46	0.1611
Error	144	5247.111111	36.438272		
Corrected Total	161	6170.500000			

Common Species Sandspurry Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	4550.271605	910.054321	2.17	0.0611
Rate	2	20.975309	10.487654	0.02	0.9754
Rate x product	10	1095.320988	109.532099	0.26	0.9884
Error	144	60502.66667	420.15741		
Corrected Total	161	66169.23457			

Common Species Broadleaf Plantain Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	311.2901235	62.2580247	2.19	0.0584
Rate	2	118.3086420	59.1543210	2.08	0.1285
Rate x product	10	249.9876543	24.9987654	0.88	0.5538
Error	144	4092.222222	28.418210		
Corrected Total	161	4771.808642			

Common Species Planted Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	38461.80247	19230.90123	12.85	<.0001
Rate	2	1101.06173	550.53086	0.37	0.6936
Rate x product	4	1908.79012	477.19753	0.32	0.8645
Error	72	107774.4444	1496.8673		
Corrected Total	80	149246.0988			

Common Species Crabgrass Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	10817.85185	5408.92593	4.79	0.0111
Rate	2	364.96296	182.48148	0.16	0.8511

Rate x product	4	500.07407	125.01852	0.11	0.9784
Error	72	81285.11111	1128.95988		
Corrected Total	80	92968.00000			

Common Species White Clover Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	28544.02469	14272.01235	13.92	<.0001
Rate	2	2056.61728	1028.30864	1.00	0.3718
Rate x product	4	2136.64198	534.16049	0.52	0.7206
Error	72	73817.7778	1025.2469		
Corrected Total	80	106555.0617			

Common Species Bentgrass Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	1960.518519	980.259259	1.80	0.1728
Rate	2	1540.666667	770.333333	1.41	0.2498
Rate x product	4	1147.037037	286.759259	0.53	0.7167
Error	72	39226.00000	544.80556		
Corrected Total	80	43874.22222			

Common Species Quackgrass Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	3330.666667	1665.333333	4.89	0.0102
Rate	2	561.555556	280.777778	0.82	0.4426
Rate x product	4	1131.555556	282.888889	0.83	0.5101
Error	72	24520.22222	340.55864		
Corrected Total	80	29544.00000			

Common Species Path Rush Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	15624.00000	7812.00000	27.40	<.0001
Rate	2	209.85185	104.92593	0.37	0.6934

Rate x product	4	545.92593	136.48148	0.48	0.7513
Error	72	20528.22222	285.11420		
Corrected Total	80	36908.00000			

Common Species Black Medick Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	749.209877	374.604938	2.74	0.0710
Rate	2	778.172840	389.086420	2.85	0.0643
Rate x product	4	2458.567901	614.641975	4.50	0.0026
Error	72	9826.66667	136.48148		
Corrected Total	80	13812.61728			

Common Species Sandspurry Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	1659.950617	829.975309	1.36	0.2637
Rate	2	631.876543	315.938272	0.52	0.5985
Rate x product	4	370.419753	92.604938	0.15	0.9617
Error	72	44005.55556	611.18827		
Corrected Total	80	46667.80247			

Common Species Broadleaf Plantain Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	534.0987654	267.0493827	3.55	0.0337
Rate	2	45.6543210	22.8271605	0.30	0.7390
Rate x product	4	387.1604938	96.7901235	1.29	0.2827
Error	72	5410.000000	75.138889		
Corrected Total	80	6376.913580			

Common Species Planted Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	41916.62346	8383.32469	5.43	0.0001
Rate	2	621.12346	310.56173	0.20	0.8181

Rate x product	10	5860.58025	586.05802	0.38	0.9539
Error	144	222388.8889	1544.3673		
Corrected Total	161	270787.2160			

Common Species Crabgrass Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	2352.771605	470.554321	0.62	0.6867
Rate	2	328.938272	164.469136	0.22	0.8062
Rate x product	10	5687.654321	568.765432	0.75	0.6799
Error	144	109747.1111	762.1327		
Corrected Total	161	118116.4753			

Common Species White Clover Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	17217.60494	3443.52099	4.78	0.0005
Rate	2	7473.56790	3736.78395	5.19	0.0067
Rate x product	10	6984.13580	698.41358	0.97	0.4724
Error	144	103711.5556	720.2191		
Corrected Total	161	135386.8642			

