Evaluating the effects of kelp (*Ascophyllum nodosum*), mushroom compost, and slow release fertilizer amendments on the growth, health, survival, and drought tolerance of plants growing on extensive green roofs.

By: Stephanie Appleby-Jones

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Halifax, Nova Scotia

Approved: **Dr. Jeremy Lundholm**
Supervisor
Department of Biology &
Environmental Studies Program

Approved: **Dr. Norman Goodyear**
External Examiner
Dalhousie University

Approved: **Dr. Wilber Menendez-Sanchez**
Supervisory Committee Member
Nova Scotia Community College

Approved: **Dr. Zhongmin Dong**
Supervisory Committee Member
Biology Department

Approved: **Dr. Colleen Barber**
Graduate Studies Representative

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Stephanie Appleby-Jones

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Abstract

Extensive green roofs offer the opportunity to grow plant species that are being lost due to urbanization. With shallow substrate that is low in organic matter and highly erodible, green roofs are a difficult environment for plants due to high irradiance, strong winds, and drought conditions. Kelp soil amendments can improve drought survival in plants but have not been tested on green roofs. Seed germination, early growth, health, and drought tolerance was evaluated using liquid kelp and slow release fertilizer (SRF) in a greenhouse experiment. Native plants and *Sedum* in green roof vegetated mats were also tested using kelp meal, mushroom compost, and SRF as amendments while measuring plant growth and erosion. Liquid kelp improved early germination, plant health and drought tolerance in the greenhouse experiment. The native plants thrived on the green roof and erosion on the vegetated mats was reduced with the application of the organic amendments.

"Our ability to perceive quality in nature begins, as in art, with the pretty. It expands through successive stages of the beautiful to values as yet uncaptured by language."

Aldo Leopold

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Introduction: Green roofs, ecosystem services, and diversifying plant species on extensive green roofs from a horticulturist's perspective.

Chapter 1: Introduction to green roofs, ecosystem services, and diversifying plant species on extensive green roofs from a horticulturist's perspective.

Green Roofs

It was in the late 9th century that turf was first used as a building material by the Vikings in Iceland. Their traditional houses consisted of both turf roofs and walls, constructed practically with ingenuity as there were few other building materials available (van Hoof & van Dijken 2007). These buildings are now considered culturally and historically significant in Iceland. In Newfoundland, Canada, Le Anse aux Meadows is a UNESCO World Heritage site where evidence of Norse presence from the 11th Century was discovered in the remains of the wood-framed peat-turf buildings similar to those in Iceland. Replicas of the Viking longhouses and their turf roofs can be visited at this National Historic site (whc.unesco.org).

The modern green roof originated in Germany. Invented by a barrel maker from Hirschberg, Silesia in 1839, the *Holzzementdach,* or tar paper roof was designed for insulation and fire protection of the wooden buildings they were installed upon (Köhler & Poll 2010). Köhler & Poll (2010) looked at plant populations on some of these tar paper green roofs that were installed around 1870-1900 and compared them to younger extensive green roofs (planted in the 1980's) in Berlin. They found that certain plant species were persistent on the roofs and in some cases, rare species colonised the roofs. There were different plant species found on the old roofs compared to the younger roofs. The differences were attributed to variation in substrates and the original species that were planted on the roofs. These German roofs are also historically significant. Their longevity makes them valuable for long term research. The plant populations that exist on them (over 100 species were recorded) reinforce the need for further research so we can continue to create long-lived, healthy green roofs for modern times.

Urbanization

Why are we continuing with this ancient form of architecture? Almost 9 billion people are expected be living on the earth by 2050 and two thirds of those people will likely live in urban areas (Cook-Patton & Bauerle 2012). Urbanization is known to have negative effects on the environment due to the increase of impervious surfaces and the reduction of green spaces that are a result of constructed roads and buildings (MacIvor & Lundholm 2011b; Nagase & Dunnett 2012). This reduction of green areas can result in a loss of biodiversity in both flora and fauna populations (Cook-Patton & Bauerle 2012).

As more people migrate to urban areas, buildings occur with increasing density resulting in a higher demand for energy use in the city. Radiant heat becomes stored in building materials (Liu et al. 2012) and higher temperatures have created a phenomenon called urban heat island where both daytime and nighttime urban temperatures are elevated compared to outlying suburban and rural areas (Jim & Tsang 2011; Santamoris 2012). Not only do buildings and roads create a change in the balance of energy within an urban area, the green spaces that were removed and replaced with these impervious surfaces are no longer offering cooling benefits through evapotranspiration (Rowe 2011; Susca et al. 2011; Santamoris 2012).

Benefits

Green roofs are one tool that urban planners may use to help negate the effects of urbanization and loss of species (Francis & Lorimer 2011). They can be used to improve the sustainability of a city (Lin & Lin 2011) and they exhibit many functional qualities that provide both ecological and environmental benefits (Nardini et al. 2012). Green roofs provide aesthetic beauty which comes from the plants and green roof landscape (Nagase & Dunnett 2011). Many green roofs are being designed to complement a building's architecture while providing green space in urban areas (Berndtsson 2010; Rowe et al. 2012; Spala et al. 2008).

Functional ecosystem services of green roofs include the retention of stormwater (Köhler & Poll 2010; Schroll, et al. 2011; Berndtsson 2010), the reduction of noise and particulate pollution (Rowe 2011), cooling of buildings in the summer which in turn leads to energy cost savings (Sailor & Hagos 2011; Jaffal et al. 2012; Susca, et al. 2011), evapotranspiration by vegetation and substrate which aids in the reduction of the heat island effect (Susca, et al. 2011; Anderson, et al. 2010), and habitat provision for both flora and fauna (Oberndorfer et al. 2007).

Construction

These green engineered systems are made up of many different components including vegetation layers, substrate, drainage material, insulation, and waterproofing. The two most common types of are extensive and intensive. Extensive green roofs typically have a thin layer of substrate that can be from 6-20 cm thick, they require less maintenance, are lighter in weight and have a reduced plant palette compared to intensive roofs. Intensive green roofs have more than 20 cm of substrate, an expanded plant palette, and require more maintenance (FLL 2002; Mentens et al. 2006; Schrader & Böning 2006; Snodgrass & McIntyre 2010; MacIvor & Lundholm 2011a; MacIvor & Lundholm, 2011b; Cook-Patton & Bauerle 2012).

The green roof industry in Europe has experienced years of development, research and documentation to aid designers and architects in their decisions regarding green roof installations (Dvorak & Volder 2010). The Guideline for the Planning, Execution and Upkeep of Green-Roof Sites (FLL 2002), a German document that has been translated to English, is often referred to in North America as a guide for design, construction and maintenance of green roofs (Dvorak & Volder 2010). North America has many different ecoregions within it (Dvorak & Volder 2010), so while this document is useful, research is necessary to continue to develop the green roof industry in North America. This includes testing and choosing appropriate building materials, seeds, plants, substrates, organic matter, and soil amendments required for the installation and maintenance of sustainable green roofs.

Plants

There are many factors to consider when choosing plant species and installing them on a green roof. The environment on a roof is extremely harsh where high winds, temperature fluctuations, and full sun (Nagase & Dunnett 2013) can be expected. The substrate depth and physical properties can determine what species may survive and thrive (Farrell et al. 2012) and there are many different green roof systems on the market today that are designed for different climates, end use, and agricultural expectations (Bianchini & Hewage 2012). Plants can be seeded directly on a roof (Nagase & Dunnett 2013), planted directly on a roof with plugs that are started in a greenhouse (Nagase & Dunnett 2012), planted with cuttings that are rooted and grown in a greenhouse and planted directly on a roof (Alsup et al. 2010; Beck et al. 2011), or installed using vegetated plant mats (FLL 2002) that are pre-grown in a field and transported to the roof location.

It is essential that we increase our knowledge for selecting ideal green roof plant taxa (Dvorak & Volder 2010). Failed plant establishment on a roof may reduce the ecosystem services provided by the plants, leave open soil that is vulnerable to erosion, and look aesthetically unacceptable. Optimal characteristics for green roof plant taxa include a high transplant survival rate, the ability to establish quickly and the potential to cover the green roof substrate (Monterusso et al. 2005). Plant combinations using the limited flora of various *Sedum* species are the norm for extensive green roof installations (Cook-Patton & Bauerle 2012) and have been vigorously tested by researchers. This group of plants does have excellent qualities and desired characteristics for establishing and surviving the harsh green roof environment (Durhman & Rowe 2007; VanWoert et al. 2005). Moving beyond *Sedum* species, there is research taking place throughout the world and locally in Nova Scotia that should help to expand the choices of plant species for green roof culture. The goal is that a variety of species will be able to deliver optimum growth, survival, and ecosystem services (Clark & Zheng 2012; Cook-Patton & Bauerle 2012; Köhler 2010; Nagase & Dunnett 2010; Nagase & Dunnett 2013) for the extensive green roof, the building that they grow on, and the surrounding environment. Research that includes testing both native plant species and non-native species in order to find favorable candidates that can be grown successfully on green roofs in Nova Scotia is essential to continue increasing the number of diverse, flourishing, sustainable green roofs in this area.

Urbanization is altering native habitat and can be considered as a leading cause of endangering native species (McKinney 2006). Green roofs are frequently looked at as an extension of the landscape on the ground (Butler et al. 2012) and landscape architects and designers are frequently incorporating native plant species into green roof plantings. Using native plants can promote regional biodiversity and provide habitat for flora and fauna (Madre et al. 2014; Smetana & Crittenden 2014). However, the thin substrate, extreme temperatures, and drought conditions on extensive green roofs can negatively affect the performance of native plants species (Monterusso et al. 2005). Therefore, research that tests the abilities and limitations of native species is necessary so that researchers may continue to promote the use of a diversity of plants on green roofs.

Butler et al. (2012) discussed the importance of defining "native" since definitions found in the literature can show large variation. In the context of this study, "native" plants are species that have colonized freely, overtime on the barrens of Nova Scotia. MacIvor & Lundholm (2011b) tested numerous plant species that are native to the coastal barrens of the Nova Scotia. These areas exhibit similar environmental conditions that exist on green roofs; high winds, drought, shallow, rocky soil. The barrens are currently undergoing environmental pressures from the use of all-terrain vehicles and the development of ocean front homes that require roads to be built in order to obtain access to these areas (Porter 2013). Plant rescue, propagation, and installation on green roofs are one way of conserving the native species that exist on the barrens. This study includes a number of species native to the coastal barrens in Nova Scotia, non-native commercial green roof grasses, annual cultivars from a local seed supplier, and *Sedum* species.

Species diversity in green roof plant communities could help plant species to resist temperature fluctuations, reduce invasion of weed species, and lessen insect and disease pressures (Cook-Patton & Bauerle 2012). Should diversity be limited to native species and known survivors such as *Sedum* species? Research is also exploring the use of non-native grasses and forbs and annual cultivars. Nagase & Dunnett (2013) examined the establishment of annual species on an extensive green roof. This research took place in the United Kingdom and they found that when 22 different annual species were sown on a green roof, the plants provided a long blooming period that required little irrigation or maintenance. The diversity of flowers also attracted many bees to the extensive green roof. In Switzerland, Hennig & Ghazoul (2012) found that plant diversity significantly affected bee diversity and floral profusion positively affected bee visits and diversity when looking at pollinators in an urban environment.

While ecosystem services are an essential component of green roofs, aesthetics and human enjoyment are also an important benefit of green roofs as they can provide relief and escape from the urban environment. Vegetation preference can be used to evaluate the restorative capacity of a green space (Hartig & Staats 2006). White & Gatersleben (2011) reported that people could be positively influenced by the presence of flowers. In their survey using pictures of houses with different vegetated and non-vegetated roofs, meadow plantings were consistently rated higher than non-vegetated roofs, brown roofs, *Sedum* roofs and turf roofs. The researchers thought that the flowers in the meadow plantings could have contributed to people's positive perceptions. Jungels et al. (2013) found negative reactions to green roofs that were dominated by stoloniferous grasses compared to *Sedum* dominated roofs or mixed perennial forb roofs. In contrast, Lee et al.

(2014) found the most preferable and restorative green roof planting was taller, green and contained both grasses and flowers. The lower growing red *Sedum* were less preferred in this study. Lee's research indicated the importance of choosing species that will lengthen the blooming season on a green roof to increase aesthetic value. In Switzerland, when participants were challenged to create the ideal meadow in both physical and mental tests, they designed species rich plantings that contained plant diversity, animal diversity, and colour diversity (Lindemann-Matthies & Bose 2007). Flowers and grasses were the most frequently listed plants in the mental testing. Increasing vegetation diversity on extensive green roofs is the reason that a variety of life forms and species were tested in this study.

Drought

Plants growing on green roofs may be more successful if they are adapted to dry conditions (Köhler 2003). High winds and strong solar radiation causes the shallow substrate on extensive roofs to dry out rapidly (MacIvor & Lundholm 2011b; Monterusso et al. 2005). Drought tolerant plants must have the ability to withstand periods of low water availability and high temperatures that exist on green roofs (Durhman et al. 2006). If green roof plants are considered to be ornamental, it is important to maintain their aesthetic functions as well as maintaining plant functions for survival (Butler & Orians 2011). A drought on a roof can cause plant tissue to die back to the ground level making the plant dormant, or the plant could die completely (Kreyling et al. 2008). Plants that are exposed to inadequate amounts of water during establishment may have reduced leaf and root size. This lack of growth results in a reduction in photosynthesis due to interference with the uptake of water and nutrients (Thuring et al. 2010). Larger, healthier plants could offer greater cooling services as water transpires through the stomata (Takakura et al. 2000).

Many succulents including *Sedum* species have rounded fleshy leaves that store large quantities of water to use during periods of drought (Durhman et al. 2006; Butler & Orians 2011). They may have short internodes between leaves that reduce the distance water travels in the plant. Succulents also exhibit crassulacean acid metabolism (CAM) where the stomata are closed during the day when water availability is low and temperatures are high. The stomata open at night to take up carbon dioxide from the atmosphere. This mechanism protects CAM plants from drying out during the day by reducing transpiration (Durhman et al. 2006; Escamilla-Trevino 2012). Plants that exhibit CAM mechanisms are also known to have fewer stomata than non-CAM plant species (Sayed 2001).

Hair on leaves is a form of protection from the sun's rays and may create a calm layer of air around the plant leaves that could reduce transpiration (Baron 1963). Decreasing stomatal conductance is the most commonly known reaction that plants exhibit to drought conditions (Berninger et al. 1996). Stomatal conductance is a measure of the rate of the amount of carbon dioxide entering or water vapour exiting through the stomata of a leaf. When stomata close, transpiration rates are lowered and the photosynthetic process in plants slows down. Stomatal closure causes a reduction in the growth potential of a leaf due to the negative impact on photosynthesis which results in a reduction in biomass accumulation (Woo et al. 2008; Tardieu 2012). Some of the plant species chosen for this study include ones that exhibit hairs on leaves (*Luzula* sp.) and leaf nodes (*Portulaca grandiflora*), and succulents (*Sedum*) that exhibit CAM photosynthesis.

Fertilizer

Applying fertilizer is recommended during the production, installation and first few years of a green roof's life (FLL 2002). The over use of nitrogen fertilizers and the subsequent run off into water ways are known to cause contamination of both ground water and surface waters (Johnson et al. 1991). Nitrogen fertilizer has been blamed for the hypoxic zone in the Gulf of Mexico. This non-point source of pollution is not just restricted to this area. There are many such zones in coastal areas around the world (Malakoff 1998). These hypoxic areas negatively affect marine life due to changes in the pH and acidification of the ocean waters (Gobler et al. 2014).

Green roof substrate typically contains a combination of organic matter, mineral aggregates, and synthetic fertilizer which is the norm for green roof plant production. Therefore, green roofs can be a source of phosphorus and nitrogen runoff (Czemiel Berndtsson 2010; Monterusso et al. 2004; Teemusk & Mander 2007) and there is a risk of increased runoff from green roofs that have been treated with synthetic fertilizer (Czemiel Berndtsson 2010). Emilsson et al. (2007) found a direct link between release of nutrients and use of fertilizer on green roofs.

The concentrations of nitrogen depend on the type of substrate, the age of a green roof installation, and the application amount and the timing of fertilization (Czemiel Berndtsson 2010). It was recommended by Czemiel Berndtsson (2010) that conventional fertilizers be avoided to prevent undesirable runoff during the first weeks in the life of a green roof. The type of green roof could also have an effect on the nutrient runoff. Monterusso et al. (2004) found that nitrogen runoff was highest in *Sedum* green roof systems that were generated by seed compared to vegetated mats. Are there other alternatives to using synthetic, conventional fertilizer?

Ascophyllum nodosum

Ascophyllum nodosum (Norwegian kelp, rockweed) has been extensively researched (Norrie 2008; Khan et al. 2009). Brown seaweeds, including *A. nodosum* are the second most abundant group of seaweeds in the world and are the most commonly used seaweed for agriculture (Khan et al. 2009). They have a long history of being used as soil conditioners (Haslam & Hopkins 1996). Millions of metric tonnes of seaweed products are being produced annually (FAO 2006) with many of these products being used in agriculture and horticulture as biofertilizers (Khan et al. 2009). In Nova Scotia and the Maritimes, there are extensive kelp beds growing in intertidal shores (Ugarte & Sharpe 2012) and these beds are an important part of marine coastal ecosystems (Khan et al. 2009). In recent years, there has been an increase in algal biomass which is causing eutrophication in some coastal ecosystems (Eyras et al. 2008; Kumari et al 2012). Removing some of this biomass from coastal areas may help alleviate the pressure on the ocean's ecosystem.

Seaweeds have been proven to contain biochemical compounds that promote growth of both roots and shoots of terrestrial plants (Thorsen et al 2010; Rayorath et al. 2008). It has been found that seaweed is a biostimulant (Khan et al. 2009) that contains plant hormones which are known to increase plant vigour and yield (Crouch & van Staden 1993). Biostimulants are not conventional fertilizers, but are claimed to promote plant growth when applied in small quantities (Zhang & Schmidt 1997). When added as an amendment, seaweed can increase organic matter, improve aeration, and improve aggregate stability of soil (Crouch & Staden 1993; Haslam & Hopkins 1996).

One of the beneficial effects of seaweed application is the development of a strong root system (Crouch & van Staden 1993). Seed germination can also be significantly improved (Thorsen et al. 2010). Gibberellins and cytokinins are known plant growth regulators present in seaweed (Crouch & van Staden 1993; Papenfus, et al. 2013) and cytokinins are known to promote cell growth that creates larger plants (Letham 1969). Both cytokinins and auxins have been found in fresh seaweed and seaweed extracts (Crouch & van Staden 1993; Khan et al. 2009; Thorsen et al. 2010; Papenfus et al. 2013). These hormones may help seeds to overcome germination inhibitors and increase germination (Thorsen et al. 2010).

Growth regulators, organic compounds, and wetting agents can help to retain soil moisture and nutrients (Khan, et al. 2009; Kumari, et al. 2012). There are also betaines and betaine-like compounds found in A. *nodosum* extracts that help alleviate osmotic and drought stresses. The water holding capacity of soil may be improved with the application of *A. nodosum* which can improve soil texture by reducing soil compaction and increasing soil aeration (Haslam & Hopkins 1996; Kumari, et al. 2012). Betaines are also known to enhance leaf chlorophyll (Crouch & van Staden 1993; Norrie 2008; Khan et al. 2009). Zhang & Ervin (2004) found that it was the hormonal cytokinin components in the seaweed extracts rather than the mineral components that aid in drought stress tolerance of turfgrass. The cytokinin properties were lost when both humic acid and seaweed extracts were ashed.

Commercial turfgrass management has a strong research interest in soil amendments due to the practice of using turf on sports fields, home lawns, golf courses and other challenging environments. Seaweed extracts, humic substances, and organic matter have been used as fertilizer supplements in this industry (Zhang et al. 2003). Work has been done to find appropriate dilution rates of both seaweed extracts and humic acid by measuring leaf growth and senescence. Zhang & Schmidt (1997) have shown that the application of both seaweed and humic acid can aid turf grass in resisting drought. Their findings in a two year study showed that the quality of the turf was improved the most with a combination of both seaweed extract and humic acid. Humic acids are known to help soil and sediments retain water, buffer pH, bind metals, and adsorb solutes (Radwan et al. 1997). Radwan et al. (1997) isolated humic acid from various seaweeds that were collected in Nova Scotia and Boothbay Harbor, Maine, USA. While some species of seaweed did not contain humic acid, the researchers found that *A. nodosum* did contain humic acid.

Mushroom Compost

Mushroom compost (MC) is the waste product of mushroom production. Using MC as a soil amendment for media improvement is a practical way to manage organic waste (Gonani et al. 2011), increase soil organic matter (Bonilla et al. 2012), and improve soil quality (Arthur et al. 2012). Aeration and moisture retention can be improved when the compost ameliorates the soil structure by binding mineral components of the soil together. When MC is applied as mulch, the MC can moderate soil temperature and moisture, reduce erosion, and help control weed seed germination (Dougherty 1999).

Mushroom compost is a potential source of macro and micro nutrients (Gonani et al. 2011) that can become available for plant growth. Applying organic matter in the form of MC will introduce soil microbiota and can enhance microbial activity, increase microbial diversity in green roof soil and as a result, improve soil biological health (Dougherty 1999; Perez-Piqueres et al. 2006). The increased microbial activity aids in the mineralization of nitrogen. This reduces volatilization and immobilizes the nitrogen in the system for a longer period of time where it can be released slowly for the plants to take up when necessary for plant growth (Holbeck et al. 2013).

Gonani et al. (2011) reported that MC incorporated into soil at a rate of 15% and 25% volume, significantly improved the growth and fruit production of greenhouse grown cucumber plants. Arthur et al. (2012) tested MC in sandy soil. The compost was incorporated into the soil. Tomato plants grew taller than the controls and two other types of vegetable/plant based composts. The tomato plants treated with MC also produced more fruit and had a larger biomass. Improved growth and production was partly due to changes in the chemical and physical properties of the soil. Kwack et al. (2012) tested a number of different mushroom composts and found that the white button mushroom compost they tested produced high seed germination in lettuce plants. These studies were measuring growth of food plants.

Testing MC on a green roof with native plants and *Sedum* may provide evidence that MC can also improve the low organic matter in green roof substrate and improve the growth of green roof plants. The MC in this study was applied on top of the soil as mulch and not incorporated because of the nature of the vegetated plants mats. The mats form a barrier between the lower soil profile and the upper soil profile that exists on top of the mats.

There is a possibility that management of MC can pollute (Phan & Sabaratnam 2012) if disposed of improperly. When treated and used appropriately, it can be less of an environmental hazard compared to mineral fertilizers (Arthur et al. 2012).

Germination

Establishing a green roof plant population by seed broadcasting can be a cost-effective way of introducing plants onto a green roof (Dunnett & Kingsbury 2004). Seeding rates and germination success are important factors in the early establishment of a green roof plant population. Germination testing is the main internationally accepted criterion for seed viability (Hampton & TeKrony 1995). Seed germination can occur when both external and internal conditions are in place to enable the seed to germinate. Dormancy is a survival mechanism that protects the seed from germinating before the conditions are right to support the emerging primary root and subsequent lateral roots of a young plant. Water, oxygen, temperature and in some cases, light, are all factors that allow germination to occur (Raven et al. 2005).

Once a seed has germinated, the next critical stage of development is the seedling stage. This period of establishment is crucial in terms of natural selection (Pelton 1953). It is critical that young seedlings develop nutritional patterns that will allow them to survive and thrive (Pelton 1953). The ongoing development of the root system is dependent on moisture, temperature, and composition of soil (Raven et al. 2005). Here, the root-to-shoot signal is led by the presence of abscisic acid which is critical in signaling to the leaves whether there is sufficient water for the plant or not. If there is not, stomata will close to protect the plant from moisture loss (Raven et al. 2005).

Phytohormones are organic compounds that are created at one site in plants and can control growth in another site (Letham 1969). These hormones guide the processes that lead to growth, development, and metabolism of plants (Khan 1971). Cytokinins, indole acidic acid, and gibberellins are phytohormones known to have an effect on the physiological metabolism of both seeds and plants (Khan 1971). Cytokinins and gibberellins are known to aid in breaking dormancy in seeds (Letham 1969). This introduction to the study has previously discussed the presence of these phytohormones in *A. nodosum* and it is for those reasons that it was used to study the germination, growth, and drought tolerance of green roof plants.

Seedling vigour is not considered to be the same form of measure as germination (Hampton & TeKrony 1995). The International Seed Testing Association defines seedling vigour as "the sum total of those properties of the seed which determine the level of activity and performance of the seed during germination and seedling emergence". This research explored the rate of seed germination and seedling growth as described by Hampton & TeKrony (1995). Further to this, Nichols & Heydecker (1968) described measuring the period from sowing and the mean germination time. Butola & Badola (2004) adapted this by applying two different calculations to analyze their data. The calculations are as follows:

Mean germination time (MGT) was calculated using MGT= $\sum(fx)/\sum x$, where x is the number of newly germinated seed on each day and f is the number of days after seeds were set to germinate. Low MGT and accumulation of dry biomass are a good indication of seedling vigour and Butola & Badola's (2004) method to measure Seedling Vigour Index (SVI) is: SVI = (dry weight per seedling/MGT) x 100.

Thesis objectives

In this study, two experiments were completed. The first was a greenhouse study that quantified seed germination and health, comparing two volumes of liquid *Ascophyllum nodosum* (liquid kelp) treatments, one volume of slow release fertilizer, and one control with nothing added. Plant health was monitored as plants grew from seedling stage to maturity. Plant health and longevity continued to be measured during a prolonged two month drought, again comparing different treatments. In the second experiment, objectives were to measure the growth and winter survival of native plants and *Sedum* species growing in a vegetated mat system. Erosion of the green roof substrate was also quantified. The plants were treated with two different volumes of granular *A. nodosum* (kelp meal), one treatment of slow release fertilizer, and one treatment of mushroom compost. Because it is considered more likely that extensive green roofs be installed as retrofits on existing buildings, an extensive substrate depth of 10 cm was tested in both experiments. The greenhouse experiment allowed controlled measurements and treatments in pot culture. The green roof experiment explored a whole system green roof using one metre squared plots for measurement and comparison of various treatments.

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CHAPTER 2

The effects of kelp (Ascophyllum nodosum) and fertilizer on seed germination, health, and drought tolerance of green roof plants.

Abstract

Discovering plant species that are able to survive in the shallow substrate of extensive green roofs can increase plant diversity and ecosystem services that are provided by this green technology. The soil additive *Ascophyllum nodosum* (kelp) has proven benefits that include increasing drought tolerance of plants, improving soil structure, and promoting seed germination, yet there has been no published research testing this amendment on green roofs. Liquid kelp extract and slow release fertilizer were tested in a pot culture experiment in a greenhouse and on a green roof. Seed germination, plant health, soil water content, and drought tolerance of ten green roof plant species that included annuals, perennial cultivars, and three species native to the coastal barrens of Nova Scotia were evaluated. Plant health and longevity were improved with kelp amendments in both a short term and a long term drought. Soil water content was higher in kelp treated pots compared to fertilizer treated pots. Application of this local renewable resource to green roof plants could help to improve plant and substrate health while increasing drought tolerance of plants on green roofs.

Keywords: Extensive green roofs, *Ascophyllum nodosum* (kelp), germination, plant growth, drought

Chapter 2: The effects of kelp (Ascophyllum nodosum) and fertilizer on seed germination, health, and drought tolerance of green roof plants.

Introduction

Green roofs are used to provide a number of benefits for the environment, the buildings they are installed on, and the people that both live and work in them (Dvorak & Volder 2010). Conventional roofing on buildings increases the impervious surfaces of the constructed landscape. Exposed roof membranes can heat up the atmosphere and the building they sit upon while being degraded by the ultraviolet light of the sun (McDonough & Braungart 2002). Green roofs are being used to mitigate rising urban temperatures (Saadatian et al. 2013), extend the life of building membranes (McDonough & Braungart 2002), reduce stormwater runoff (Czemiel Berndtsson 2010), provide habitat for flora and fauna (Oberndorfer et al. 2007) and reduce human stress by providing green space for spiritual renewal, peace, and quietness in what can be a noisy, concrete urban environment (Yuen & Hien 2005).

The two main types of green roofs are extensive and intensive. Extensive roofs are typically installed to help retain stormwater, improve the thermal performance of a building, and provide fireproofing. Their weight is between 70-170 kg per m^2 with the substrate depth between 2 and 20 centimetres. Plant species commonly found on extensive roofs are *Sedums*, mosses, and grasses. These shallow roofs require less maintenance than intensive roofs and are often more functional than accessible. Intensive green roofs are installed to help retain stormwater, improve the thermal performance of a building, improve aesthetics with the addition of greenery and flowers on a roof, and even allow food production. They are heavier than extensive roofs at 290-970 kg per m^2

because the substrate thickness is over 20 cm. This increased depth allows for a larger variety of plant species to be installed, increased need for maintenance, and the necessity of irrigation. Intensive roofs are usually more accessible for people than extensive roofs (Mentens et al. 2006; Schrader & Böning 2006; Snodgrass & McIntyre 2012; MacIvor & Lundholm 2011; Cook-Patton & Bauerle 2012; Oberndorfer et al. 2007).

Visually pleasing green roof design can include selecting a variety of vegetation that exhibit structural differences, an extended flowering period, and a mixture of coloured foliage so they are appreciated by the public (Fernadez-Canero et al. 2013). Besides public acceptance, diverse green roofs can offer improved ecosystem services (Lundholm et al. 2010). *Sedum* species are often exclusively planted in many extensive green roof designs due to their ability to survive the dry conditions and shallow substrate that exist on green roofs (Emilsson 2008). Working to increase the plant palette beyond *Sedum*, Lundholm et al. (2010) and MacIvor & Lundholm (2011) tested a number of plant species that are native to Nova Scotia. Lundholm's preferred native plants for green roof testing are ones that have established on the coastal barrens of the province. Here the soil is shallow and rocky, while the environment is windy and extreme, similar to the conditions found on building rooftops (Nagase & Dunnett 2010). While Lundholm's research found success with native plant survival, Monterusso et al. (2005) found that native plant diversity on a Michigan green roof declined over a three year period with some species completely dying out while *Sedum* sp. survived over the same period. The researchers recommended that without irrigation, green roof plants must be drought resistant, cover the substrate quickly, and be able to self-seed or propagate by roots. It was also suggested that native plants be tested further in order to evaluate the ability of different plant species to tolerate drought conditions that are likely to happen on a green roof.

Plants can be directly seeded onto a green roof and when doing this, rapid germination and early growth is essential to help stabilize the substrate (with root growth) and protect the seed from being blown or washed away. It is this successful growth from a viable seed developing into a healthy plant that flowers and sets new seed that is important in terms of species continuation in a green roof plant community and many plants will produce seed on a green roof (Kircher 2004). Köhler & Poll (2010) evaluated older tar paper green roofs and modern green roofs in Germany and found 70 different vascular species growing on them. The researchers surmised that the initial planting of a green roof has a positive effect on species richness since there were more species found on the modern green roofs compared to the older roofs; however, floral quality was greatly reduced with water deficiency. Water deficiency can be related to the water holding capacity of a green roof substrate.

Green roof substrate is essential for supporting growing plants, and nutrients within the substrate can help green roof plants to thrive, and perpetuate on a green roof (Emilsson 2008). Green roof substrate is typically low in organic matter and high in minerals (Emilsson 2008). Nagase & Dunnett (2011) found that the amount of organic matter in soil significantly affected soil moisture and drought can be one of the most limiting factors that affect the growth of plants (Thuring et al. 2010). Monterusso et al. (2005) found that plants performed better when provided with the appropriate amount of water during establishment. Many green roofs are being installed without irrigation leaving the plants vulnerable to the negative effects of drought and if a prolonged drought happens, there is an increased risk of plant death.

There has been no information found in the literature where *Ascophyllum nodosum* (kelp) has been tested in green roof research. Research from other disciplines has shown that kelp contains plant growth regulators that can enhance the growth of plants (Crouch & van Staden 1993), can increase the pore volume and aggregate stability of soil (Haslam & Hopkins 1996), and can have a positive effect in water relations of plants that are exposed to drought (Spann & Little 2011).

Green roof plant installations commonly apply slow release fertilizer at planting time to provide the new plants with the essential nutrients that are needed to grow and thrive on the roof (Emilsson, et al. 2007). Other types of nutrient amendments have been tested in green roof research and adding amendments to soil can help to improve the growing conditions for plant communities (Ohsowski et al. 2012). Nagase & Dunnett (2011) tested green waste compost derived from mixed plant materials, Farrell et al. (2013) explored the use of polymers and their effect on water availability, Molineux et al. (2009) looked at a conifer-bark compost, while Alsup et al. (2010) did an experiment using pine bark as an organic amendment. Expanding kelp research for application on green roofs can help to increase our knowledge about the addition of amendments to green roof substrate.

Dvorak & Volder (2010) suggested that we develop a better understanding of how different green roof plants grow in commercial green roof substrate in order to promote the continued development of the green roof industry in North America. The ten species of green roof plants that were evaluated in a greenhouse experiment at Saint Mary's

University in Halifax, Nova Scotia were started from seed and grown in pots filled with a commercial green roof substrate. Two volumes of liquid kelp were tested along with one treatment of slow release fertilizer, and a control in which nothing was added to the substrate.

This research explored a diversity of plant species using three native species, four non-native green roof cultivars, and three annual cultivars (chosen for their drought tolerance and ability to self-seed). Objectives of the study were to evaluate and compare seed germination and early growth of the plant species in various treatments. Woo et al. (2008) recommended that experimental imposition of soil drying is one of the most practical methods that can provide quantitative data on drought tolerance, so the performance of the plants during a short term, six day drought and a long term, two month drought was also evaluated along with soil moisture and plant survival. Extreme environmental conditions that exist on green roofs include high solar radiation and strong winds that can quickly dry out substrate. We wanted to find which species offered superior growth and performance during the trial and if the amendments could aid plant health and survival during drought on a green roof.

Materials and methods

Species selection

Ten plant species were chosen for a greenhouse study which took place at Saint Mary's University campus in Halifax, Nova Scotia. Three perennial, native species which grow on the barrens of Nova Scotia were selected. The seeds were collected from the wild by the Lundholm lab. Four perennial cultivated species were supplied by an industry partner, Vitaroofs. Three of the species are not native to Nova Scotia. One species, *Deschampsia caespitosa* is native in Nova Scotia, however the seed was not from the Nova Scotia ecoregion (it was European) and therefore evaluated as a non-native species. These four species are known to be successful candidates for green roof cultivation. Three annual, non-native cultivars were selected and purchased from Halifax Seed (Halifax, Nova Scotia, Canada). Table 1 describes family, species, origin, and growth habit of species tested.

Table 1: Family, genus, specific epithet, common names, and growth habits of plants tested in green roof experiment.

Family	**Botanical Name**	**Common Name**	**Origin**	**Growth Habit & life cycle**
Caryophyllaceae	*Sagina procumbens*	Pearlwort	Northern Hemisphere	Prostrate annual
Juncaceae	*Luzula multiflora*	Heath Woodrush	North America	Perennial, wood rush
Poaceae	*Festuca rubra*	Red Fescue	North America	Perennial, clumping graminoid
Juncaceae	*Luzula nivea*	Snowy Woodrush	Western and Central Europe	Tufted, evergreen, perennial, graminoid
Poaceae	*Anthoxanthum odoratum*	Sweet vernal Grass	Eurasia	Perennial, graminoid
Poaceae	*Deschampsia caespitosa*	Tufted Hair Grass	Cultivar, naturalized in Canada	Clump forming, perennial, tufted graminoid
Poaceae	*Poa supina*	Supina Bluegrass	Cultivar	Perennial, stoloniferous bluegrass
Brassicaceae	*Lobularia maritima* 'Snowcloth'	Sweet Alyssum	Northern temperate zones	Compact, mounding annual
Papaveraceae	*Eschscholzia californica* 'Prize Mixture'	California Poppy	Western United States	Naturalizing annual
Portulaceae	*Portulaca grandiflora* 'Double Mixed Colors'	Moss Rose	Brazil, Argentina, Uruguay	Prostrate, succulent, annual

Ondra (2002); Cheers (2003)

Twenty seeds were planted in each pot (plastic, terracotta colour, 5.5” Jumbo Square Pot, Myers Industries Lawn & Garden Group, Middlefield, OH, USA) for the greenhouse experiment by sprinkling seeds on top of Sopraflor X green roof substrate (Soprema Inc., Drummondville, QC, Canada). Seed was lightly rubbed into the substrate to aid seed to soil contact and to provide a light soil cover. Substrate depth was 10 cm and substrate volume was 1200 ml per pot. Mean seed weights and acronyms are found in Table 2.

Table 2: Mean weight ten green roof plant seeds taken from three samples of twenty seeds per sample.

Species name	**Species acronym**	**Mean of 20 seeds (gms)**
Escholzia californica (Prize Mixture)	EPM	0.0287
Lobularia maritima (Snowcloth Alyssum)	LmA	0.0057
Portulaca grandiflora (Double Mixed Colors)	PDM	0.0022
Anthoxanthum odoratum	Ao	0.0118
Deschampsia caespitosa	Dc	0.0046
Luzula nivea	Ln	0.0053
Poa supina	Ps	0.0048
Festuca rubra	Fr	0.0138
Luzula multiflora	Lm	0.0087
Sagina procumbens	Sp	0.0005

Three samples of the Sopraflor X green roof substrate were analyzed at the Nova Scotia Department of Agriculture, Quality Evaluation Division, Laboratory Services, Truro, N.S., Canada. The mean of soil pH, organic matter, macro and micro nutrients, metals, nitrates, and % nitrogen follow in Table 3.

Table 3: Mean pH, Organic matter, macro and micro nutrients, metals, nitrates, and % nitrogen of Sopraflor X green roof substrate (*n=3*).*

pH, OM, Nutrients	Analysis	Std. Error
pH	7.20	0.10
Organic Matter (%)	7.03	0.35
P2O5 (kg/ha)	916.60	25.41
K20 (kg/ha)	1698.00	65.51
Ca (kg/ha	5128.30	78.08
Mg (kg/ha)	721.30	18.19
Na (kg/ha)	321.60	23.62
Sulphur (kg/ha)	480.30	107.12
Al (ppm)	567.95	27.92
Fe (ppm)	147.33	4.06
Mn (ppm)	29.00	1.15
Cu (ppm)	1.35	0.04
Zn (ppm)	7.20	0.25
B (ppm)	1.20	0.02
Nitrate –N (ppm)	117.66	26.02
% Nitrogen	0.37	0.02

*Analysis completed at Nova Scotia Department of Agriculture, Quality Evaluation Division, Laboratory Services, Truro, N.S., Canada.

Four plant species were planted on May 1, 2013 (*Eschscholzia californica* 'Prize Mixture', *Festuca rubra, Lobularia maritima* 'Snowcloth Alyssum', *and Portulaca grandiflora* 'Double Mixed Colours'). On May 3, 2013 the remaining six species (*Anthoxanthum odoratum, Deschampsia caespitosa, Luzula nivea, Poa supina, Luzula multiflora,* and *Sagina procumbens*) were seeded into the pots. For the germination portion of the experiment, the plants were grown in the greenhouse located on the lower green roof which is approximately 5 metres above ground. Greenhouse temperatures ranged from 25/18º (day/night) with the photoperiod: 16/8 hours (day/night) and light intensity 250umol/m², plus natural light.

Experimental design

Three hundred and twenty pots were used in the germination portion of this experiment. There were eight replicates per plant species and four treatments. The high kelp treatment (K+) was 3.5 ml of liquid kelp (Batch #13582, Acadian Seaplants, Dartmouth, Nova Scotia, Canada) per litre of water, the low kelp treatment (k-) was 1.5 ml of liquid kelp per litre of water, the fertilizer treatment (F) was 2.5 ml of 10N:10P:10K Scott's Miracle-Gro® Shake 'n Feed Slow Release Plant Food per pot, and the control treatment (C) had no amendments added. Table 4 shows nutrient amounts of liquid kelp used in this experiment. Upon planting, pots and seeds were immediately watered according to their treatment (K+ and k- were watered with appropriate amount of liquid kelp and water while F and C treatments were watered with water and no liquid kelp) using 500 ml of liquid per pot. Plants were watered weekly. After two weeks, it was decided that the 500 ml of water per pot should be cut down to 250 ml of water due to large amounts of water running out of the pots. Starting May 16, 2013 all of the pots were watered weekly with either 250 ml of water/kelp treatment or 250 ml of water until the last application on August 1, 2013.

Pots were randomized in a complete randomized block and placed approximately 2 cm apart, in rows of ten, directly on the greenhouse bench. This placement allowed excess water to flow freely out of the bottom of the pots so as not to contaminate neighbouring pots with a different treatment.

Table 4: Acadian liquid seaweed concentrate specifications from batch number 13582, production date December 20, 2012. *

Element (Total)		**Actual Value**	**Specification**
Nitrogen (N)	g/100g	0.20	0.1-0.6
Phosphorus (as P205)	g/100g	0.62	≤0.2
Potassium (as K20)	g/100g	6.36	5.0=7.0
Calcium (Ca)	g/100g	0.08	0.05-0.15
Magnesium (Mg)	g/100g	0.10	0.05-0.15
Sodium (na)	g/100g	0.90	0.7-1.2
Iron (Fe)	mg/kg	51.00	30-90
Manganese (Mn)	mg/kg	5.00	3-11
Copper (Cu)	mg/kg	1.00	<4
Zinc (Zn)	mg/kg	6.00	4-17
Boron (B)	mg/kg	25.00	20-40
Water	g/100g	71.00	≤71%

*Analysis obtained from Acadian Seaplants.

Greenhouse germination trial

Germination counts were performed every two days starting May 6, 2013 for all pots. Germination counts ended for all species except *Luzula nivea* and *Luzula multiflora* on May 28, 2013. At this time, 76% of the pots had a steady plant count for 3 days and 63% of the pots had a steady plant count for at least five days. Different plant species germinate at different rates and *Luzula nivea* and *Luzula multiflora* were slower to germinate. On May 28, 2013, 60% of the *Luzula* pots did not have a steady count for three days, so the plant count for these pots continued every two days until June 3, 2013. At that time, 63% of the 62 pots had a steady plant count for at least three days and the germination count was ended.

Percent germination was calculated for all species and treatments. Mean germination time (MGT) was calculated using a formula originally from Nichols & Heydecker (1968) and adapted by Butola & Badola (2004):

$$MGT = \sum(fx)/\sum x,$$

Where x is the number of newly germinated seeds on each day and f is the number of days after the seeds were set to germinate.

Once the germination counts were concluded, a random selection (Microsoft Excel 2010) of three pots per species and treatment (120 pots) were selected to be removed from the experiment. On June 3, 2013, *Eschscholzia californica, Festuca rubra, Lobularia maritima, and Portulaca grandiflora* were harvested and fresh above ground biomass was recorded. On June 5, 2012, the remaining six species *Anthoxanthum odoratum, Deschampsia caespitosa, Lobularia maritima, Luzula multiflora, Luzula nivea, Sagina procumbens* were harvested and fresh above ground biomass was recorded. These dates coincided with the different planting dates and allowed the last six species to grow the same amount of days as the first four species.

Above ground biomass was dried in a 40º C oven for approximately twenty four to thirty six hours. Samples were removed from the oven and cooled in a desiccator which had a sealed lid. They were then removed one at a time for weighing. If a steady weight was not found, the sample was put back into the desiccator for further cooling.