Common Species Bentgrass Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	3970.864198	794.172840	1.57	0.1716
Rate	2	501.345679	250.672840	0.50	0.6099
Rate x product	10	1573.765432	157.376543	0.31	0.9772
Error	144	72745.55556	505.17747		
Corrected Total	161	78791.53086			

Common Species Quackgrass Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	1000.475309	200.095062	0.81	0.5417
Rate	2	79.864198	39.932099	0.16	0.8503

Rate x product	10	882.283951	88.228395	0.36	0.9621
Error	144	35406.66667	245.87963		
Corrected Total	161	37369.29012			

Common Species Spotted Spurge Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	905.290123	181.058025	2.34	0.0444
Rate	2	808.901235	404.450617	5.23	0.0064
Rate x product	10	2481.320988	248.132099	3.21	0.0009
Error	144	11130.44444	77.29475		
Corrected Total	161	15325.95679			

Common Species Path Rush Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	496.345679	99.269136	1.92	0.0949
Rate	2	143.790123	71.895062	1.39	0.2527
Rate x product	10	1000.506173	100.050617	1.93	0.0452
Error	144	7454.222222	51.765432		
Corrected Total	161	9094.864198			

Common Species Sandspurry Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	272.1049383	54.4209877	1.02	0.4071
Rate	2	55.4197531	27.7098765	0.52	0.5955
Rate x product	10	138.8765432	13.8876543	0.26	0.9884
Error	144	7669.111111	53.257716		
Corrected Total	161	8135.512346			

Common Species Broadleaf Plantain Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	61.5864198	12.3172840	2.53	0.0313
Rate	2	3.1975309	1.5987654	0.33	0.7202

Rate x product	10	110.8765432	11.0876543	2.28	0.0164
Error	144	699.7777778	4.8595679		
Corrected Total	161	875.4382716			

Common Species Barnyard Grass Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	5	22.50000000	4.50000000	0.73	0.5990
Rate	2	12.03703704	6.01851852	0.98	0.3771
Rate x product	10	90.40740741	9.04074074	1.47	0.1544
Error	144	882.666667	6.129630		
Corrected Total	161	1007.611111			

Common Species Planted Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	24788.22222	12394.11111	8.00	0.0007
Rate	2	650.29630	325.14815	0.21	0.8111
Rate x product	4	5357.25926	1339.31481	0.87	0.4892
Error	72	111479.1111	1548.3210		
Corrected Total	80	142274.8889			

Common Species Crabgrass Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	1617.061728	808.530864	0.73	0.4835
Rate	2	1889.209877	944.604938	0.86	0.4285
Rate x product	4	1883.975309	470.993827	0.43	0.7882
Error	72	79309.33333	1101.51852		
Corrected Total	80	84699.58025			

Common Species White Clover Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	13393.55556	6696.77778	6.76	0.0020
Rate	2	927.62963	463.81481	0.47	0.6281

Rate x product	4	2644.59259	661.14815	0.67	0.6169
Error	72	71351.77778	990.99691		
Corrected Total	80	88317.55556			

Common Species Bentgrass Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	710.8888889	355.4444444	0.83	0.4388
Rate	2	49.8518519	24.9259259	0.06	0.9433
Rate x product	4	163.7037037	40.9259259	0.10	0.9834
Error	72	30712.44444	426.56173		
Corrected Total	80	31636.88889			

Common Species Quackgrass Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	5890.765432	2945.382716	5.90	0.0042
Rate	2	931.950617	465.975309	0.93	0.3978
Rate x product	4	1517.679012	379.419753	0.76	0.5545
Error	72	35928.00000	499.00000		
Corrected Total	80	44268.39506			

Common Species Spotted Spurge Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	481.654321	240.827160	3.89	0.0249
Rate	2	423.876543	211.938272	3.42	0.0380
Rate x product	4	1428.641975	357.160494	5.77	0.0004
Error	72	4457.555556	61.910494		
Corrected Total	80	6791.728395			

Common Species Path Rush Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	173.7283951	86.8641975	8.58	0.0005
Rate	2	1.8765432	0.9382716	0.09	0.9116

Rate x product	4	1.9753086	0.4938272	0.05	0.9954
Error	72	728.6666667	10.1203704		
Corrected Total	80	906.2469136			