Butola & Badola (2004) developed a method to measure seedling vigour index (SVI). The formula recognized the mean germination time (MGT) and the biomass of the seedlings to be a reasonable measure of seedling health:

$$SVI = (\text{dry weight per seedling/MGT}) \times 100.$$

Calculations were performed to find SVI on the 120 pots that were harvested from the experiment. All remaining pots (200 pots) were moved together in rows of ten using the same randomized order that was created at the beginning of the experiment. Watering and kelp treatments continued weekly.

Data were analyzed in Minitab using one-way ANOVA's. Significant differences were assessed using Tukey's Post Hoc Test.

Green roof trial

On June 14, 2013 the remaining 200 pots were moved out onto the upper atrium green roof at Saint Mary's University (above ground height approximately 25 metres). The pots were kept in the same randomized order as in the germination portion of the experiment. The plants were thinned to three plants per pot or less.

Watering and kelp treatments continued and plant health was evaluated using a health score adapted from Butler & Orians (2011), Monterusso et al. (2005), and Nagase & Dunnett (2010). Plant health was rated from three (healthy) to zero (dead) for all ten species. A description of plant health scores and a description of the physical effect of the drought on the plants can be seen in Table 5.

Table 5: Health scores and plant health description for ten species of potted plants exposed to drought in greenhouse on Saint Mary's green roof. *

Health Score	**Physical description**
3	Healthy, green leaves with very few brown tips
2	Less than 50% yellow or brown leaves
1	Greater than 50% yellow or brown leaves or stems, wilting, 50% of leaves absent or folded (*Luzula*), leaves could also be shrivelled (*Portulaca*), grasses could have slight moisture in crown of plant.
0	Dead, could have green leaves but are dried, no moisture in crown of grasses.

*Adapted from Butler & Orians (2011), Monterusso et al. (2005), and Nagase & Dunnett (2010).

After a six day drought on July 17, 2013, percent volumetric water content (%VWC) was measured using a soil moisture/temperature probe, ProCheck GS3 soil moisture sensor (Decagon Devices Inc., Pullman, WA, USA) to compare differences in substrate moisture content between the four treatments.

Data were analyzed in Minitab using one-way ANOVA's. Significant differences were assessed using Tukey's Post Hoc Test.

Greenhouse dry down trial

On July 31, 2013 all 200 pots were moved back into the greenhouse. Health scores and %VWC were conducted on the plants before moving them into the greenhouse. On August 1, 2013 the final kelp treatments and watering were applied to all pots.

Plant health scores were conducted three times per week from August 1, 2013 until September 30, 2013. As each plant died, the date of death was recorded and the above ground biomass was harvested. In this study, the above ground biomass was an accumulation of plant material both before and after the drought, so all plant material present in a pot was harvested, dried, and weighed. The pots and substrate were left in situ for the remainder of the experiment. This was so the substrate moisture of the remaining plants would not be affected by an empty space (edge).

Flowering, the presence of buds, and the presence of seed was also recorded for the annual species (*Eschscholzia californica, Lobularia maritima, and Portulaca grandiflora*). At the end of the experiment, all species had died except for *Portulaca grandiflora.*

Plant biomass was dried in a 40º C oven for approximately twenty four to thirty six hours. Samples were removed from the oven and cooled in a desiccator which had a sealed lid. They were then removed one at a time for weighing. If a steady weight was not found, the sample was put back into the desiccator for further drying.

Data were analyzed in Minitab using one-way ANOVA's. Significant differences were assessed using Tukey's Post Hoc Test.

Results

Early Germination

Seed germination is determined largely by the amount of water available and environmental temperature (Dürr et al. 2015). Different species germinate at different rates; therefore comparisons were not made between species but rather between treatments. Refer to Table 2 for species acronyms. Two species Ao and Dc showed first signs of germination in five days. Four species, EPM, LmA, PDM, and Fr started germinating in six days. Ps took seven days to start germinating. Ln and Sp took nine days to begin germination and Lm took 15 days before germination began (Fig 1).

There were significant differences between treatments during the germination period for five species, EPM, Dc, Ps, Lm, and Sp. EPM had significant differences for all five days of data collection. The F treatments had higher germination than the K+ and k- treatments all five days and on day three, the k- treatments were also significantly lower than the C treatments. Neither volume of kelp treatments improved germination for this species. (Tukey's pairwise comparisons for all species can be seen in Table 6.)

Significant differences were found between treatments of Ps on three different days of data collection. On day two, the C treatments were significantly higher than the K+ and F treatments. On day four and five, the C treatments were significantly higher than the K+ treatments. For Ps, the C was the best treatment. The K+ treatment did not aid this species in germination.

One significant difference was found in the Dc species on day 2. The C treatments were significantly higher than the k- treatments. The lower kelp treatment did not improve germination for Dc.

There were significant differences found on day three, four, and five for Lm. The k- treatments were significantly higher than the F treated on all three days and the F treatments were significantly lower than the C treatments on day four and five. The lower kelp treatment was the best one for improving germination for Lm while the F treatment was not beneficial for germination of this species.

The k- treatments were higher on all five days for Sp. There was one significant difference on day four where the k- treatments were significantly higher than the K+ treated pots.

While not significant, the k- treatment was the best for improving germination for LmA & Ao. It was second to the F treatment in PDM. The K+ treatment wasn't the best for germination in any species and appeared to have a negative effect on the germinating seeds.

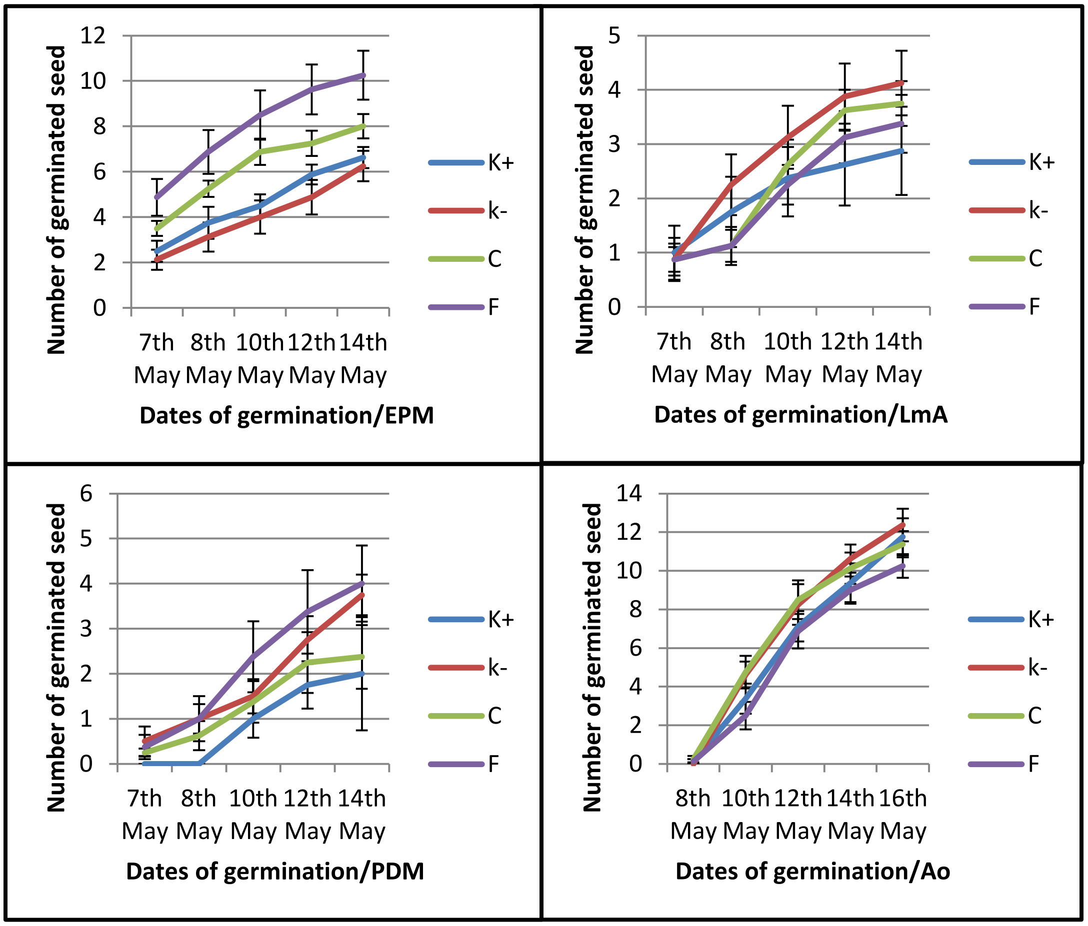

Figure 1: Mean number of germinated seeds (twenty seeds per pot, eight pots per treatment) from first day of germination (variable among species) to eight days afterward, planted in Soprema green roof soil, using three treatments and one control. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Error bars represent standard error. *(n=8)* (continued on next page).

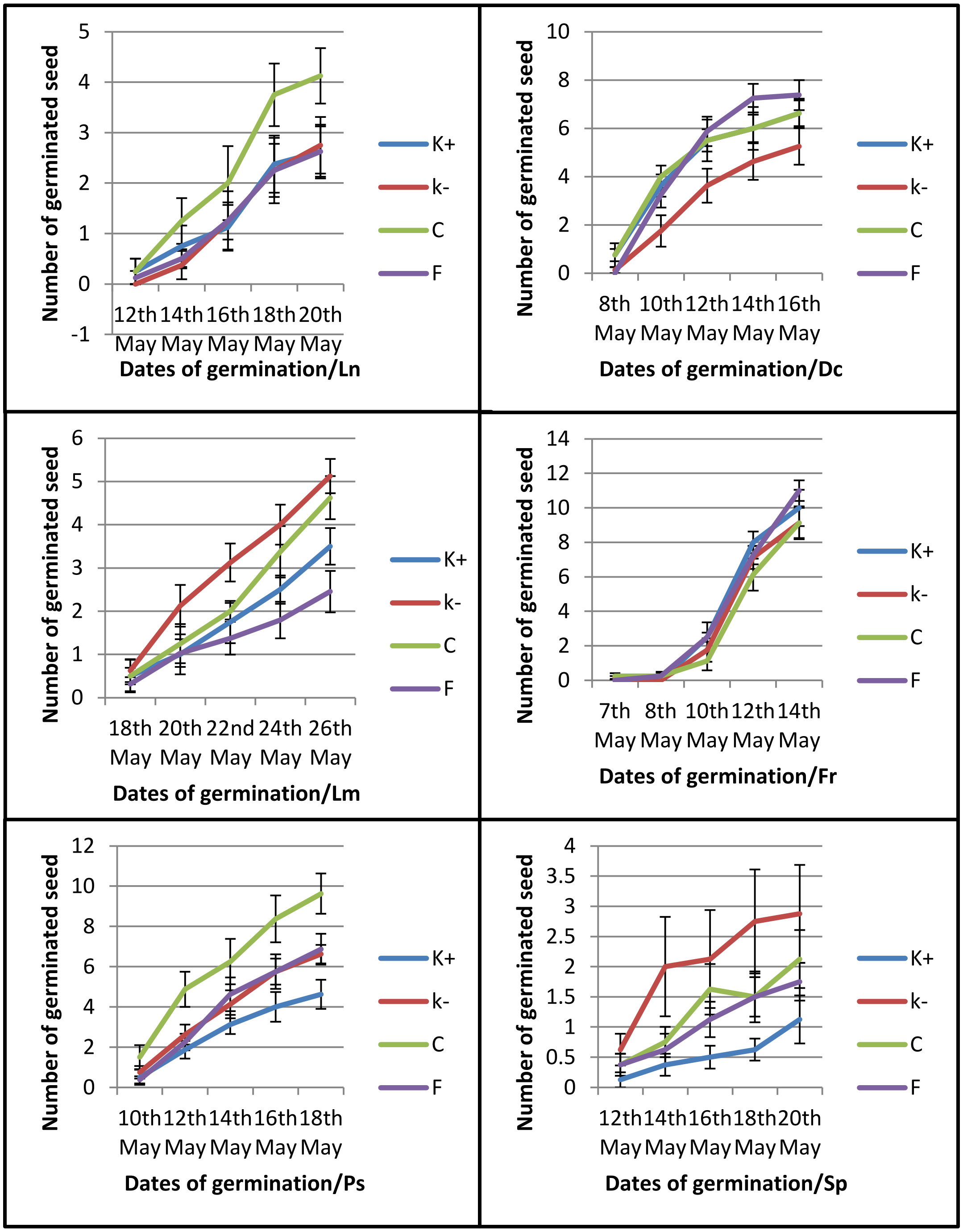

Figure 1 (continued)

Table 6: Significant differences (assessed by Tukey's Post Hoc Test) in the mean number of germinated seeds per pot, of ten species of green roof plants during the first eight days of germination in greenhouse conditions. Data was recorded every two days. Germination count started on the day the first seeds of a species germinated. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Means that do not share a letter (within a species) are significantly different. (*n=8*)

Species	**First day data**				**Second day data**				**Third day data**				**Fourth day data**				**Fifth day data**			
	K+	**k-**	**F**	**C**	**K+**	**k-**	**F**	**C**	**K+**	**k-**	**F**	**C**	**K+**	**k-**	**F**	**C**	**K+**	**k-**	**F**	**C**
EPM	*b*	*b*	*a*	*ab*	*b*	*b*	*a*	*ab*	*bc*	*c*	*a*	*ab*	*b*	*b*	*a*	*ab*	*b*	*b*	*a*	*ab*
LmA	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
PDM	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
Ao	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
Dc	*a*	*a*	*a*	*a*	*ab*	*b*	*ab*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
Ln	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
Ps	*a*	*a*	*a*	*a*	*b*	*ab*	*b*	*a*	*a*	*a*	*a*	*a*	*b*	*ab*	*ab*	*a*	*b*	*b*	*ab*	*a*
Fr	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
Lm	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*ab*	*a*	*b*	*ab*	*ab*	*a*	*b*	*a*	*ab*	*a*	*b*	*a*
Sp	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*b*	*a*	*ab*	*ab*	*a*	*a*	*a*	*a*

Percent Germination

Environmental temperature and water availability affect not only germination rate, but also percent germination (Dürr et al. 2015). Significant differences in percent germination were found between different treatments in three of the plant species. The EPM F treatment was significantly higher than the two kelp treatments. The Ps C treatment was significantly higher than the K+ treatment. For Sp the k- treatment was significantly higher than the K+ treatment. (See Figure 2 for percent germination of all species and Tukey's pairwise comparisons.)

The highest percent germination was Ao k- and the lowest was Sp K+. The lowest percent germination among the annuals was PDM, while Ln had the lowest in the non-native perennials and Sp was lowest among the natives.

While not significant in all cases the k- treatment had the highest percent germination in four species (LmA, Ao, Fr, and Sp). The F treatment had the highest percent germination in three species (EPM, PDM, and Dc). The C treatment had the highest percent germination in three species (Ln, Ps, and Lm).

While not statistically significant, four F treatments had the lowest percent germination (Lma, Ao, Ln, and Lm). Four K+ treatments had the lowest percent germination, although two were tied with the k- treatment (EPM (tied), Dc (tied), Ps, and Sp). Three k- treatments had the lowest percent germination (EPM (tied), PDM, and Dc (tied). The C treatment only had one species with the lowest percent germination (Fr) and this was not significant.

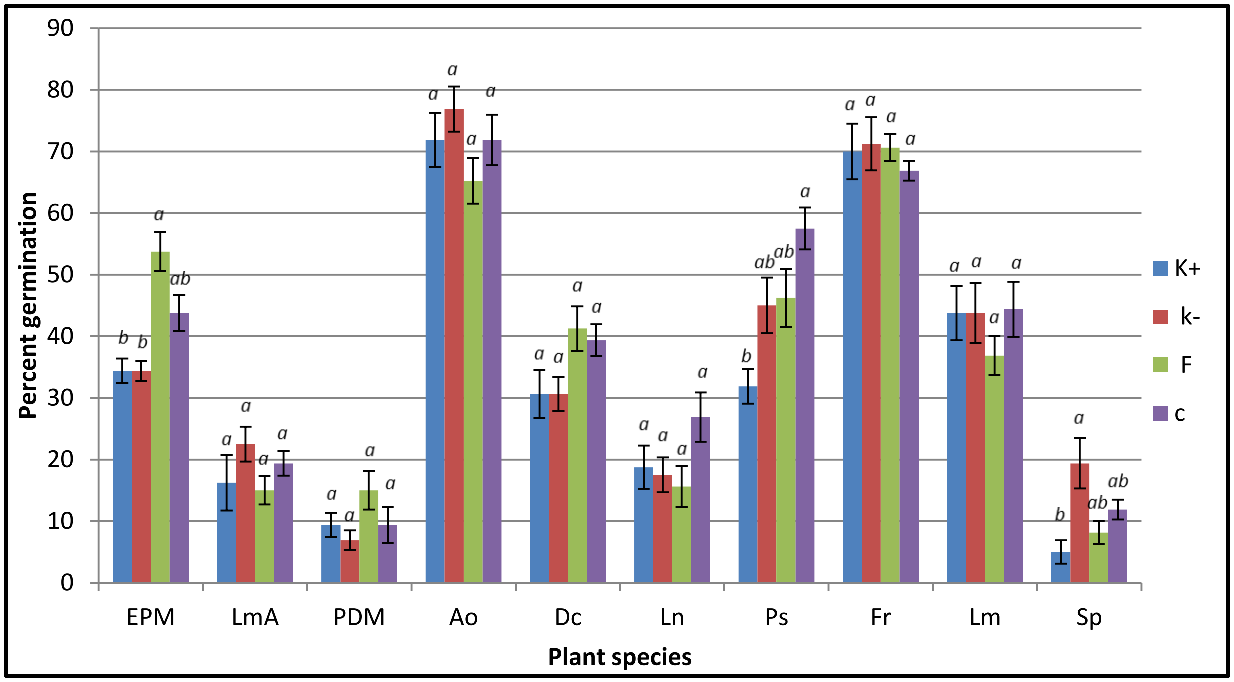

Figure 2: Mean percent germination of ten plant species, over 30 days, planted in Soprema green roof soil, using three treatments and one control. Twenty seeds per pot, eight pots per treatment. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Error bars represent standard error. Means that do not share a letter are significantly different. *(n=8)*

Germination biomass

Significant differences were found in the annual EPM where the F treatments were significantly larger than all the other treatments. The majority of F treatments (EPM, LmA, PDM, Ao, Dc, Fr, and Sp) produced more biomass on average for all plant species except Ln where the k- produced slightly more, Ps where K+ produced a larger biomass and Lm, where the control was larger.

The annual species produced more biomass than the perennial species. The F treatment produced more biomass in all three annual species. After the F treatment, the k- treatment produced a higher amount of biomass in EPM and LmA, while the control in PDM was larger compared to the two kelp treatments.

Figure 3 shows the germination biomass of the three annual species. The k- treatment produced more biomass in EPM and LmA than the C treatment. The sample size was small (*n=3*). A larger sample size might have resulted in more significant differences.

There was a significant difference with the F treatment being larger than the K+ in the treatment for the non-native perennial Ao. There was also a significant difference between the F treatment and the control for this species. While not significant, the k- treatment had the second highest biomass in Ao. (Results can be seen in Figure 4.)

There were no significant differences in the biomass of the native plant species. Two of the native species, Fr and Sp, had highest biomass in the F treatments (not significant). The control was the highest biomass for Lm. Figure 3 shows the biomass of the three native species. The biomass was extremely low weight for all species as only three pots were harvested to analyze early germination for each species and treatment.

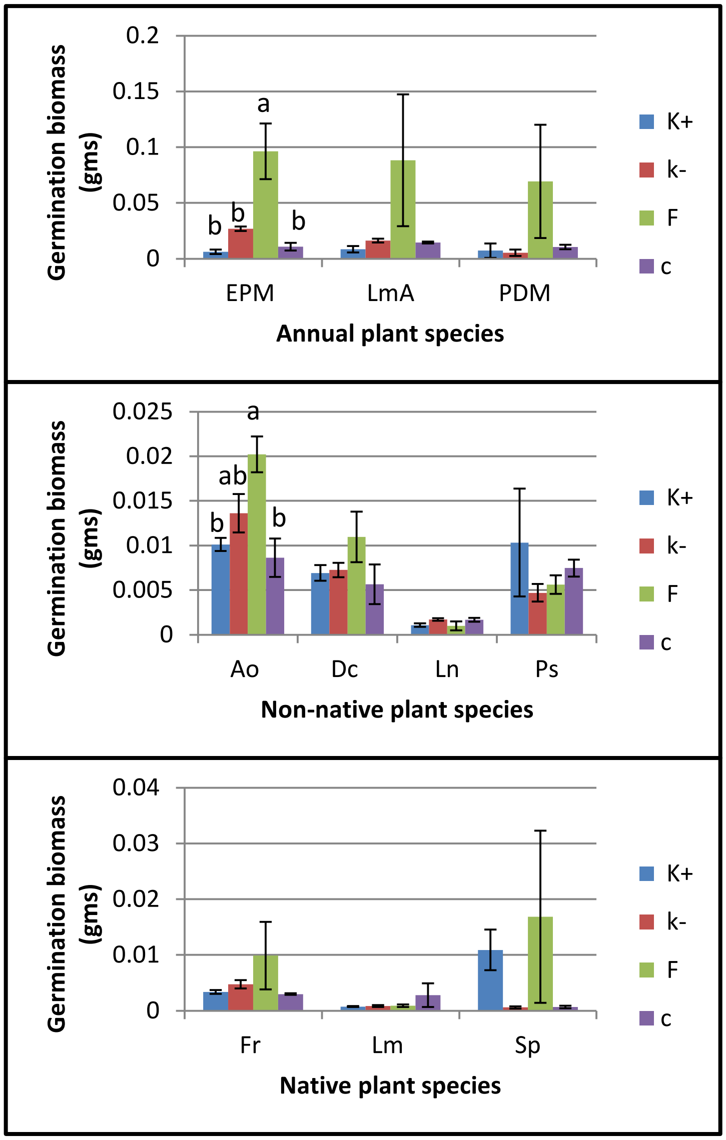

Figure 3: Germination biomass after four weeks of three annual plant species EPM, LmA, and PDM, four non-native species Ao, Dc, Ln, and Ps, and three native species Fr, Lm, and Sp. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Twenty seeds per pot, three pots per treatment. Error bars represent standard error. Means that do not share a letter are significantly different. *(n=3)*

Mean germination time (MGT)

There were no significant differences in Mean Germination Time (MGT). While not significant, the K+ treatment in Dc species was the lowest (shown in Figure 4) while the F treatment in Lm species was the highest MGT.

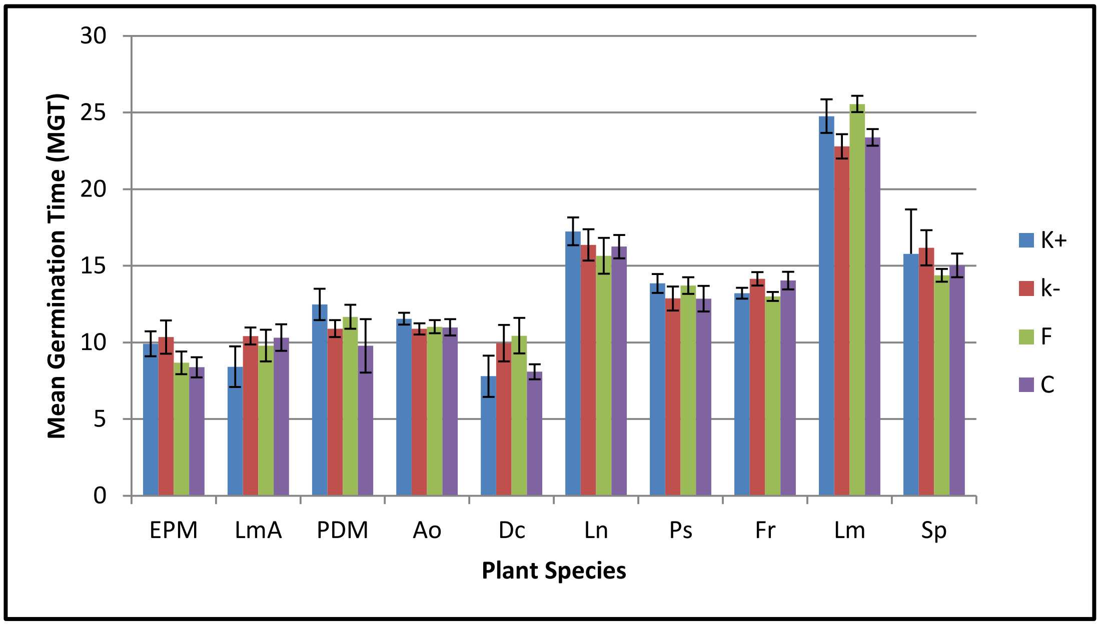

Figure 4: Mean germination time of ten plant species, 20 seeds per pot, three pots per treatment, over 30 days, planted in Soprema green roof soil. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Error bars represent standard error. *(n=8)*

Table 7 shows the number of times a treatment had the lowest (most desirable) and highest (least desirable) MGT during the germination portion of the study.

Table 7: Number of times each treatment had the lowest mean MGT and the highest mean MGT during two week germination period testing ten species of green roof plants (*n=8)*. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control.

Treatment	Lowest MGT	Highest MGT
K+	2	4
k-	2	4
F	3	2
C	3	0

Seedling vigour index (SVI)

There was one significant difference with the EPM F treatment being higher than the other three treatments. While not significant, six of fertilized treatments had higher SVI than other treatments (EPM, LmA, PDM, Ao, Fr, and Sp). Differences in all SVI can be seen in Figures 5, 6, and 7. Because of low numbers and large variation, the annual species, native species, and non-native species were separated into three figures.

When fertilized treatments were excluded from the analysis, two K+ treatments had a higher SVI (Ps and Sp) than the other two treatments, four k- treatments were higher (EPM, LmA, Ao, and Fr) in this scenario, and four controls were higher (PDM, Dc, Ln, and Lm).

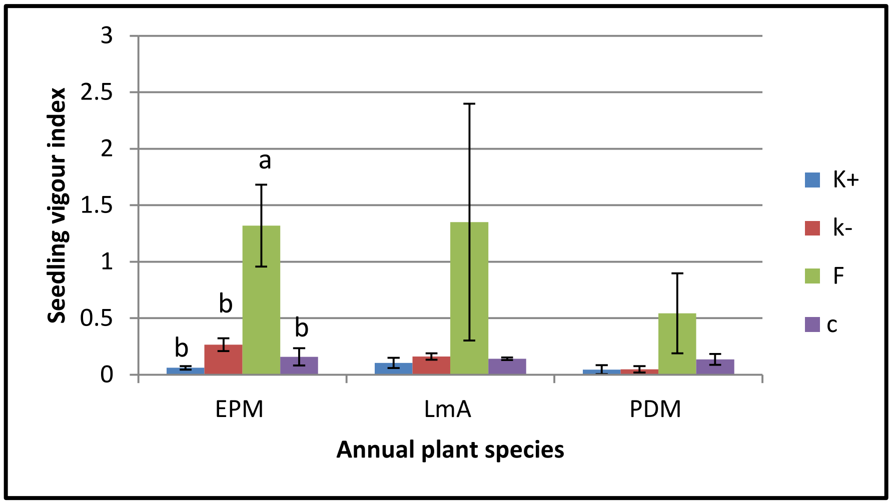

Figure 5: Effect of three treatments and one control on seedling vigour of green roof annual plants after four week germination period in greenhouse conditions. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Error bars represent standard error. Means that do not share a letter are significantly different. (*n=3*)

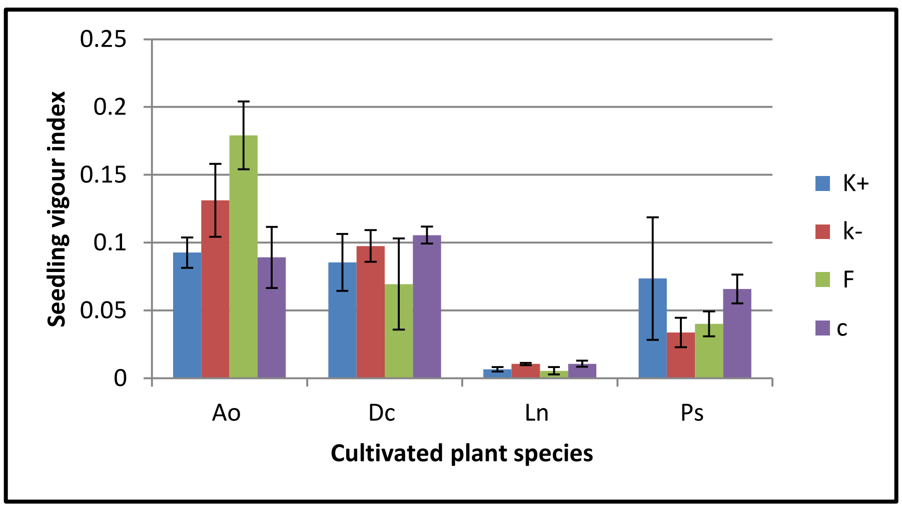

Figure 6: Effect of three treatments and one control on seedling vigour of green roof perennial plants after four week germination period in greenhouse conditions. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Error bars represent standard error. (*n=3*)

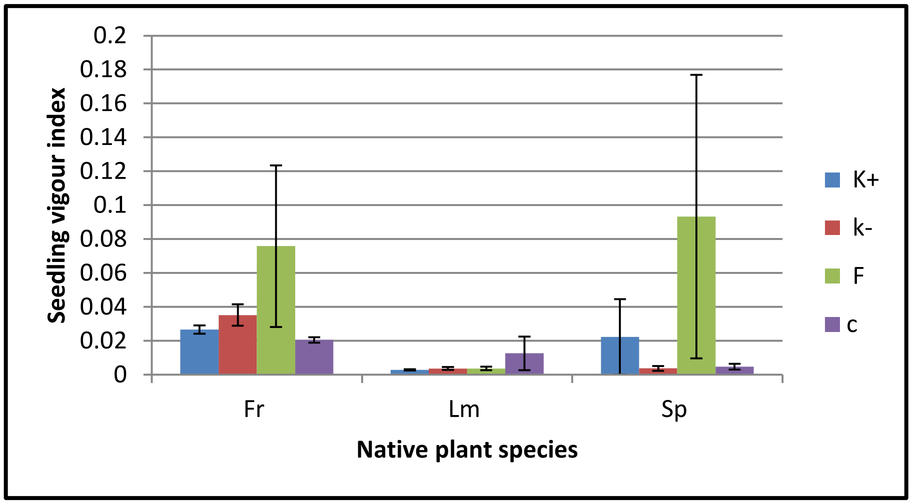

Figure 7: Effect of three treatments and one control on seedling vigour of green roof native plants after four week germination period in greenhouse conditions. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Error bars represent standard error. (*n=3*)

Green roof trial

Volumetric water content (VWC) July 1, six day drought

Following the germination portion of the study, the remaining 200 plants were moved outside in order to expose the plants to outdoor green roof environmental conditions.

Significant differences were found among the treatments for five species of plants after a six day drought on the green roof (Figure 8). The F treatments had the lowest VWC for all five species. The K+ and the C treatments in EPM were significantly higher than the F treatments. For Ps and Fr species, the K+ treatment was significantly higher than the F treatments. The Lm species K+ treatments had the highest VWC at 22.9%. This was significantly higher than the F and C treatments. For the Ao species, the K+ treatments were significantly higher than the F and C treatments. The Ao F treatment exhibited the lowest VWC reading of the day with a mean of 5.56%. Showing a further trend, but not significant, three other plant species (PDM, Dc, and Sp) had the F treatments with the lowest VWC reading between treatments.

The data show that the liquid kelp treatments did help the green roof substrate retain moisture at a higher rate than the F treatments. In nine of the ten plant species either the K+ or k- treatment had a higher VWC than the C treatments. This shows that applying kelp can increase substrate moisture on a green roof compared to adding nothing to the soil. Applying fertilizer to green roof plants could negatively affect plant health by causing drought stress due to the reduced soil moisture.

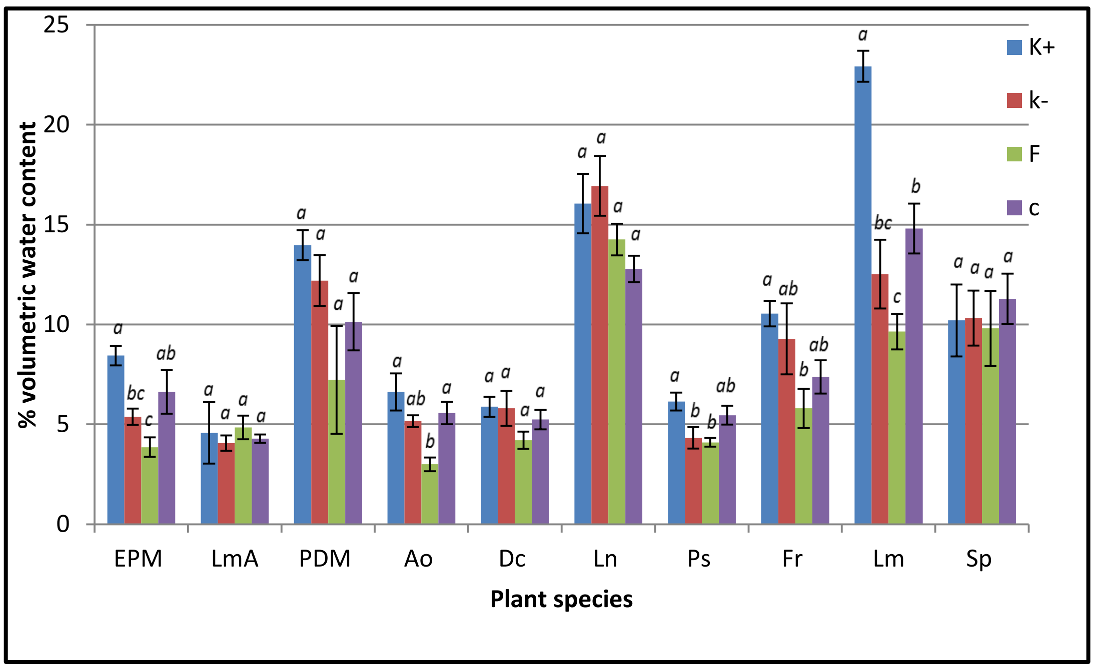

Figure 8: Mean volumetric water content (VWC) of ten species of green roof plants on the sixth day of a drought (July 17, 2013) on the Saint Mary's green roof. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Error bars represent standard error. Means that do not share a letter are significantly different. ($n = 5$)

Volumetric water content (VWC) prolonged drought

After two months outside in the green roof environment, the 200 remaining plants were moved back into the greenhouse in order to apply a prolonged drought. Figure 9 shows the mean volumetric water content (VWC) of the ten separate plant species over the first fourteen days of the drought. Data were taken for the two month period of the drought until plants died. The first fourteen days are analyzed here because constant daily plant death affected the sample size as days of drought continued.

Seven days into the drought, the highest VWC was in Sp K+ treatments (29.38) and the second highest VWC was in Lm K+ treatments (28.8). The lowest VWC% on Day 7 was in Fr F treatments (11.42) and the second lowest was in EPM F treatments (11.64). On Day 14, the highest VWC was in Lm K+ treatments (19.08) and the second highest VWC was in PDM K+ treatments (18.8). The lowest VWC on Day 14 was in Ps F treatments (3.68) and the second lowest was in LmA F treatments (4.7). While treatments within a species were statistically compared, I did not compare different species with statistical tests.

The VWC of all of the species were combined together to compare the overall effect of each treatment. On Day 7, the k- treatments had a slightly higher VWC than the K+ treatments and the F treatments had the overall lowest VWC. On Day 14, the K+ treatments had the highest VWC and again the F treatments were the lowest overall. This trend continued on day 19.

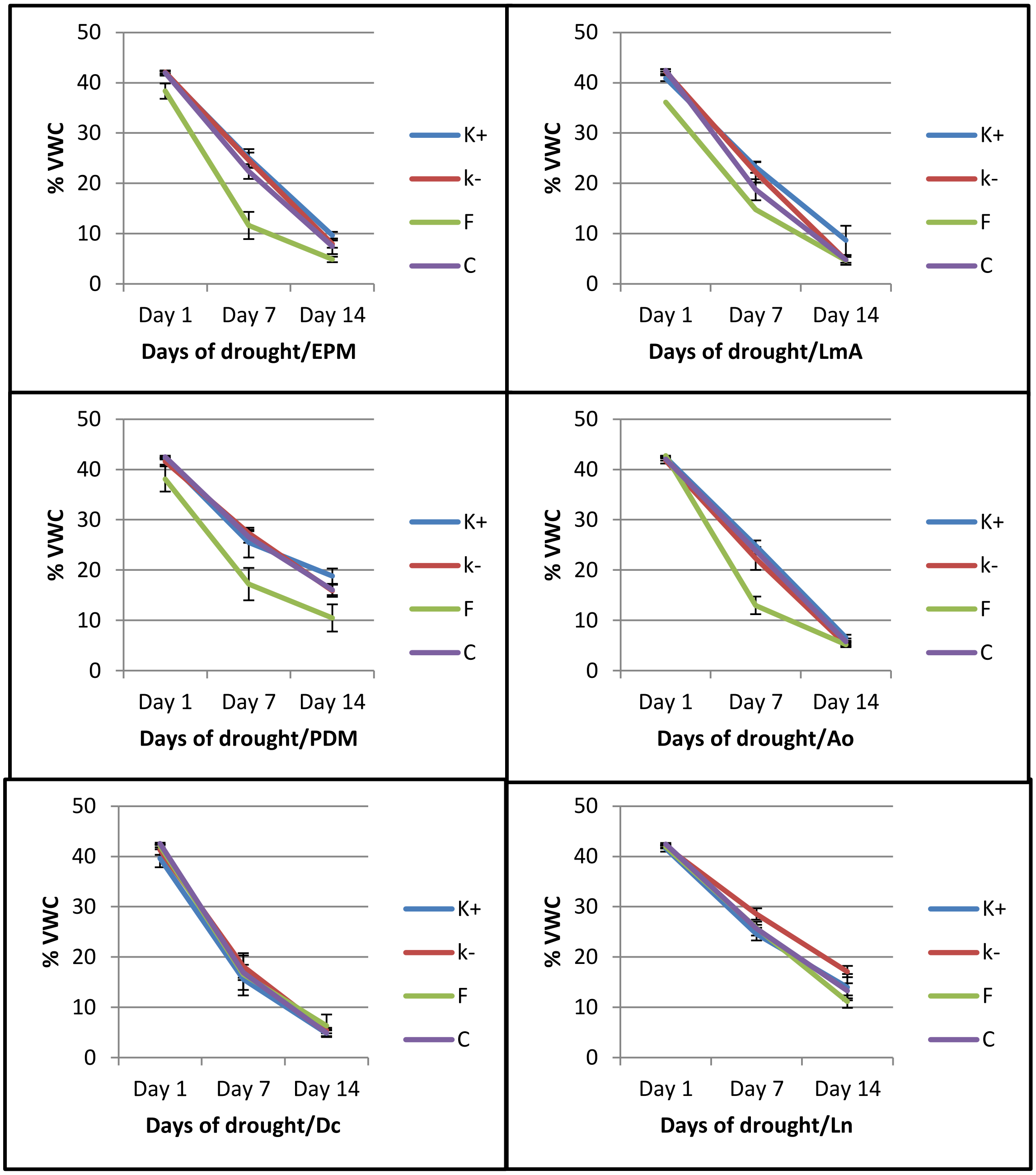

Figure 9: Mean volumetric water content (VWC) of ten species of green roof plants during first fourteen days of prolonged drought in the greenhouse at Saint Mary's University. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Means that do not share a letter are significantly different. (continued on next page).

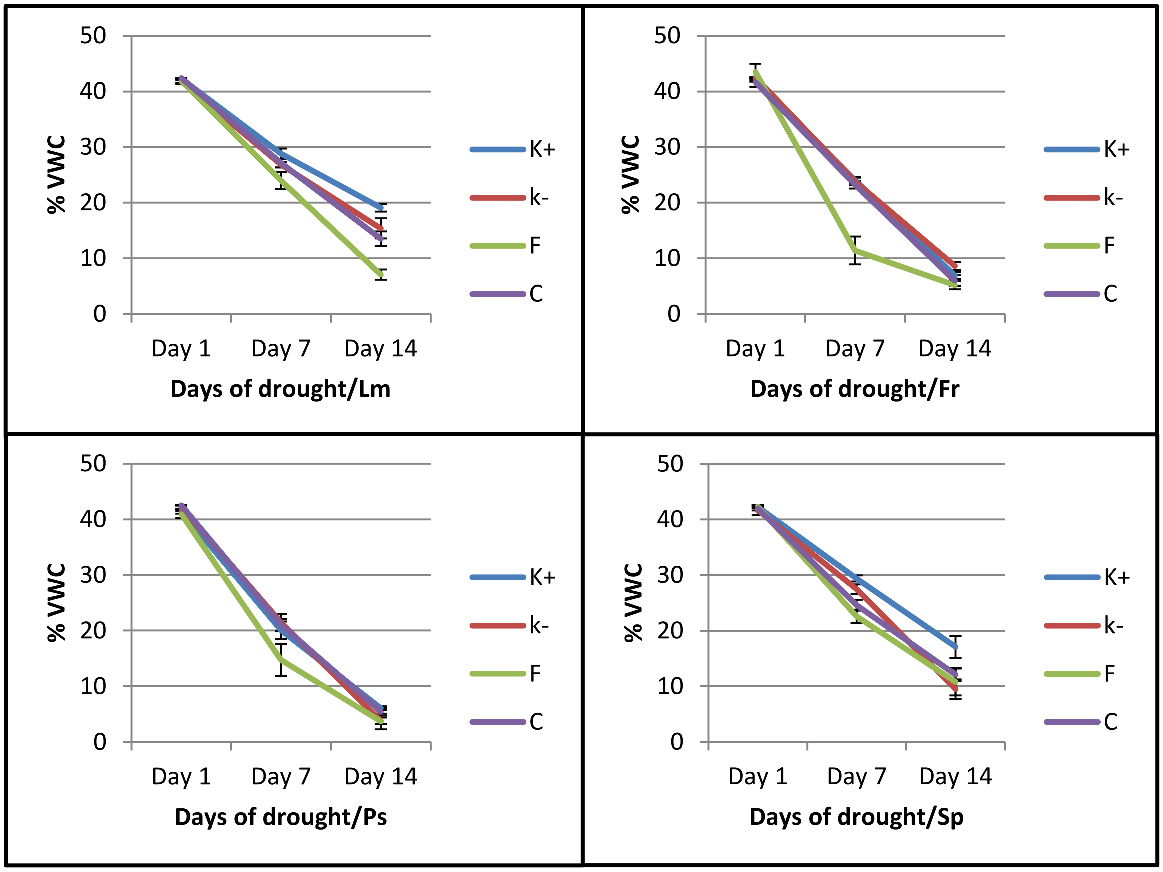

Figure 9: continued

Table 8 shows the significant differences in VWC for ten plant species in the study. There were six species of plants in the F treatments that had significantly lower VWC on Day 7 of the drought. Even on the first day of the prolonged drought, just after the last watering, the F treatment in EPM was significantly drier than the other three treatments.

Table 8: Significant differences (assessed by Tukey's Post Hoc Test) in the mean volumetric water content (VWC) of ten species of green roof plants during a fourteen day drought in greenhouse conditions. Data was recorded every two days. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Means that do not share a letter (within a species) are significantly different. (*n=5*).