Common Species Sandspurry Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	233.1851852	116.5925926	1.92	0.1543
Rate	2	3.1851852	1.5925926	0.03	0.9741
Rate x product	4	6.7407407	1.6851852	0.03	0.9985
Error	72	4375.777778	60.774691		
Corrected Total	80	4618.888889			

Common Species Broadleaf Plantain Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	130.0740741	65.0370370	2.89	0.0621
Rate	2	36.0740741	18.0370370	0.80	0.4528
Rate x product	4	63.6296296	15.9074074	0.71	0.5901
Error	72	1621.111111	22.515432		
Corrected Total	80	1850.888889			

Common Species Barnyard Grass Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Product	2	139.1851852	69.5925926	3.24	0.0451
Rate	2	154.2962963	77.1481481	3.59	0.0327
Rate x product	4	187.8518519	46.9629630	2.18	0.0793
Error	72	1548.222222	21.503086		
Corrected Total	80	2029.555556			

Perennial Coverage Location 1 Compost June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.10903736	0.05451868	0.53	0.5971
Product	2	0.00021911	0.00010955	0.00	0.9989

Rate x product	4	0.10939328	0.02734832	0.27	0.8958
Error	18	1.84918845	0.10273269		
Corrected Total	26	2.06783820			

Planted Coverage Location 1 Compost June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.06613622	0.03306811	0.45	0.6444
Product	2	0.18688257	0.09344128	1.27	0.3042
Rate x product	4	0.05502719	0.01375680	0.19	0.9419
Error	18	1.32190058	0.07343892		
Corrected Total	26	1.62994656			

Perennial Coverage Location 1 Compost September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00992444	0.00496222	0.07	0.9366
Product	2	0.03452392	0.01726196	0.23	0.7977
Rate x product	4	0.06077165	0.01519291	0.20	0.9343
Error	18	1.35789883	0.07543882		
Corrected Total	26	1.46311883			

Planted Coverage Location 1 Compost September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.01167036	0.00583518	0.09	0.9169
Product	2	0.01266840	0.00633420	0.09	0.9102
Rate x product	4	0.02488751	0.00622188	0.09	0.9835
Error	18	1.20526812	0.06695934		
Corrected Total	26	1.25449439			

Perennial Coverage Location 2 Compost June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00491420	0.00245710	0.10	0.9043
Product	2	0.09908416	0.04954208	2.04	0.1591

Rate x product	4	0.06541868	0.01635467	0.67	0.6191
Error	18	0.43725775	0.02429210		
Corrected Total	26	0.60667479			

Planted Coverage Location 2 Compost June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00535136	0.00267568	0.11	0.8997
Product	2	0.58028937	0.29014468	11.53	0.0006
Rate x product	4	0.03572549	0.00893137	0.35	0.8373
Error	18	0.45308208	0.02517123		
Corrected Total	26	1.07444830			

Perennial Coverage Location 2 Compost September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00586886	0.00293443	0.03	0.9705
Product	2	0.12815298	0.12815298	0.66	0.5310
Rate x product	4	0.02154624	0.00538656	0.06	0.9938
Error	18	1.75853609	0.09769645		
Corrected Total	26	1.91410417			

Planted Coverage Location 2 Compost September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00458363	0.00229181	0.11	0.8960
Product	2	0.27624702	0.13812351	6.66	0.0068
Rate x product	4	0.00551165	0.00137791	0.07	0.9912
Error	18	0.37341587	0.02074533		
Corrected Total	26	0.65975816			

Perennial Coverage Location 3 Compost June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00622400	0.00311200	0.05	0.9484
Product	2	0.23314133	0.11657066	1.99	0.1654

Rate x product	4	0.02650737	0.00662684	0.11	0.9762
Error	18	1.05344002	0.05852445		
Corrected Total	26	1.31931271			

Planted Coverage Location 3 Compost June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.01603700	0.00801850	0.35	0.7086
Product	2	0.46630515	0.23315258	10.21	0.0011
Rate x product	4	0.00861055	0.00215264	0.09	0.9830
Error	18	0.41108946	0.02283830		
Corrected Total	26	0.90204216			

Perennial Coverage Location 3 Compost September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00363369	0.00181684	0.03	0.9730
Product	2	0.66511241	0.33255621	5.01	0.0186
Rate x product	4	0.01647397	0.00411849	0.06	0.9922
Error	18	1.19391574	0.06632865		
Corrected Total	26	1.87913582			

Planted Coverage Location 3 Compost September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00822305	0.00411152	0.14	0.8711
Product	2	0.56032263	0.28016132	9.48	0.0015
Rate x product	4	0.02313760	0.00578440	0.20	0.9374
Error	18	0.53211791	0.02956211		
Corrected Total	26	1.12380119			

Perennial Coverage Location 1 Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.02787503	0.01393751	0.14	0.8715
Product	5	0.24752341	0.04950468	0.49	0.7812

Rate x product	10	0.16369040	0.01636904	0.16	0.9979
Error	36	3.63441170	0.10095588		
Corrected Total	53	4.07350054			

Planted Coverage Location 1 Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.16738729	0.08369365	0.84	0.4390
Product	5	0.27734590	0.05546918	0.56	0.7311
Rate x product	10	0.32725283	0.03272528	0.33	0.9674
Error	36	3.57688297	0.09935786		
Corrected Total	53	4.34886899			

Perennial Coverage Location 1 Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.01606802	0.00803401	0.16	0.8502
Product	5	0.12968962	0.02593792	0.53	0.7547
Rate x product	10	0.10620476	0.01062048	0.22	0.9933
Error	36	1.77368073	0.04926891		
Corrected Total	53	2.02564313			

Planted Coverage Location 1 Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00541130	0.00270565	0.06	0.9438
Product	5	0.02994077	0.00598815	0.13	0.9850
Rate x product	10	0.06916821	0.00691682	0.15	0.9986
Error	36	1.68043474	0.04667874		
Corrected Total	53	1.78495501			

Perennial Coverage Location 2 Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00332008	0.00166004	0.08	0.9277
Product	5	0.23568360	0.04713672	2.13	0.0835

Rate x product	10	0.11948445	0.01194844	0.54	0.8492
Error	36	0.79488836	0.02208023		
Corrected Total	53	1.15337649			

Planted Coverage Location 2 Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.25118136	0.12559068	4.54	0.0175
Product	5	1.10561047	0.22112209	7.99	<.0001
Rate x product	10	0.32513148	0.03251315	1.17	0.3392
Error	36	0.99661195	0.02768367		
Corrected Total	53	2.67853526			

Perennial Coverage Location 2 Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.00270644	0.00135322	0.02	0.9772
Product	5	0.14441457	0.02888291	0.49	0.7791
Rate x product	10	0.11605173	0.01160517	0.20	0.9952
Error	36	2.10811006	0.05855861		
Corrected Total	53	2.37128279			

Planted Coverage Location 2 Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.02670112	0.01335056	0.65	0.5289
Product	5	0.31684381	0.06336876	3.08	0.0205
Rate x product	10	0.14550503	0.01455050	0.71	0.7120
Error	36	0.74117490	0.02058819		
Corrected Total	53	1.23022486			

Perennial Coverage Location 3 Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.03060962	0.01530481	0.35	0.7070
Product	5	0.29677798	0.05935560	1.36	0.2631

Rate x product	10	0.10556870	0.01055687	0.24	0.9895
Error	36	1.57372457	0.04371457		
Corrected Total	53	2.00668085			

Planted Coverage Location 3 Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.18555367	0.09277684	1.90	0.1647
Product	5	0.63943202	0.12788640	2.61	0.0407
Rate x product	10	0.35683728	0.03568373	0.73	0.6919
Error	36	1.76066162	0.04890727		
Corrected Total	53	2.94248459			

Perennial Coverage Location 3 Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.01135693	0.00567847	0.11	0.8923
Product	5	0.70000978	0.14000196	2.82	0.0301
Rate x product	10	0.11029495	0.01102950	0.22	0.9924
Error	36	1.78808547	0.04966904		
Corrected Total	53	2.60974714			

Planted Coverage Location 3 Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	0.02321676	0.01160838	0.46	0.6350
Product	5	0.70472610	0.14094522	5.58	0.0007
Rate x product	10	0.21615266	0.02161527	0.86	0.5802
Error	36	0.90867147	0.02524087		
Corrected Total	53	1.85276698			

Annual Total Count Locations 2 and 3 Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	379.166667	189.583333	0.26	0.7720
Product	5	2658.972222	531.794444	0.73	0.6043