Species	**Day 1**				**Day 7**				**Day 14**			
	K+	k-	F	C	K+	k-	F	C	K+	k-	F	C
EPM	*a*	*a*	*b*	*a*	*a*	*a*	*b*	*a*	*a*	*ab*	*b*	*ab*
LmA	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
PDM	*a*	*a*	*a*	*a*	*ab*	*a*	*b*	*a*	*a*	*ab*	*b*	*ab*
Ao	*a*	*a*	*a*	*a*	*a*	*a*	*b*	*a*	*a*	*a*	*a*	*a*
Dc	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
Ln	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
Ps	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*	*a*
Fr	*a*	*a*	*a*	*a*	*a*	*a*	*b*	*a*	*ab*	*a*	*b*	*ab*
Lm	*a*	*a*	*a*	*a*	*a*	*ab*	*b*	*ab*	*a*	*ab*	*c*	*b*
Sp	*a*	*a*	*a*	*a*	*a*	*ab*	*c*	*bc*	*a*	*a*	*a*	*a*

Health scores during prolonged drought

The differences in health scores among species can be seen in Figure 10 and a description of health scores can be found in Table 5. There were numerous significant differences in the number of days it took the individual plants to have reduced health scores when analyzing the various treatments. Some treatments caused health scores to lower more quickly. In almost all the species except Ps (where the C treatments took longer to reach a health score of zero), plants in one or both kelp treatments (K+, k-) took longer to reach a health score of one or zero. In all ten plant species, the F treatments reached a health score of one and zero first. These data show that the kelp treatments kept the plants healthier for longer and kept them alive for longer compared to the C treatments and the F treatments.

The least drought tolerant species were LmA and EPM in the F treatments. This could be because the plants are annuals and they were further along in their life cycle than the perennial species. They were flowering and had produced seeds while the perennials were in a vegetative stage of growth with no flower buds showing. Their health scores reached one in 7.8 and 8.8 days respectively. In two weeks or less, the plants were dead. The EPM K+ treatments lived almost two weeks longer than the F treatments.

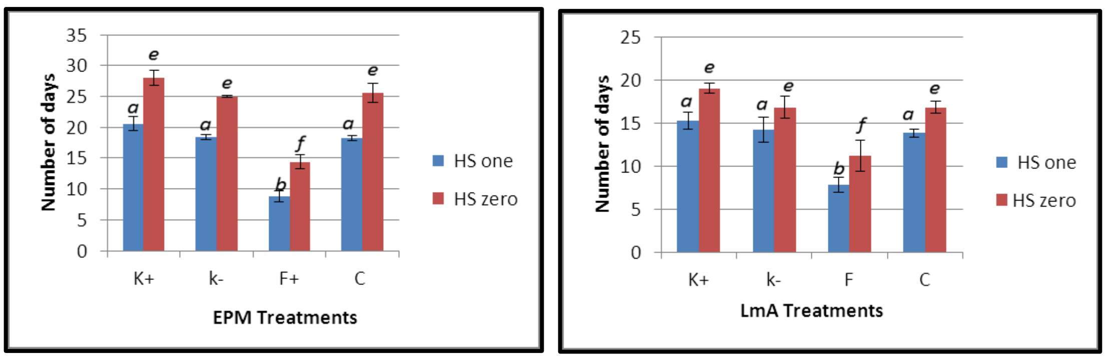

Figure 10: Mean number of days until plants reached health scores of one or zero, for ten species of green roof plants during two month drought in Saint Mary's University greenhouse. Health scores were 1 (greater than 50% yellow or brown leaves, wilting, folded leaves and 0 (dead). Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Means that do not share a letter in HS One are significantly different. Means that do not share a letter in HS Zero are significantly different. (continued on next page).

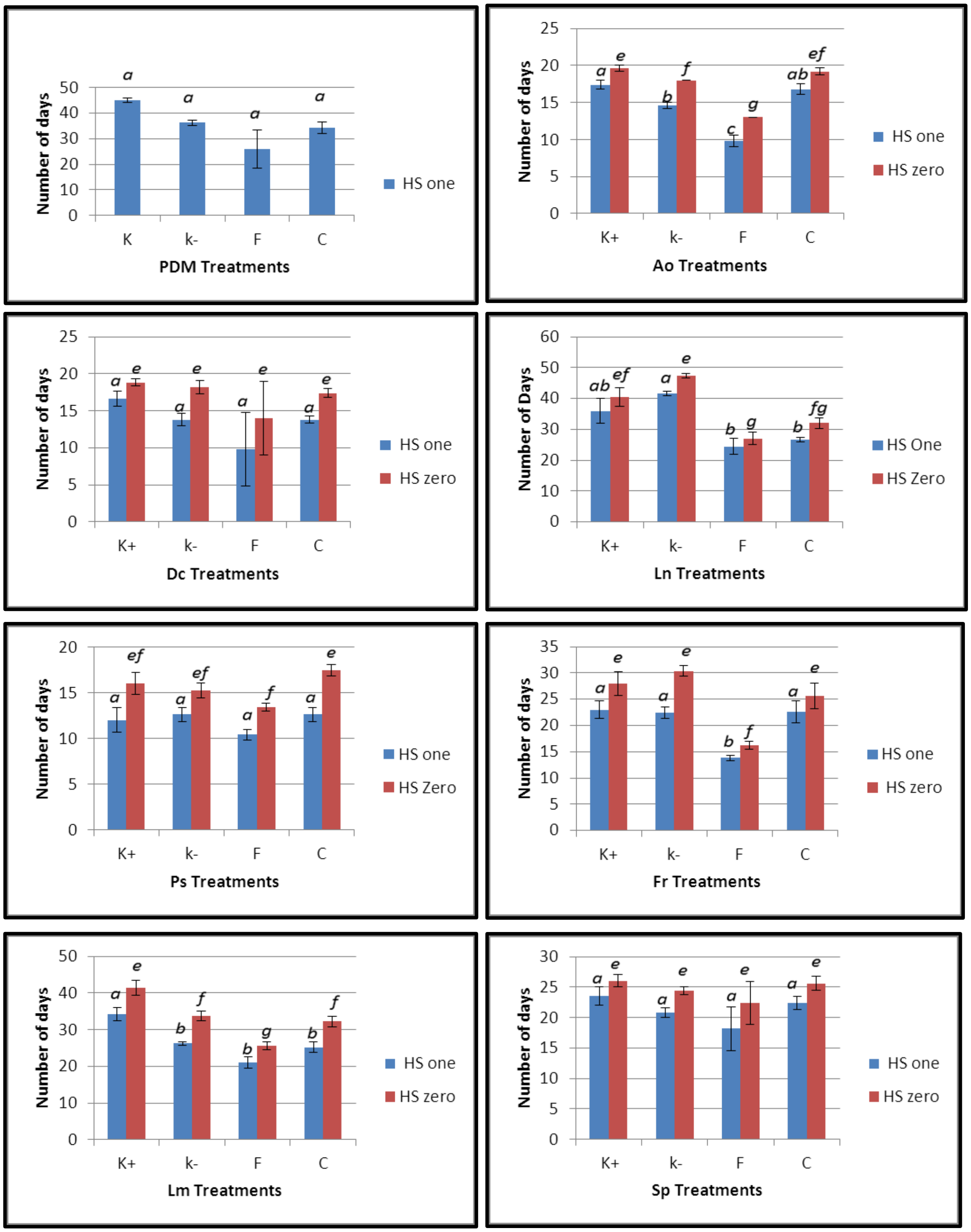

Figure 10: continued

Figure 11 shows all ten species combined together and the health scores of one and zero. Results were very similar compared to the individual species. The health of the F treatments during the drought deteriorated in two weeks and the plants were dead only a few days later. The K+ treatments took over three weeks to visually deteriorate to a health score of one and lived for three more days before dying. The k- treatments took just under three weeks to reach a health score of one and died approximately four days later. These data show that the kelp did help prolong the health and the life of the plants during drought and when the plants reach a health score of one, it took only a few days for them to die.

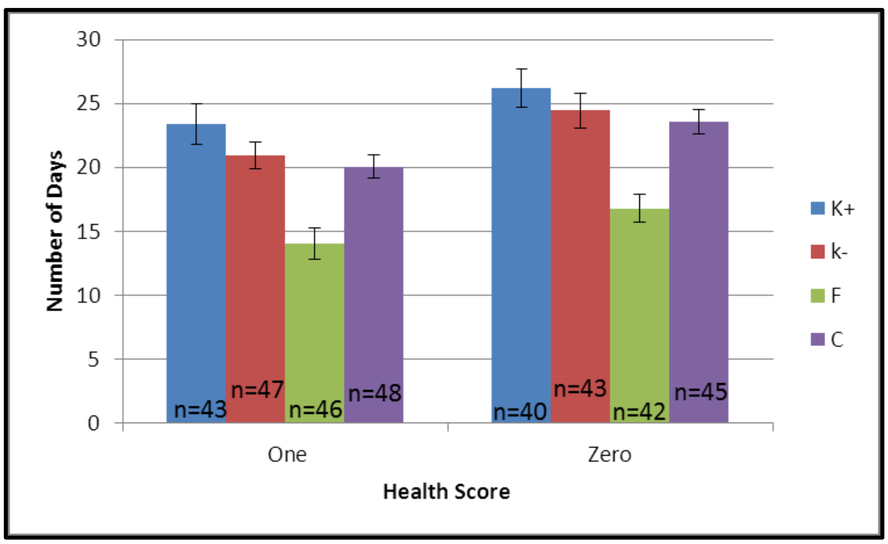

Figure 11: Mean number of days it took all plant species to reach health scores of one and zero during two month drought in Saint Mary's University greenhouse. The health scores shown here are One (greater than 50% yellow or brown leaves, wilting, folded leaves to Zero (dead). Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control.

Biomass after drought

Biomass of all the remaining 200 plants was weighed after they died in the drought and in the case of PDM, when the experiment was finished. The weight was cumulative with all biomass from before and after the drought being measured. Six species (EPM, LmA, Ao, Dc, Ps, and Fr) in the F treatments had significantly larger biomass than all other treatments and the Lm F treatments had significantly larger biomass than the two kelp treatments. These results can be seen in Figure 14. The species with the largest biomass, the LmA F treatments were the first to die during the drought.

When the F treated plants were excluded from analysis, the EPM k- treatments were significantly larger than the K+ and C treatments, the LmA k- treatments were significantly larger than the K+ treatments, the Ao K+ and k- treatments were significantly larger than from the C treatments, and the Ps K+ treatments were significantly larger than the C treatments.

There is some effect in applying kelp to the different plant species. The biomass was larger in some species compared to the C treatments. Two different volumes of kelp were applied weekly for three months. The volumes and frequency could be adjusted and should be explored in future research.

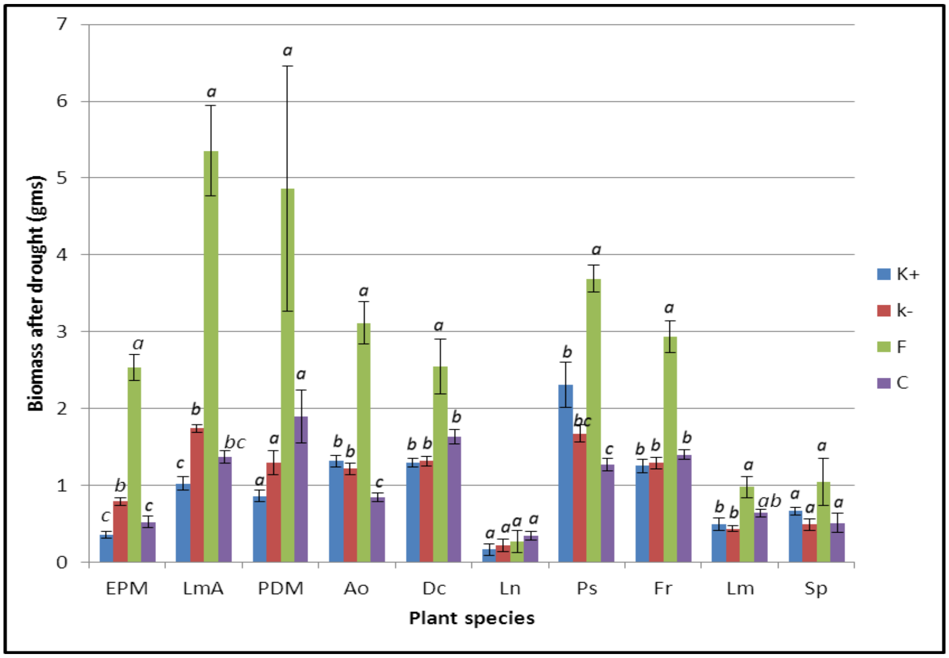

Figure 12: Mean biomass of ten green roof plants after two month drought. Treatments were, K+, 3.5 ml per litre of water, k-, 1.5 ml per litre of water, F, 2.5 ml of slow release fertilizer applied one time only, and C, control. Error bars represent standard error. Means that do not share a letter are significantly different. *(n=5)*

Discussion

Early plant growth

A relationship was found when the significant differences between treatments in the first two weeks of germination (early germination) (Table 6) were compared with percent germination (Figure 2). For EPM, the F treatments were higher in early germination and this was carried over with higher percent germination in the F treatments. This was also the case with Ps in the C treatments and Sp in the k- treatments where higher earlier germination led to higher percent germination.

While not significant, this trend was further observed when looking at Figures 1 and 2 where the same pattern of higher early germination led to higher percent germination in the following species and treatments: LmA (k-), PDM (F), Ao (k-), Dc (F), and Ln (C). This finding highlights the importance of those first early days when seeds are emerging. If seeds are able to take advantage of the moisture, temperature, and light that are available to them, there will be a larger plant population due to higher percent germination as the growing season continues. It appears that early germination is an accurate predictor of the percentage of seeds that will eventually germinate.

In this study, the F treatments produced higher earlier germination in 4 of 10 species and higher percent germination in only 3 of 10 species showing that it may not be practical to apply F at time of planting seeds.

The kelp treatments (K+ and k-) showed higher early germination than the C treatments for 6 out of 10 species (LmA, PDM, Ao, Lm, Fr, and Sp). These differences were not significant. Thorson et al. (2010) also tested kelp and concluded that the presence of cytokinins and gibberellins in the kelp solutions increased germination of *Trifolium repens* (white clover) and *Avena strigosa* (bristle oat). It has been shown in other research that kelp contains cytokinins (Khan et al. 2009; Zhang &Ervin 2004) and gibberellins (Crouch & van Staden 1993). These two phytohormones can work synergistically and can induce the germination of different seed species by helping transport nutrients (Letham 1969). Differences in germination continued with *Luzula multiflora* (Lm). This species took the longest of all species to begin germination. Once germination started, the k- treatment was significantly higher than the F treatments. This is a plant species native to Nova Scotia. Native species are typically adapted to local conditions and often grow better without the aid of fertilizers (Butler et al. 2012). *Luzula multiflora* grows in peaty areas of the barrens in Nova Scotia and may already have an association with kelp by obtaining nutrients from salt spray or storm debris that may be washed up close to where it grows. The improved moisture provided by the kelp may also have been a benefit to significantly improve the germination of this species. While not significant, the higher germination for the five other green roof plant species that reacted positively to the kelp treatments early on in the experiment shows that the kelp was beneficial for germination.

The F treatment in *Eschscholzia californica* 'Prize Mixture' (EPM) had the highest percent germination, (which was significantly different from the two kelp treatments) and the C treatment was second for the species. This plant is native to California where it is hot and dry. The increased moisture that was available in the kelp treated pots may have affected the germination negatively. However, when it came to the prolonged drought, the F treatment was detrimental to the health and survival of EPM while both K+ and k- treatments lengthened the number of days the plants stayed healthy and increased the survival time of the kelp treated EPM plants.

The annual *Portulaca grandiflora* 'Double Mixed Colors' (PDM) also had the highest percent germination in the F treatment. This species is a C4 succulent dicot that can exhibit CAM photosynthesis (Guralnick et al. 2002; Ku et al. 1981; Kraybill & Martin 1996) and this species appears to have responded positively to the drier conditions that the F treatment created. During the prolonged drought the F treatments health did deteriorate faster (not significant) however, this species did not die during the drought. All treatments in PDM survived for two months with no water and continued to flower 58 days into the drought.

Analyzing mean germination time (MGT) produced no significant differences among treatments in this study. Due to space constraints in the greenhouse, there were eight replicates for each species and treatment at the beginning of the experiment to measure MGT. A larger sample size may have resulted in significant differences.

It was predicted that kelp treatments would lower the MGT of some of the plant species being tested. This was the case for four different species (see Table 7).

Five species (EPM, LmA, PDM, Ao, and Dc) had a lower MGT over all treatments compared to the other five species regardless of the treatments. If seeding a diverse green with a mixture of plant species, attention should be paid to the germination time of each species included in a seed mixture. If there are species that are germinating faster than others, these plants could take space, nutrients, and water from other species that may take longer to germinate. This could have a long term effect on the plants in a community on a green roof which in turn could affect ecosystem services provided by the roof since different plants species offer different ecosystem services (Lundholm et al. 2010).

Fertilizers are designed to provide optimal nutrients in balanced amounts for plant growth (Follett et al. 1981). This was clear in the germination biomass as the F treatments were heavier in seven plant species. While F didn't improve the percent germination, the seeds that did germinate were able to put on biomass quickly.

Second to the F treatments, the k- treatment exhibited higher germination biomass than the K+ and C treatments in six species and the K+ treatment had higher biomass in two species. Leach et al. (1999) found that the application of kelp *(A. nodosum)* reduced the amount of nitrate leaching in sandy soil. It possible that the kelp added to the green roof soil in this experiment reduced the nitrates leaching out of the soil making the nutrients available to the growing plants. Leachate was not measured in the experiment. Further research would be useful on green roofs comparing leachate of kelp treated plants compared to other treatments since younger green roofs can leach nutrients that can become a possible source of pollution (Berndtsson 2010) and the application of kelp could ameliorate the leachate.

The improved higher germination biomass could be in part due to the presence of cytokinins in *A. nodosum* (Zhang & Ervin 2004) that translocate from the root apex to the leaf of plants (Letham 1969) and are known to affect plant growth. Khan et al. (2009) stated that the presence of cytokinins and other biomstimulants can be beneficial to plants treated with *A. nodosum*. In a study by Rayorath et al. (2008) the root tip growth of *Arabidopisis thaliana* using liquid *A. nodosum* derived from Acadian Seaplants kelp powder was improved compared to controls at three, five, and seven days after application. Plant growth was also significantly larger than the controls. Other studies have also shown that applications of kelp can improve plant growth and vigour (Beckett & van Staden 1989; Thorsen et al. 2010). We can surmise that there are a number of factors that come from kelp that are beneficial to plants even with small applications. Further germination studies may help us to discover what other green roof plant species may benefit from liquid kelp applications.

When seedling vigour index (SVI) was analyzed, the F treatments again dominated because this measure is related to biomass and the F biomass was heavy. Comparing the kelp and control treatments resulted in the SVI being higher for six plant species (EPM, LmA, Ao, Ln, Ps, Fr, and Sp) in kelp treatments compared to the C treatments showing that applying kelp produced healthier seedlings compared to adding nothing to the substrate. While not significantly different, a larger sample size may have resulted in more significant results.

The results for early biomass and seedling vigour show that the application of kelp was beneficial for the early growth of some plant species.

Drought

Numerous studies have been done to evaluate the drought tolerance of green roof plants (Butler & Orians 2011; Liu et al. 2012; Monterusso et al. 2005; Nagase & Dunnett 2010; and Thuring et al. 2010). If we are going to expand the range of species being used in Nova Scotia from mainly *Sedum* for green roof applications, analyzing the drought tolerance of different species will enable us to choose appropriate plants to create sustainable and diverse green roofs. After a six day drought on the Saint Mary's roof, eight species of plants in the F treatments exhibited lower substrate moisture compared to other treatments. This was likely due to higher water use by the larger plants in the F treatment. The K+ treatments exhibited significantly higher moisture levels for five plant species. These results are similar to those found by Zhang & Ervin (2004) where they applied liquid seaweed extract to *Agrostis palustris*, a creeping bentgrass grown in pot culture. The seaweed extract treated containers had higher average moisture levels compared to the control.

After a two month period on the green roof, the plants were transferred back into the greenhouse in order to expose them to a long term drought. The first fourteen days of the drought were analyzed. While data was taken throughout the whole two months, plants were dying and obtaining robust statistical results past the first fourteen days was not practical as the number of plants alive decreased.

All plants were watered one last time before the prolonged drought began. Even on the first day, immediately after watering, the VWC of the soil in the F treatment of EPM was significantly lower compared to the other treatments. There are a few things that could have been happening, the root mass of the EPM could have been large and reduced the amount of water that the pot was able to hold or the plant size in the F treatment could have quickly taken up water and lowered the moisture content of the soil. By day seven of the drought, five species in the F treatments were significantly drier than other treatments. Some of these species were smaller than the EPM, so it logical to consider that it was the F in combination with the water use of the plant species that caused the substrate moisture to be lower.

One way to analyze if a plant is lacking water is to observe a plant's appearance. Drooping leaves and flowers, brown leaves and stems are visual clues that there is a problem that needs to be addressed. The visual health scores in this experiment provided evidence that the application of fertilizer accelerated drought symptoms for all of the plant species. Photographs of the different plant species and their visual appearance throughout the drought can be seen in Figure 14. The loss of plant species on a green roof can be aesthetically undesirable, could reduce biodiversity on a green roof, and may reduce ecosystem services such as evapotranspiration from vegetation, canopy shading, and stormwater retention.

There were significant differences in the health scores (described in Table 5) of seven species of plants when health scores reached one. In all cases, the F treatments health deteriorated first compared to the other treatments. In eight of the ten species of plants, the trend was for the K+ treatments to stay healthier than the k- and C treatments when the health score reached one. There were two species where the k- treatment stayed healthier for longer than the K+ treatments (Ps & Ln). There were significant differences in the health scores when the plants reached zero (dead) in eight out of the ten species, the F treated plants died first. The F treated plants died first in all species except PDM, where all plants in all treatments were still alive at the end of the experiment. Photographs of the health scores of the annual species (EPM, LmA, PDM) can be seen in Figure 13 along with samples of a grass (DC), Luzula (Lm), and the native perennial (Sp). Not all species are pictured due to similarities in growth forms and appearance.

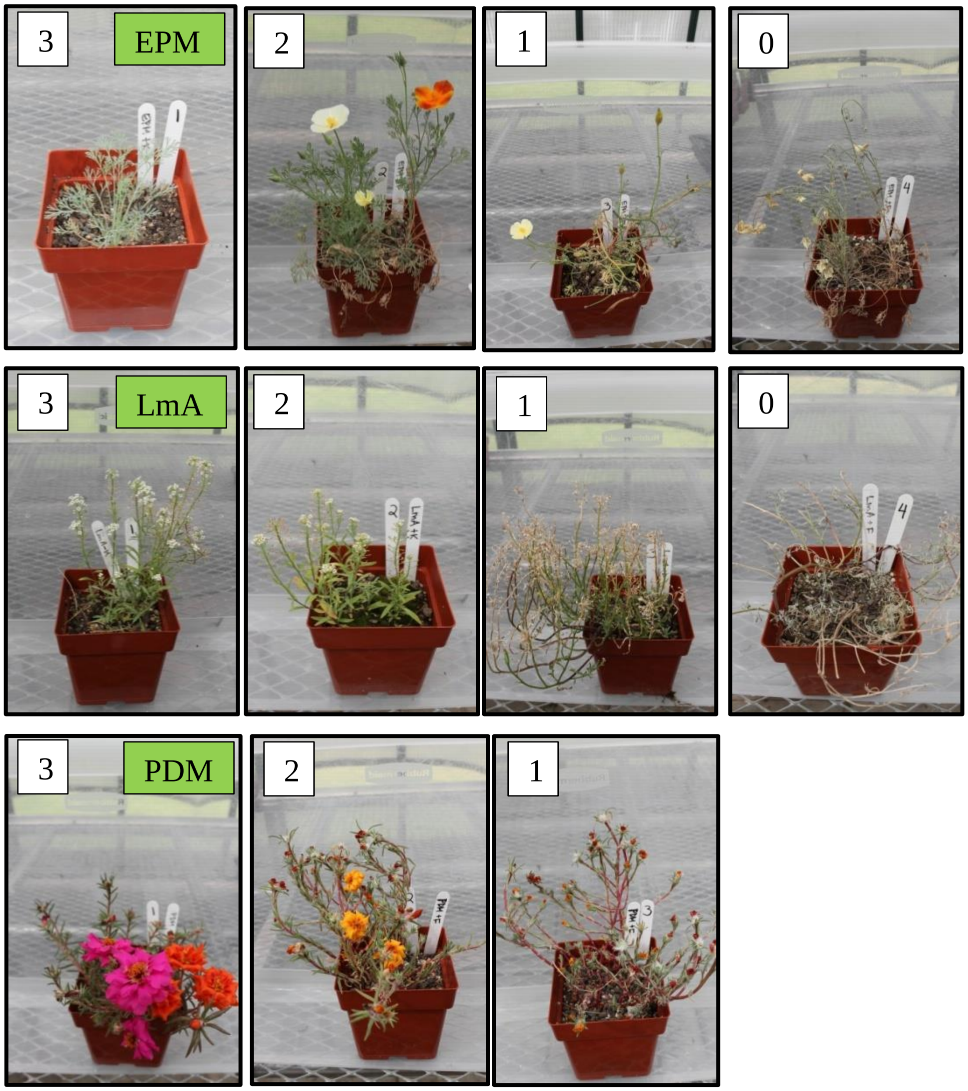

Figure 13: Visual health scores of green roof plants (EPM, LmA, PDM, Dc, Lm, Sp) exposed to long term drought. Plants were treated with 3.5 ml of liquid kelp (K+) per week, 1.5 ml of liquid kelp (k-) per week, 2.5 ml of 10N:10P:10K Scott's Miracle-Gro® Slow Release Plant Food per pot (F), and a control (C) in which no amendments were added. (continued on next page).

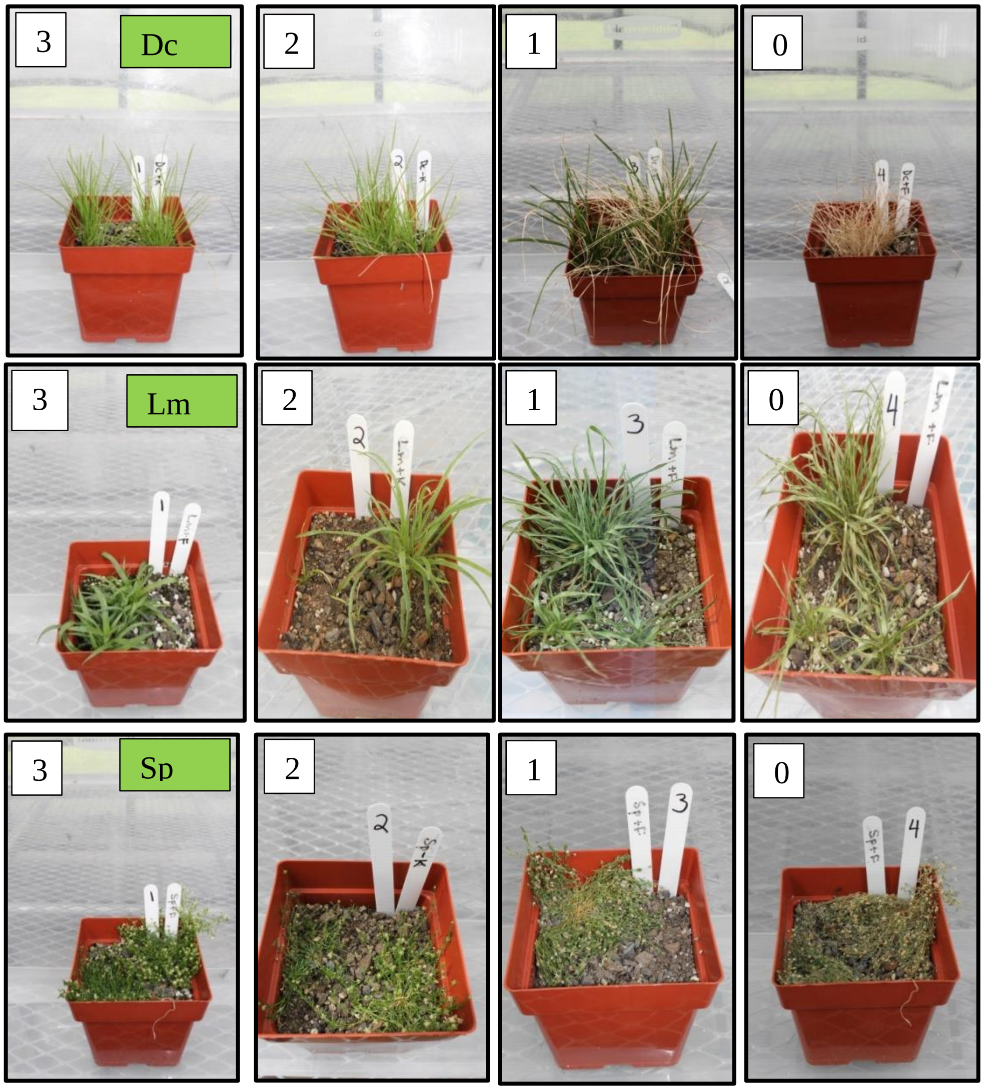

Figure 13: (continued)

It is clear that the liquid kelp treatments had an effect on the soil moisture and the higher water content kept the plants healthy for a longer time than the controls and the fertilized treatments. Betaines have been isolated from brown seaweeds, are known to behave like cytokinins (Crouch & van Staden 1993) and could be partly responsible for helping plants to resist drought stress (Craigie 2010). Betaines can protect cells against drought and salinity by accumulating in the cells and while some plants accumulate betaines naturally (Hanson et al. 1985), the application of liquid kelp may have provided plants with a ready source of betaines that they were able to assimilate, thus their health was improved during drought conditions.

Haslam & Hopkins (1996) studied the physical and biological effects of another species of brown seaweed, *Laminaria digitata* and found an increase in pore volume and aggregate stability of a sandy soil. The increase in the pore volume increased the water-holding capacity of the aggregates. Their study was done with chopped pieces of kelp fronds while this study was done with liquid kelp. The soil in this experiment wasn't analyzed after the study, so we can only surmise that the liquid kelp improved the aggregate stability and thus the moisture holding capacity of the green roof soil.

Biomass

Biomass is considered a preferred measure of assessing species performance (Chiarucci et al. (1999). The dry biomass in this study was significantly higher in the F treatments for seven species. Two other species showed a trend of higher biomass in the F treatments. All nine of these species died first, showing that the high biomass created survival problems in a drought situation.

Using fertilizer in this experiment produced larger plants that we would consider more robust than the smaller ones produced by the kelp and control treatments. Fertilizer is commonly used on green roofs to improve and encourage fast plant growth and coverage, yet the application of fertilizer can negatively affect the long term quality of the plants (Berndtsson 2010). In a study by Emilsson et al. (2007), plant biomass was significantly higher in vegetated plant mats treated with a higher amount of fertilizer compared to a low and mid-range fertilization level. Fresh weight of the plants was increased by with the higher application of fertilizer, but dry weight was not. It is this water filled, leafy growth that is vulnerable to drought.

Plant size can affect green roof performance. Larger plants can provide more cover on a green roof, absorb more stormwater and could capture more particulate pollution. These benefits are useful, but not if the plants are dead. The larger biomass produced by the F treatments in this study made the plants vulnerable to drought conditions. In a stressful green roof setting, where high winds, shallow substrate, and high irradiance can quickly dry out the soil, large plants could be a liability.

Conclusions

Choosing a diverse mixture of plant species could offer protection from drought as some species in the experiment died more quickly than others. Perennials may die in a drought, while the seed from annual species could persist and germinate when moisture returned. All of the plant species tested in this experiment could be combined together to seed a green roof and are recommended for green roof culture. The three annual species all bloomed and set seed. *Lobularia maritima* (LmA) was the first to bloom (k-treatment). It set seed and produced new seedlings in July that would have provided floral resources for pollinators later in the growing season. *Portulaca grandiflora* (PDM) did not die in the drought and continued to bloom long after many species had died. *Eschscholzia californica* (EPM) had high germination and provided mixed coloured flowers. *Anthoxanthum odoratum* (Ao) was not very drought tolerant likely due to large coarse leaves. Because of its high germination, it is recommended that less volume of seed be used in a seed mix so it doesn't crowd out other plants. *Poa supina* (Ps) exhibited a prostrate growth habit that is useful for covering the substrate quickly. The clump grasses, *Deschampsia caespitosa* (Dc) and *Festuca rubra* (Fr) had narrow leaves and offered good colour and upright growth. *Luzula nivea* (Ln) *and Luzula multiflora* (Lm) took a long time to germinate and this could be a problem when seeding a roof if other species move in to an area first. *Sagina procumbens* (Sp) had very low germination and could have been due to the tiny seed. The seed could have been washed away and this would be a possibility on a green roof. However, the plants that did grow produced dozens of seedlings showing that the plant could become established on a green roof. Due to the low germination, more seed would be recommended in a mix.

The literature provides evidence that kelp is beneficial for plant growth, drought tolerance, and soil stability. Results of this experiment support this. Improved germination of some species, increased biomass of kelp treated plants compared to control treatments, higher moisture levels of substrate during drought conditions, and improved health and longevity of plants treated with kelp compared to fertilizer and control treatments is encouraging.

This was a short term experiment (four months) compared to the possible time a green roof might exist as urban green infrastructure. Long term performance could show different results and plant communities would evolve overtime and may be quite different compared to this brief period of time. If green roofs are to be sustainable, they will have to be resilient to environmental stresses such as drought and applying liquid kelp could help with this. A biodiverse green roof containing annuals, cultivated grasses, and native plants could be considered a long term, urban ecosystem (Seabrook et al. 2011) that would contribute to urban green space by offering a variety of benefits that come from a green roof system.

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Chapter 3

Effects of soil amendments on substrate erosion and the establishment and growth of native plants and Sedum in an extensive, vegetated mat green roof system.

Abstract

Expanding the varieties of plant species grown on green roof vegetated mat systems from the industry standard *Sedum* can help to create diverse roofs that may provide improved habitat, greater floral resources, and be aesthetically pleasing for the urban population. Extensive green roofs have shallow substrate that can erode making it difficult for plants to colonize. There are no published studies of applying *Ascophyllum nodosum* (kelp meal) on green roofs to aid in plant growth and survival and very few using mushroom compost. These soil amendments and fertilizer were top-dressed onto vegetated mats that were growing *Sedum* and native plants from the coastal barrens of Nova Scotia. Canopy density, plant survival, and erosion were evaluated; and substrate temperatures, floral resources, habitat availability, and species change over time were observed during a one year experiment on a green roof in Dartmouth, Nova Scotia. Adding organic amendments to the vegetated mats reduced erosion, and helped to establish and maintain healthy native plant and *Sedum* populations on the green roof

Keywords: Green roof, vegetated mat, native plants, kelp, mushroom compost, erosion, plant establishment

Chapter 3: Effects of soil amendments on the growth of plants in an extensive, vegetated mat green roof system.

Green roofs

Green roofs are constructed, vegetated ecosystems that offer the built environment both aesthetic beauty and environmental benefits (Ranalli & Lundholm 2008; Emilsson 2008; Rowe 2011). The two most common types of green roofs are differentiated mainly by substrate depth. Intensive roofs have substrate depths of more than 20 cm and extensive roofs have substrate depths of 20 cm or less (Olly et al. 2011). Extensive roofs are popular as they are less costly to install (Olly et al. 2011) and they are practical for retro-fitting on existing roofs because usually no extra building reconstruction is required to install them (Emilsson 2008).

Green roofs provide ecosystem services such as stormwater management (Mentens et al. 2006; Schroll et al. 2011), cooling services through plant evapotranspiration that help mitigate the urban heat island (Oberndorfer et al. 2007; Blanusa et al. 2013), reduction of particulate pollution (Rowe 2011; Cook-Patton & Bauerle 2012), and noise attenuation (Rowe 2011). Other benefits for people include the aesthetic beauty (Jungels et al. 2013) of the green space and psychological benefits by contributing a source of nature for urbanites (Lee et al. 2014). Green roofs also can provide flora for pollinators (Ksiazek et al. 2012; Nagase & Dunnett 2012), habitat for urban wildlife (Brenneisen 2006; Molineux et al. 2009) including habitat for rare species (Köhler 2006), and they can be used for the conservation of native plant species that are being removed from urban areas due to the construction of buildings and roads (Grant 2006; Madre et al. 2014).

Plants on green roofs

A great range of plant species can be established on extensive green roofs although *Sedum* species are most commonly installed due to their drought tolerance, prostrate growth habit, and ability to survive in the shallow substrate (Dunnett & Kingsbury 2004). *Sedum* can be planted in open soil on a green roof by broadcasting seed, spreading shoots, planting plugs, transplanting potted plants, or installing prefabricated vegetation mats (Dunnett & Kingsbury 2004). Plant production of vegetated mats starts in the field with a geotextile mat laid in long strips, a 2 cm layer of green roof substrate (growing medium) is applied over the mats, *Sedum* seeds are broadcast onto the substrate, and the mats are fertilized and watered until the plant cover reaches approximately 80%. Once this is achieved, they are cut, rolled up, and brought to a waiting roof for installation. While this type of plant propagation offers instant cover, it is more expensive to install (Dunnett & Kingsbury 2004) and the vegetated mats are typically composed of one plant genus, *Sedum*.

Planting a genus monoculture is an intensive, industrial agricultural method of producing green roof plants that can provide uniform quality and ease of installation. A plant community composed of one genus, or growth form lacks diversity and can make a green roof vulnerable to insect outbreaks, disease, and weed invasions (Reddy 2013). Polycultures are considered ecologically superior in agricultural systems (Igbozurike 1978). A variety of plant species can use soil nutrients more efficiently while one species can deplete favorable nutrients while leaving others (Igbozurike 1978). Nagase & Dunnett (2012) found that *Sedum* retained less stormwater than grasses and forbs, showing that there may be other plant choices for a green roof depending on the purpose of the green roof. To some, a low growing expanse of *Sedum* is appealing while for others the monoculture may not be. It is important to recognize the true purpose of the green roof when considering what plant species to install (Rowe et al. 2012). Is the roof installed to increase biodiversity, improve aesthetics, provide habitat, provide pollen, stormwater retention, mitigation of the urban heat island, or roof cooling to lower building energy costs? By narrowing down the expectations of the green roof's services, the choice of optimal green roof plant species may be clearer.

Habitat template

Lundholm (2006) has been exploring the habitat template approach by suggesting we use plant species that grow in an environment similar to a green roof. MacIvor & Lundholm (2011) tested various native plant species that grow on the coastal barrens of Nova Scotia where the environment is extreme and similar to that on a green roof. With high winds, shallow soil, and at times, low soil moisture conditions, the barrens and green roofs beget comparable growing conditions and appear to fit in to Lundholm's habitat template approach. Lundholm et al. (2010) also found that using a combination of plant forms and species, mixtures offered improved ecosystem services compared to monocultures.

It is sound ecology that we use a variety of plant species on a green roof rather than relying on a monoculture of one species or genus. Yet, there can be problems with sustainability of native plant populations on green roofs. Monterusso et al. (2005) found that out of eighteen native plants tested; only three were suitable for growing on green roofs in the Michigan area of the United States.

Green roof substrate

Green roof soil is very different from garden soil (Snodgrass & McIntyre 2010); it is often called growing medium or substrate and is expected to perform multiple functions. The substrate supports root growth and provides nutrients to the green roof plants (Dunnett & Kingsbury 2004). The substrate's volume must stay relatively consistent with stable aggregate type materials, while the granulometric distribution is required to have appropriate amounts of silt and clay, with particle size in a certain range that is frost resistant (FLL 2002). The ability to absorb and retain water during a rain event is important and yet the substrate must be free draining in order to prevent flooding and excessive weight on the roof (FLL 2002). Ideal green roof substrate must also be lightweight so the existing structure may support the green roof load (Nagase & Dunnett 2011) without having to reinforce the building structure (Emilsson 2008). There are currently no written standards for green roof substrate in Nova Scotia or anywhere in Canada. Testing local amendments and substrates is important to expand our knowledge of how substrates act in local conditions in real green roof settings.

Vegetated mats

A number of studies have been conducted where researchers are evaluating fertilizers (Clark & Zheng 2014), plant establishment (Emilsson & Rolf 2005; MacIvor et al. 2013), and plant establishment and survival (Monterusso et al. 2005) on vegetated mats. Emilsson (2008) researched substrates with different compositions in combination with various planting techniques. The plant installation included plug planting, shoot established, and pre-grown vegetated mats. The vegetated mats that exhibited the most successful plant growth had a plant combination of 40% *Sedum acre*, 40% *Sedum album*, and 20% other succulents. Interestingly, this combination showed lower plant cover over time compared to plug planting and shoot established plots. Emilsson (2008) concluded that the benefits of using the vegetated mat system (immediate plant cover) was reduced over time for the majority of species tested. The experiment described here is unique in that it evaluated both *Sedum*, the typical genus planted on vegetated mats and native plant species that have not been evaluated in a vegetated mat system in Nova Scotia.

Organic matter

Recommended organic matter content of green roof soil using the German guidelines is 4-8% (FLL, 2002) as higher organic matter can result in compaction of the substrate as the substrate breaks down (Nagase & Dunnett 2011). In one study, Nagase & Dunnett (2011) concluded that 10% organic matter was ideal for stable plant growth. The ingredients of the organic matter can vary. Sailor & Hagos (2011) used aged waste yard compost, while Molineux et al. (2009) suggested engineering the substrate to the plants and type of roof being installed. Often the commercial substrate is designed with the organic matter and nutrients to grow the common green genus, *Sedum* (Emilsson 2008).

Agricultural soils are often amended with organic matter by incorporating manures and composts into the soil (Bonilla et al. 2012). Amendments have also been applied to the top of the soil (top-dressing) as mulch (Fehmi & Kong 2012). Adding organic amendments by top-dressing is a practical way to increase the organic matter of a green roof that has a vegetated mat system installed on it. Using local materials as amendments is a sustainable practice and a good waste management strategy (Peres-Piqueres et al. 2006) that could improve the growing conditions for plant species on green roofs.

Mushroom compost

Mushroom compost is used in in both agriculture and horticulture (Kwack et al. 2012). The compost is high in organic matter (Phan & Sabaratnam 2012) and can be applied to improve the physical and chemical properties in soil (Nidadavolu et al. 2010). Application of compost amendments can also improve microbial communities in soil (Lucas et al. 2014). Perez-Piqueres et al. (2006) incorporated mushroom compost into both sandy and clay soil. Microbial densities and microbial activities were increased and fungal density was increased both soils. Mushroom compost may be one type of organic matter that could improve substrate functioning and development on a green roof.

Ascophyllum nodosum (kelp)

Another type of organic matter that can be used to amend green roof substrate is *Ascophyllum nodosum* (kelp) that is harvested off the shores of Nova Scotia and New Brunswick commercially by Acadian Seaplants Limited (Ugarte & Sharp 2012). There are alginates in *A. nodosum* that can enhance the health of soil by improving soil compaction and aeration (Kumari et al. 2012), increasing water-holding capacity promoting growth of beneficial soil microbes (Khan et al. 2009), and reducing nitrate leaching (Leach et al. 1999). Currently there is no study in the green roof literature that has tested *A. nodosum* as an amendment for green roof substrate.