Rate x product	10	7516.944444	751.694444	1.03	0.4260
Error	90	65753.83333	730.59815		
Corrected Total	170	76308.91667			

Perennial Total Count Locations 2 and 3 Biosolids September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	4235.57407	2117.78704	0.55	0.5792
Product	5	51002.82407	10200.56481	2.65	0.0280
Rate x product	10	17344.75926	1734.47593	0.45	0.9173
Error	90	346945.8333	3854.9537		
Corrected Total	107	419528.9907			

Annual Total Count Locations 2 and 3 Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	158.925926	79.462963	0.06	0.9412
Product	2	3520.592593	1760.296296	1.34	0.2713
Rate x product	4	3581.629630	895.407407	0.68	0.6073
Error	45	58974.50000	1310.54444		
Corrected Total	53	66235.64815			

Perennial Total Count Locations 2 and 3 Composts September 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	671.59259	335.79630	0.07	0.9332
Product	2	27666.25926	13833.12963	2.85	0.0683
Rate x product	4	12285.18519	3071.29630	0.63	0.6416
Error	45	218377.3333	4852.8296		
Corrected Total	53	259000.3704			

Annual Total Count Locations 2 and 3 Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	637.90741	318.95370	0.25	0.7784
Product	5	30466.96296	6093.39259	4.80	0.0006

Rate x product	10	6343.87037	634.38704	0.50	0.8860
Error	90	114243.6667	1269.3741		
Corrected Total	107	151692.4074			

Perennial Total Count Locations 2 and 3 Biosolids June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	1154.16667	577.08333	0.28	0.7591
Product	5	12078.22222	2415.64444	1.16	0.3366
Rate x product	10	15171.61111	1517.16111	0.73	0.6975
Error	90	187904.0000	2087.8222		
Corrected Total	107	216308.0000			

Annual Total Count Locations 2 and 3 Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	506.33333	253.16667	0.14	0.8715
Product	2	21775.00000	10887.50000	5.93	0.0052
Rate x product	4	3944.33333	986.08333	0.54	0.7089
Error	45	82551.8333	1834.4852		
Corrected Total	53	108777.5000			

Perennial Total Count Locations 2 and 3 Composts June 2014

Source	DF	Sum of Squares	Mean Square	F-value	Pr>F
Rate	2	1288.777778	644.388889	0.26	0.7699
Product	2	4846.333333	2423.166667	0.99	0.3799
Rate x product	4	2521.555556	630.388889	0.26	0.9037
Error	45	110254.1667	2450.0926		
Corrected Total	53	118910.8333			

Is there a difference in speciation between the two sides of the road due to distance from traffic? Perennial species in September within the area nearest the swale. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	-2.054	64	.0441

Is there a difference in speciation between the two sides of the road due to distance from traffic? Perennial species in September within the area in the middle of the plot. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	-.900	64	.3713

Is there a difference in speciation between the two sides of the road due to distance from traffic? Perennial species in September within the area nearest the road. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	3.895	64	.00002

Is there a difference in speciation between the two sides of the road due to distance from traffic? Planted species in September within the area near the swale. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	-.552	64	.5826

Is there a difference in speciation between the two sides of the road due to distance from traffic? Planted species in September within the area in the middle of the plot. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	-1.113	64	.2697

Is there a difference in speciation between the two sides of the road due to distance from traffic? Planted species in September within the area in the middle of the plot. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	4.531	64	<.0001

Is there a difference in speciation between the two sides of the road due to distance from traffic? Perennial species in June within the area nearest the swale. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	-3.910	64	.0002

Is there a difference in speciation between the two sides of the road due to distance from traffic? Perennial species in June within the area in the middle of the plot. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	-1.084	64	.2826

Is there a difference in speciation between the two sides of the road due to distance from traffic? Perennial species in June within the area nearest the road. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	5.530	64	<.0001

Is there a difference in speciation between the two sides of the road due to distance from traffic? Planted species in June within the area near the swale. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	-2.797	64	.0068

Is there a difference in speciation between the two sides of the road due to distance from traffic? Planted species in June within the area in the middle of the plot. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	-.624	64	.5349

Is there a difference in speciation between the two sides of the road due to distance from traffic? Planted species in September within the area nearest the road. Two Sample T-Test for Means

Variances are	T statistic	Df	Pr>t
Equal	6.193	64	<.0001

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