Fertilizer

Fertilizer consumption is increasing with world consumption of nitrogen predicted to increase from 109.4 million metric tonnes in 2013 to 115.9 million metric tonnes in 2016 (Heffer & Prud'homme 2013). Manufactured, synthetic fertilizers are commonly applied during plant production in order to supply optimal nutrients for plants to grow and reproduce (Follett et al. 1981). When plants are installed on a green roof, slow-release synthetic fertilizers are often incorporated into the substrate as in Rowe et al. (2012). Nutrients can be lost by leaching from a green roof (Emilsson 2008; Alsup et al. 2011) and can be a source of pollutants (Clark & Zheng 2014); therefore caution is required when applying synthetic fertilizers. Synthetic fertilizers are made up of soluble salts and could exacerbate drought conditions on green roofs. By providing nutrients that produce increased biomass in plants, well fertilized plants may be vulnerable and become stressed if water availability is reduced (Chapter 2).

Erosion

Scouring winds on green roofs cause erosion of green roof substrate (Snodgrass & McIntyre 2010) while rain events can wash away substrate and nutrients (Clark & Zheng 2014). The canopy of a plant community is effective at offering protection to the substrate from water splash during a rain event (Lal 1994) and commercial *Sedum* mixes are chosen for their ability to provide rapid cover which reduces the loss of substrate (Emilsson & Rolf 2005). Other plant species may take longer to provide adequate canopy cover. The FLL (2002) guidelines recommend that green roof cover should be 60% by the end of the first growing season. Applying organic mulch on top of the substrate can stabilize soil and help to reduce wind erosion by binding soil particles together (Harpstead et al. 2001), thus providing protection for exposed green roof substrate. Mulches are also known to increase macropores in soil that lead to improved water infiltration (Magdoff & Weil 2004). Applying mulch on a green roof could improve stormwater retention and provide a buffer against drought. Qualitative estimates of soil erosion can be assessed by using visual measurements (Lal 1994). Figure 1 shows

Rhodiola rosea growing in the field in Greenwich, N.S with geotextile visible due to erosion of green roof substrate.

Figure 1: *Rhodiola rosea* growing on vegetated mat in Greenwich, Nova Scotia. Geotextile is visible where green roof substrate eroded away from the mat.

This research examined whether local organic amendments could improve plant establishment on an extensive green roof and protect the highly erodible green roof substrate. This study involved a new green roof installation using vegetated plant mats comprised of commercial *Sedum* species and native plants species that colonize the coastal barrens of Nova Scotia.

Materials and Methods

Green roof building components

Installation of a 75 square metre extensive green roof began on June 25, 2013 on the roof of the Nova Scotia Community College (NSCC) Centre for the Built Environment in Dartmouth, Nova Scotia, Canada (44°39'15.3"N 63°33'06.2"W). The green roof was installed on the carpentry compound roof that has an unheated area beneath it. The roof is approximately 8.2 metres high. The green roof was surrounded by Vitaroofs (VR) 7000; 140 mm aluminum edging that was installed on top of VR 7090 root barrier. Vitaroofs 7060 drainage/filter layer was laid over the root barrier. This was covered with VR7080 filter fabric. The green roof building components supported 15 cubic yards of VR7400 growing medium (substrate) that was blended in New Brunswick (ingredients proprietary). Substrate depth was 10 cm. See Table 1 for organic matter, pH, macro and micro nutrients of the substrate. Five 22.68 kg bags of Microblend ™ (Rexius Forest By-Products, Inc., Eugene, OR, USA) were blended into the substrate. Microblend ™ is a sediment reduction device. The substrate depth was rolled with a weighted lawn roller to help remove air pockets before the installation of vegetated plant mats.

Drip Irrigation was installed on top of the substrate, under the plant mats. The irrigation system included a ESP-Me Series 4-22 Station Modular Controller , a RSD-BEX Rain Sensor, a XCZ100 PRF 1" Control Zone Kit that contained a filter, valve, and pressure regulator, pressure compensating 17mm XFD06121000 Blank Drip tubing (.6 Gallons per hour 12" tubing), and a 3/4' X17000 Air Relief Valve Kit (Rainbird, Tucson, Arizona, USA).

All plants were watered in at planting time with the built in irrigation, and with an overhead spray. The irrigation schedule was started on June 28, 2103. Plants were watered for one half hour per zone (2 zones), once a day on Monday, Wednesday, Friday, and Sunday. On August 12, 2013, irrigation was changed to fifteen minutes per zone, once a day on Monday, Wednesday, Friday, and Sunday. Irrigation was shut down on September 9, 2013 and no further water was applied through the irrigation system. The roof received water only through natural rainfall for the rest of the growing season (2013). The following growing season, there was no irrigation applied and the roof received only natural rainfall. See Table 5 for rainfall amounts in Dartmouth area.

Table 1: Mean pH, Organic matter (OM), macro and micro nutrients, metals, nitrates, and % nitrogen of Vitaroofs green roof soil used in NSCC experiment. Analysis completed at Nova Scotia Department of Agriculture, Quality Evaluation Division, Laboratory Services, Truro, N.S., Canada. (*n=3*)

pH, OM, Nutrients	**Analysis**	**Standard Error**
pH	8.376	0.07
Organic Matter (%)	27.700	1.15
P2O5 (kg/ha)	700.333	82.17
K20 (kg/ha)	2957.000	275.22
Ca (kg/ha	7774.667	716.12
Mg (kg/ha)	1026.333	105.17
Na (kg/ha)	2437.333	216.58
Sulphur (kg/ha)	37.666	3.33
Al (ppm)	135.000	6.03
Fe (ppm)	178.333	15.38
Mn (ppm)	36.666	4.37
Cu (ppm)	2.583	0.35
Zn (ppm)	19.023	2.79
B (ppm)	4.220	0.42
Nitrate –N (ppm)	13.633	1.57

A standard sieve test was performed on one sample of the green roof substrate (Stantec Materials Testing Lab, Dartmouth, N.S.). Substrate physical properties include: 29.9% gravel, 69.5% sand, and 0.6% silt & clay. The granulometric distribution range of the particle sizes can be seen in Figure 2.

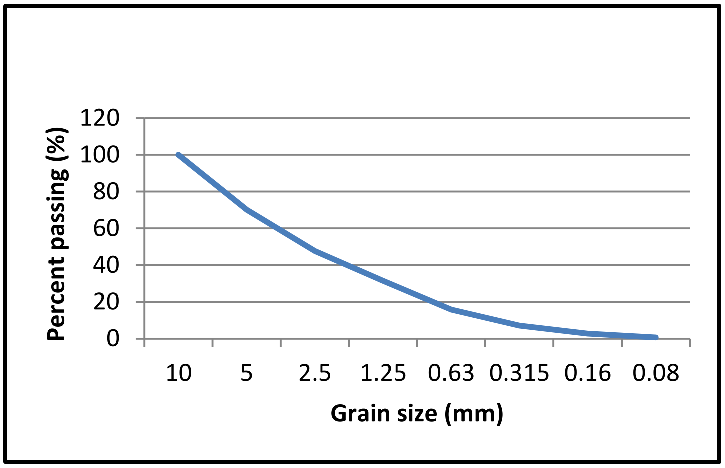


Figure 2: Granulometric distribution range of green roof substrate used on the NSCC green roof.

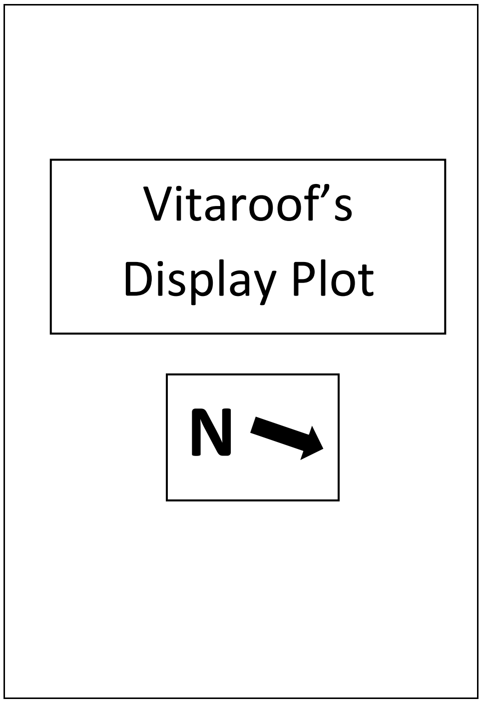
A patio stone ballast (12” x 24” x 1.8” Utility Stones, natural colour, weight 20.1 kilograms per unit, Shaw Brick, Lantz, Nova Scotia) was installed around the outside edge of the aluminum edging of the green roof installation. Black rubber blocks (3 cm x 3 cm x 1 cm high) cut from anti-fatigue matting were installed under each patio stone (four for each stone) to allow for drainage underneath the stones. All building components including substrate were installed on June 25th, 2013. A path of 18”x18”, slate coloured, recycled rubber flagstone pavers (Rubber Designs, Ranger, GA, USA.) was installed that intersected the middle of the green roof installation. The path was designed to create an axis with posts that existed on the roof and to allow for easy access to the green roof plots.

Green roof plants

On June 26th, 2013, twenty four Vitaroofs 301, 20 mm thick, pre-cultivated *Sedum* mats (each mat was 1m x 1 m), and twenty four pre-cultivated native plant mats, 20 mm thick were installed on top of the substrate, alternating one *Sedum* mat and one native mat in three of four available quadrants. See Figure 3 for layout. All edges were pinned to reduce wind lift and top dressed with the same substrate that was used underneath the mats. Vegetated mats were grown for two seasons in field conditions on the ground at Tasbo Farms, Greenwich, Nova Scotia. Originally, nine plant species were seeded onto the native mats and they are listed in Table 2. The *Sedum* species that were seeded in the field can be seen in Table 3. In the fourth quadrant, fifteen square metres of commercial *Sedum* species vegetated mats were installed by Vitaroofs, the project's industry partner, to provide a visual sample of their product on a green roof. This area was not part of the study.

Table 2: Original seeded and transplanted native plant species for Vitaroofs experiment using vegetated plant mats.

Family	**Botanical name**	**Common name**	**Originally seeded in field**	**Transplanted on roof**
Acanthaceae	*Solidago bicolor*	White goldenrod	xx	
Campanulaceae	*Campanula rotundifolia*	Harebell, Bluebell bellflower		xx
Caryophyllaceae	*Sagina procumbens*	Birdeye pearlwort	xx	
Crassulaceae	*Rhodiola rosea*	Roseroot	xx	xx
Juncaceae	*Luzula multiflora*	Heath wood-rush	xx	
Plantaginaceae	*Plantago maritima*	Sea plantain, goose tongue	xx	
Poaceae	*Danthonia spicata*	Poverty oatgrass	xx	xx
Poaceae	*Deschampsia flexuosa*	Wavy hair - grass	xx	
Poaceae	*Festuca rubra*	Red fescue	xx	
Rosaceae	*Sibbaldiopsis tridentata*	Shrubby fivefingers	xx	xx



1 Se/F	2 Na/M	3 Se/F	4 Na/M
5 Na/F	6 Se/M	7 Na/-k	8 Se/M
9 Se/C	10 Na/F	11 Se/M	12 Na/F
13 Na/M	14 Se/M	15 Na/C	16 Se/-k
17 Se/-k	18 Na/-k	19 Se/F	20 Na/+K

21 Se/+K	22 Na/C	23 Se/-k
24 Na/+K	25 Se/C	26 Na/M
27 Se/-k	28 Na/M	29 Se/F
30 Na/+K	31 Se/C	32 Na/C

33 Na/-k	34 Se/+K	35 Na/C	36 Se/C
37 Se/F	38 Na/-k	39 Se/+K	40 Na/F
41 Na/-k	42 Se/+K	43 Na/F	44 Se/-k
45 Se/+K	46 Na/+K	47 Se/M	48 Na/+K

Figure 3: Green roof design at NSCC, showing plot numbers, plant species Sedum (Se) and Native (Na), and treatments. Treatments were kelp, K+, 150 grams of kelp meal per m^2 plot, k-,75 grams per m^2 plot, mushroom compost, M, of 7 litres per m^2 plot, slow release fertilizer (10N: 10P:10K), F, 30 grams per m^2 plot and the control, C in which nothing was added.

Table 3: *Sedum* species in Vitaroofs seed mix that were originally seeded onto vegetated plant mats in the field before roof installation. Volumes are propriety and unknown.

Sedum species (Crassulaceae)	**Common name**
Sedum acre	Goldmoss Stonecrop, Biting Stonecrop
Sedum aureum	Golden Sunrise Stonecrop
Sedum album	White Stonecrop
Sedum floriferum	Weihenstephaner Gold Stonecrop
Sedum kamtschaticum var. ellacombianum	Japanese Stonecrop
Sedum middendorffianum	Stonecrop
Sedum pulchellum	Widow's Cross
Sedum reflexum	Blue Stonecrop, Reflexed Stonecrop
Sedum sexangulare	Tasteless Stonecrop
Sedum spurium	Caucasian Stonecrop, Two Row Stonecrop

Plant cover on the native mats in the field was very low. The majority of cover was from *Rhodiola rosea*. A few mats had some *Luzula multiflora*, *Festuca rubra*, or *Plantago maritima*. These plants were left on the mats to be moved to the roof and considered to be part of the overall plant cover. See Figure 4 for a photograph of plant cover with *Rhodiola rosea* coverage. To improve the plant cover of the native vegetated mats, the native species *Rhodiola rosea*, *Campanula rotundifolia*, *Danthonia spicata*, and *Sibbaldiopsis tridentata* were transplanted into the mats after the mats were installed on the roof. Holes were cut into the geotextile to provide a planting spot for the native plants. A native plant mat after transplanting can be seen in Figure 5. Although it already existed on the vegetated mats, additional *Rhodiola rosea* were planted in order to create a comparable cover for all twenty four native mats. Ten *Danthonia spicata* and ten *Sibbaldiopsis tridentata* and five *Campanula rotundifolia* were transplanted into each native plant mat. *Danthonia spicata* and *Sibbaldiopsis tridentata* came from a previous experiment and were all collected in the same season. They were then transplanted and lived in green roof modules on the same roof with no fertilizer or extra irrigation. *Campanula rotundifolia* came from the Saint Mary's University lower green roof and had been growing in four inch pots. All transplanting was completed from June 27, 2013 to July 4, 2013. After planting, photographs of each plot were taken on July 5, 2013 to show the plant cover. Changes in the plant communities were recorded with subsequent photographs taken of each plot on October 16, 2013, June 3, 2014, and July 17, 2014.

Figure 4: Typical plant cover on native plant mat before installation on the NSCC green roof. Main species before installation was *Rhodiola rosea.*

Figure 5: Typical plant cover on native plant mat after installation and transplanting on the NSCC green roof. Plots contain *Rhodiola rosea*, *Danthonia spicata*, *Sibbaldiopsis tridentata, and Campanula rotundifolia.*

While some of the *Sedum* mats had low coverage in the field, only the best possible mats were chosen for installation on the green roof. Cover on the *Sedum* mats was at least 80% for the majority of the twenty four mats. No transplanting of other plants was done on the *Sedum* mats.

Amendments

Amendments were applied on July 5, 2013. Treatments were randomly allocated among the *Sedum* mats and native mats (separately for each planting group: five replicate mats per treatment ($n=5$), except controls which had four ($n=4$) per planting group). The treatments consisted of two volumes of *Ascophyllum nodosum* (kelp meal) (Acadian Seaplants, Dartmouth, Nova Scotia), a mushroom compost treatment (Valley Mushroom Company, Waterville, Nova Scotia), a fertilizer treatment and a no-amendment control.

The kelp meal was a solid organic amendment composed of 100% ground kelp. The larger kelp treatment (K+) was 150 g of kelp meal per m^2 plot. The lesser kelp treatment (k-) was 75 g per m^2 plot. The mushroom compost treatment involved spreading 7 litres per m^2 plot. See Table 4 for a description of the compost, including pH, N, and loss on ignition. The fertilizer treatment involved 10N:10P:10K Scott's Miracle-Gro® Shake 'n Feed Slow Release Plant Food (F) applied at a volume of 30 g per m^2 plot (manufacture recommended). There was a control treatment in which nothing was added to four *Sedum* plots and four native plots.

The organic amendments (kelp meal and mushroom compost) were applied a second time later in the growing season. On October 4, 2013 the two kelp treatments were repeated on all mats that had previously been treated. Mushroom compost treatments were also repeated, but the volume of the treatment was changed to 5 litres per m^2 because the first treatment of 7 litres per m^2 was thought to be too thick. The mushroom compost treatments were repeated on all mats that had previously been treated. No slow release fertilizer was added at this time and the control plots also stayed the same.

Table 4: Mean dry matter, pH, Nitrogen, Ammonium, and Loss on Ignition (LOI) for mushroom compost (*n=3*) applied as an amendment to specific plots on NSCC green roof. Analysis completed at Nova Scotia Department of Agriculture, Quality Evaluation Division, Laboratory Services, Truro, N.S., Canada.

Parameter	**As Received (AR)**	**Standard Error (AR)**	**Dry Basis (DB)**	**Standard Error (DB)**
Dry Matter (%)	55.466	0.356	NA	NA
pH (pH Units)	6.9	0.3	NA	NA
Nitrogen (%)	0.806	0.0290	1.46	0.047
Ammonium – N (%)	0.073	0.003	0.13	0.005
LOI (%)	16.386	0.462	29.53	0.650

Percent Canopy Cover

Initial canopy cover (% of ground covered by plants) was estimated on July 27, 2013 by one observer. A quadrat was centred over the metre square plot and was divided into four quadrants to help estimate the plant cover for both the *Sedum* and native plots. Percent cover was again estimated on October 4, 2013 by the same observer.

Plant Growth

Canopy density was measured with a plastic pin frame using the point interception method (MacIvor & Lundholm 2011) on six different dates over a one year period starting July 23, 2013 and ending on July 3, 2014. The frame was one square metre quadrat and contained a fixed sixteen point grid that was equally spaced throughout the frame. All leaf hits were recorded for each of the sixteen points using the point interception method (Floyd & Anderson 1987). A 3 mm diameter rod was used at each point intercept and was inserted to the soil level. All layers of vegetation were recorded by moving the top layers to see the lower layers that were touching the rod (Emilsson 2008). *Sedum* was grouped as a single genus while native plants data were recorded by species. All measurements for native plants were taken by one observer and all measurements for *Sedum* were taken by one observer. A one-way ANOVA and a Tukey's Post Hoc test were used to analyze the data.

Relative Canopy Change

Relative canopy change is a measure of the growth rate of a whole plant that is growing freely. The relative canopy change of the *Sedum* species and *Rhodiola rosea* was measured using the pin frame data from the 2013 year and the 2014 year. The following formula was applied from Harper (1977):

$$(Ln\ (T2) – Ln\ (T1) / \#of\ days$$

Ln represents the natural log, T1 represents the first day of counting leaf hits and T2 represents the last day of counting leaf hits. Data were analyzed in Minitab using one-way ANOVA's. Significant differences were assessed using a Tukey's Post Hoc test.

Substrate temperature

In order to observe the green roof substrate temperatures over time, a datalogger was installed on August 2, 2013. Heat flux plates, moisture probes, and temperature probes were installed at the bottom of the substrate in the control plots; Sedum 9 (S9), S25, S31, S36, Native 15 (N15), N22, N32, and N35. Temperature probes were also installed just under the substrate surface in the same plots. Data was recorded at 15 minute intervals.

Weeding

The green roof was weeded regularly throughout both growing seasons. Native plant species were left in the native plots while any *Sedum* species in the native plots were removed. Other species not part of the experiment were removed from both *Sedum* and native plots. Both natives and *Sedum* were left to grow in the path which wasn't part of the experimental measurements.

Erosion

On April 18, 2014, after the green roof had overwintered, substrate erosion was measured on the native plant mats with the same pin frame that was used for leaf hits, using the point interception method (MacIvor & Lundholm 2011). The frame was one square metre and contained a fixed sixteen point grid that was equally spaced throughout the frame. A rod (3 mm in diameter) was used at each point intercept and was inserted to the soil level. Plant hits (P), soil hits (S), and geotextile hits (G) were recorded at each point. Erosion wasn't measured for the *Sedum* mats because they were covered in plants and surface erosion was not visible. Percent erosion was visually estimated on the same day for the native plant mats by dividing the one metre plots into quadrants using meter sticks and observing the amount of geotextile that was visible. The amount of geotextile visible in each quadrant was recorded as a percentage of erosion by the same observer. Data were analyzed in Minitab using one way ANOVA's. Significant differences were assessed using Tukey's Post Hoc Test.

Volumetric water content

In order to provide an illustration of the substrate moisture on the green roof, the percent volumetric water content (%VWC) was measured using a soil moisture ProCheck GS3 soil moisture sensor (Decagon Devices Inc., Pullman, WA, USA) to compare differences in soil moisture content between the five treatments and the native plant mats and *Sedum* mats. On May 7, 2014 and June 3, 2014 three randomly located readings per plot were taken for the *Sedum* mats. Four readings were taken for the native mats, with one reading taken under each of the four main plant species, *Rhodiola rosea, Sibbaldiopsis tridentata*, *Danthonia spicata,* and *Campanula rotundifolia*. Data were analyzed in Minitab using ANOVA's. Significant differences were assessed using Tukey's Post Hoc Test.

Results

Weather patterns

Table 5 shows the mean monthly temperature, maximum and minimum monthly temperatures, the total precipitation, and maximum wind gusts (duration typically 3-5 seconds) for each month of the NSCC green roof study period.

Table 5: Climate summary for study period (July, 2013-July, 2014) in Dartmouth, Nova Scotia, Canada. Obtained from the Shearwater RCS, Nova Scotia weather station, Latitude 44°37'47.000"N, Longitude 63°30'48.000"W. Source: Environment Canada, 2013. http://www.climate.weatheroffice.gc.ca.

Year 2013-2014	Mean Temp (°C)	Highest Monthly Max Temp (°C)	Lowest Monthly Min Temp (°C)	Total Precipitation (mm)	Maximum Wind Gust (km/h)
July	20.3	32.9	12.1	77.8	52
August	18.3	27.5	8.8	76.4	57
September	15.6	26.7	5.6	118.4	52
October	10.5	22.1	-2.7	155.3	56
November	4.1	16.7	-7.9	148.1	82
December	-2.2	10.7	-16.0	215.7	76
January	-2.8	11.0	-19.5	168.4	91
February	-3.3	9.9	-16.3	123.4	76
March	-2.4	9.9	-16.9	166.3	85
April	4.8	16.0	-3.4	140.6	70
May	8.8	21.6	0.2	46.3	54
June	14.8	19.5	10.1	134.4	54
July	18.5	22.8	14.2	35.8	76

Substrate temperatures

Figure 6 shows the readings from the data logger that recorded the substrate surface temperatures and the below ground (10cm) substrate temperatures. The data logger was accidently unplugged near the end of February, 2014 and reconnected in March, 2014. Data is shown from August, 2013 to February, 2014 to provide a picture of the substrate temperatures in summer, fall, and winter months.

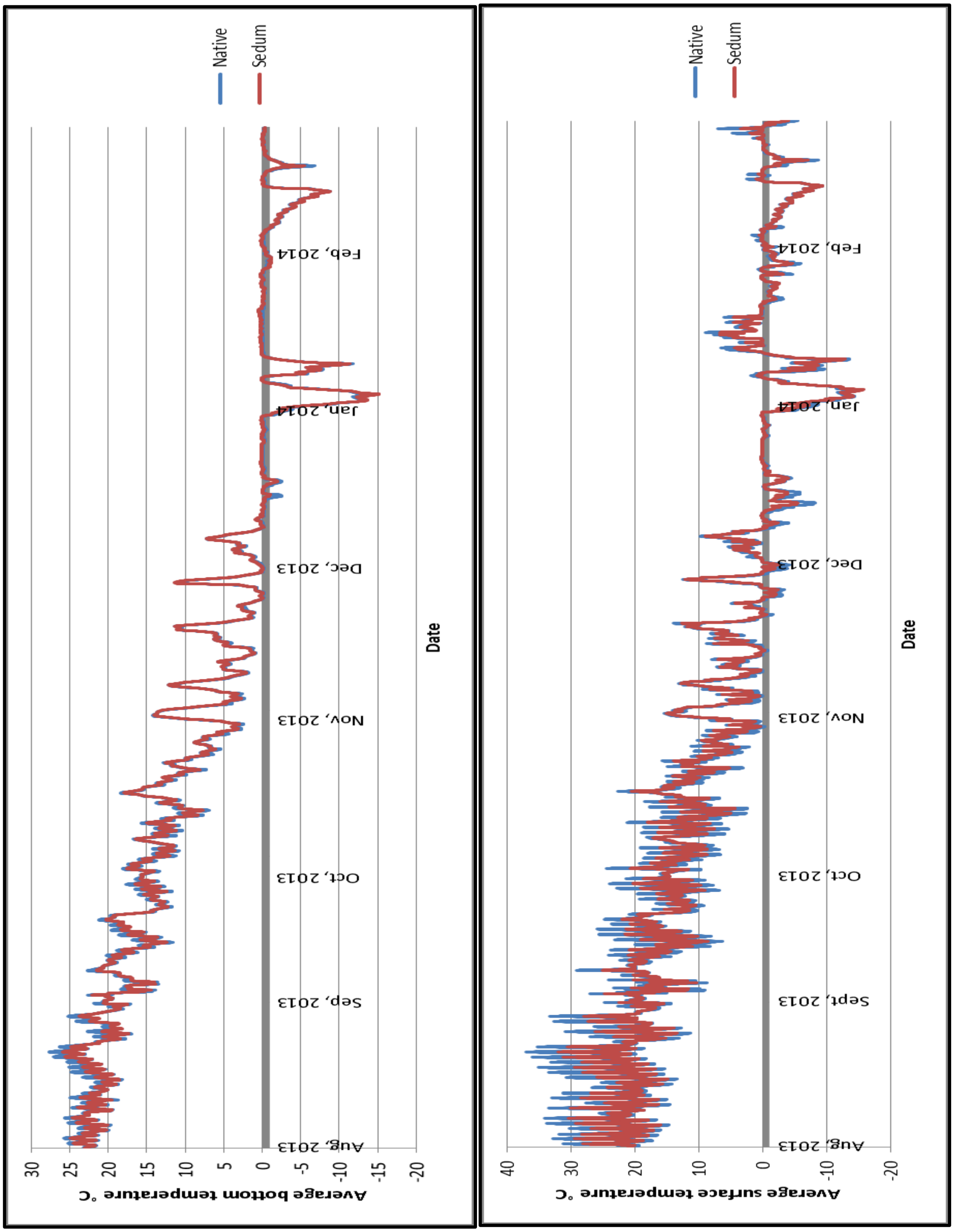


Figure 6: Datalogger bottom and surface substrate temperatures on NSCC green roof. Native plots (*n=4*) and *Sedum* plots (*n=4*).

Visual canopy cover in 2013

There were no significant differences between planting treatments and visual canopy cover in the 2013 season. Canopy cover on the native plots was much lower than the *Sedum* plots at the beginning of the green roof installation. All native plots had a canopy cover of approximately 50% as seen in Figure 7 and ended the season with over 65% cover which is in the acceptable range according to FLL (2002) standards. The native plants showed a higher rate of cover change compared to the *Sedum* when visual percent cover was estimated on October 4, 2013. After one growing season, there was still open soil in the native plots. The *Sedum* plots all showed a canopy cover of approximately 90% after one growing season. Lack of significant differences could be due to the low sample size.

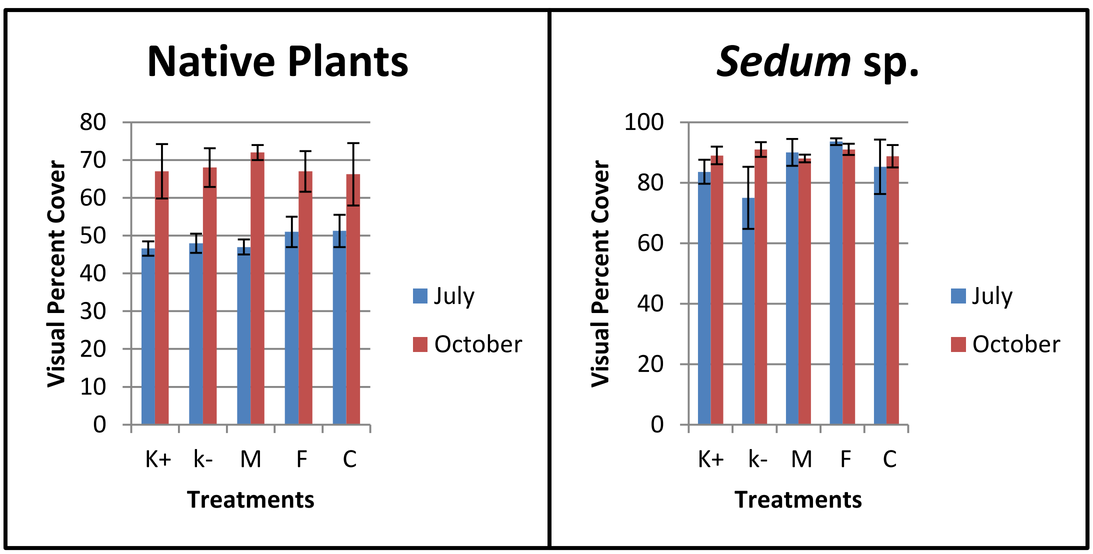


Figure 7: Percent change in visual canopy cover (2013 season) of native and *Sedum* plants growing in one metre square plots) on a vegetated mat green roof system at NSCC. Treatments were 150 grams of kelp meal (K+) per m^2, 75 grams of kelp meal (k-) per m^2, 5 litres of mushroom compost per m^2, 30 grams of 10N:10P:10K slow release fertilizer (F) per m^2, and nothing added to the control (C). K+, k-, M, & F ($n=5$), C, ($n=4$). Error bars represent standard error.

Visual cover 2013-2014

Photographs were taken of each plot on four dates through the study period (July & October 2013, June & July, 2014) to observe the changes in plant cover over time. Photographs of each plot's final plant cover can be found in the Appendix. Figure 8 shows the changes in a typical *Sedum* plot over the course of the experiment and Figure 9 shows the changes in a typical native plot over the same time period. There was a change in species relative abundances in the *Sedum* plots that showed in the photographs over the two growing seasons. At the time of installation in 2013, *S. album* and *S. acre* were the most visible species. In 2014, the plant community in the *Sedum* plots had changed to mainly *S. kamtschaticum* and *S. spurium* with *S. album* and *S. acre* almost non-existent in many plots.

Figure 8: *Sedum* plot # 16 on the NSCC green roof showing typical plant cover and community change over time. Photographs were taken on July 5th, 2013(a), October 16th, 2013 (b), June 3, 2014 (c), July 17, 2014 (d).

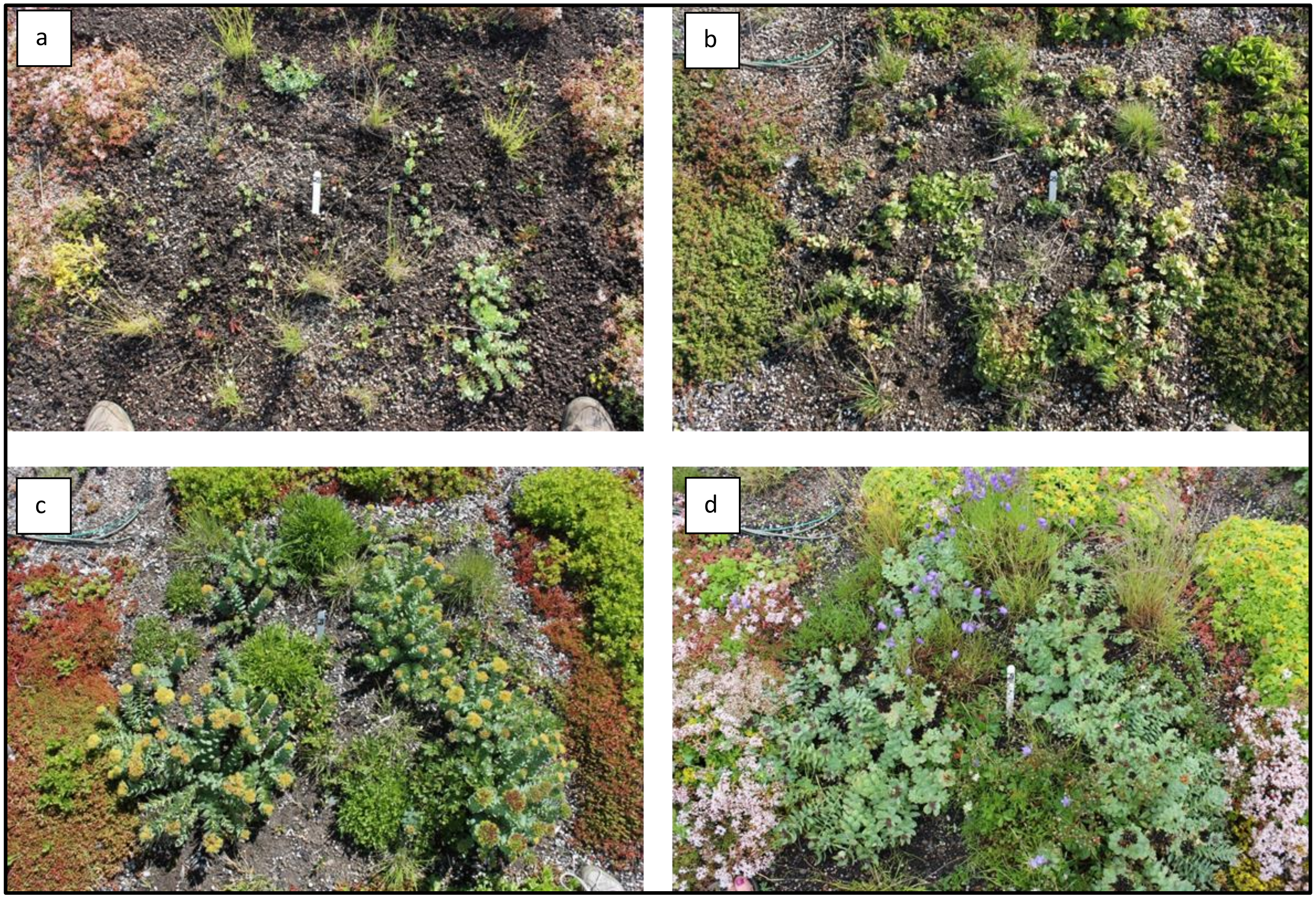


Figure 9: Native plot # 28 on the NSCC green roof showing typical plant cover and community change over time. Photographs were taken on July 5th, 2013(a), October 16th, 2013 (b), June 3, 2014 (c), July 17, 2014 (d).

Relative canopy change

Rhodiola rosea and *Sedum* species were analyzed for relative canopy change. Also called relative growth rate (Harper 1977), this was not appropriate analysis for the other native species due to low numbers which created inaccurate results. There were no significant differences in the growth rate when the different amendment treatments were compared. The M treated plots showed the highest relative cover change in both 2013 and 2014 for the native plants and was highest for the *Sedum* in 2014. The F treated *R. rosea* plots had the largest increase in 2014. No fertilizer was applied on these plots during the second year. The smallest relative cover change of the *R. rosea* the first year and the subsequent improvement when there was no fertilizer applied shows that *R. rosea* may grow best without the application of the slow release fertilizer. Results can be seen in Figure 10.

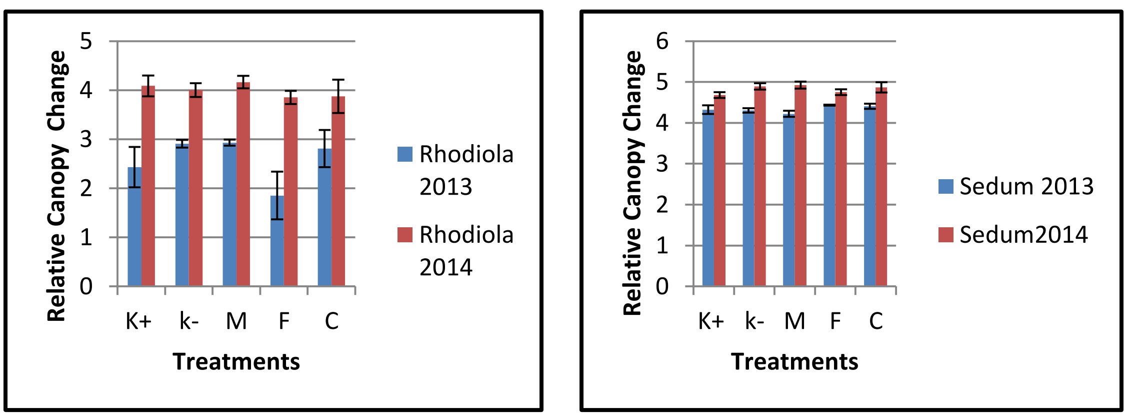


Figure 10: Relative canopy change for *Rhodiola rosea* and *Sedum* in a vegetated mat system on NSCC green roof. Growth for 2013 was calculated for the interval between July and September, in 2014 between May and July. Treatments were 150 grams of kelp meal (K+) per m², 75 grams of kelp meal (k-) per m², 5 litres of mushroom compost (M) per m², 30 grams of 10N:10P:10K slow release fertilizer (F) per m², and nothing added to the control (C). K+, k-, M, & F (*n=5*), C, (*n=4*). Error bars represent standard error.

Canopy density (individual native species)

Figure 11 shows the mean number of leaf hits for each of the four main native plant species on the NSCC green roof. There was only one significant difference between the treatments when analyzing the four native species canopy density for all six days of data collection. Although not significant, *R. rosea* the plots treated with M had the highest canopy density in four out of six dates of data collection. In year two, the kelp amendments were better for *R. rosea* growth compared to the C and F treatments. The highest number of leaf hits recorded in one plot was 110 in a K+ treated plot. All *Danthonia spicata* treated plots experienced loss in the first month on the green roof. In September 2013 the C plots had significantly higher canopy density compared to the M treated plots. The highest number of leaf hits for *D. spicata* in one plot was 23 in a C treated plot. Many *Sibbaldiopsis tridentata* plants experienced cholorosis and this was thought to be due to high pH of the substrate. There was a reduction of canopy cover during the first year and an increase in the second year. Many new plants grew from the creeping rhizomes that are a characteristic growth habit of the species. The K+ treatments had the lowest increase in canopy density five out of six times. This amendment amount is not appropriate for *S. tridentata*. *Campanula rotundifolia* thrived in this study and the canopy density steadily improved with no significant differences. At the beginning of the study, the M treated plots had zero leaf hits in every plot. At the end of the study, there was no less than 10 leaf hits per M treated plot and a high of 25 leaf hits in one plot. The highest number of leaf hits for *C. rotundifolia* was in a C treated plot (40 hits). Using spent mushroom compost as an amendment for growing *C. rotundifolia* is recommended. A larger sample size may have produced more significant differences.

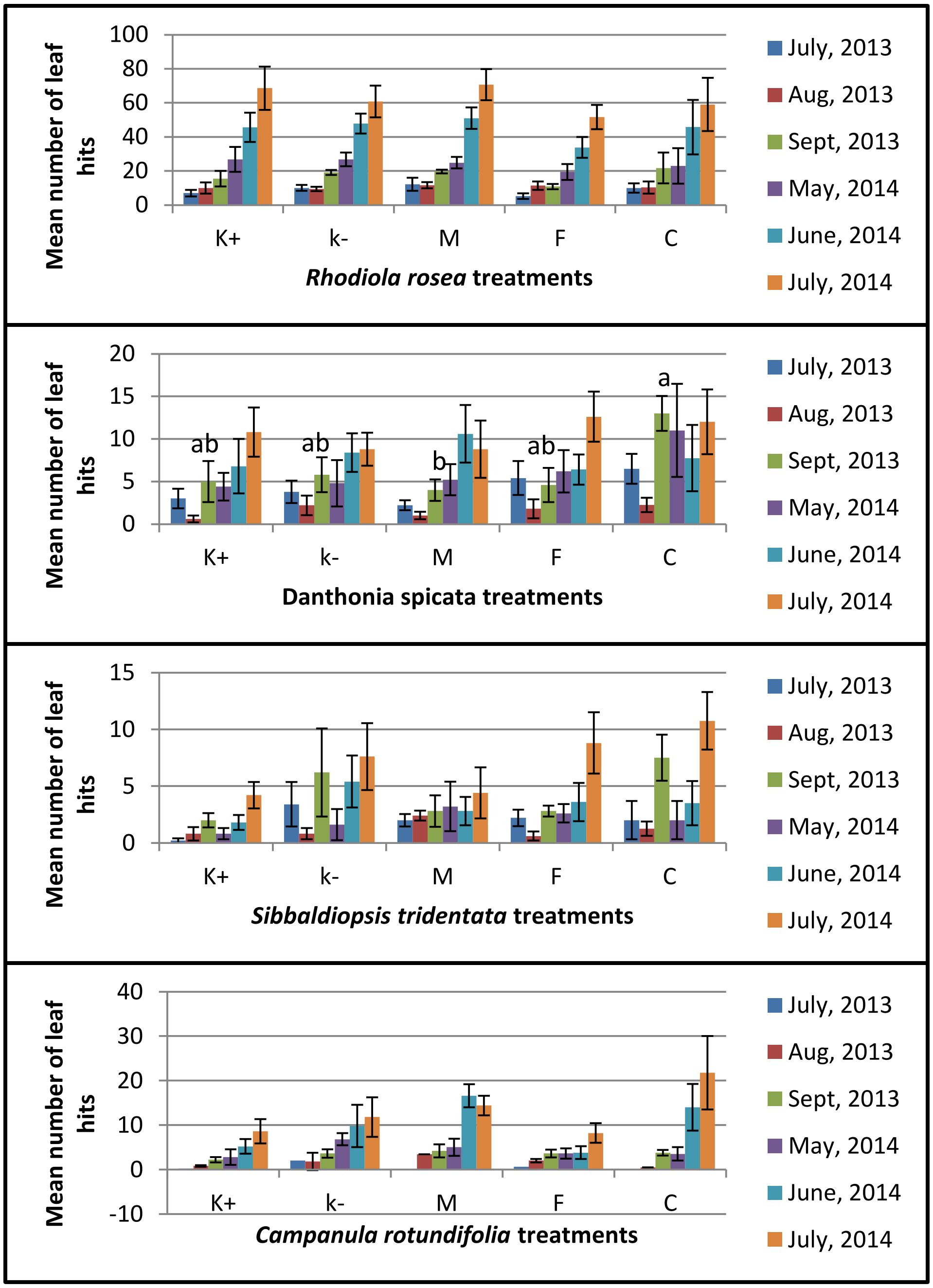


Figure 11: Growth in canopy density of *Rhodiola rosea*, *Danthonia spicata*, *Sibbaldiopsis tridentata*, and *Campanula rotundifolia* over one year period from July, 2013 to July 2014 on NSCC green roof. Treatments were 150 grams of kelp meal (K+) per m² , 75 grams of kelp meal (k-) per m², 7 litres of mushroom compost (M) per m² , 30 grams of 10N:10P:10K slow release fertilizer (F) per m², and nothing added to the control (C). Error bars represent standard error. Means that do not share a letter are significantly different. K+, k-, M, & F (*n=5*) C (*n=4*)

Canopy density (Sedum and all natives combined)

Table 6 shows the Tukey's Pairwise Comparisons of the changes in canopy density comparing various treatments with all of the leaf hits from the native plants compiled together. Twice during the study there were significant differences with the C treated plots having significantly higher canopy density compared to the F treated plots.

Table 6: Canopy density for 24 native plant plots on NSCC green roof. Main plant species include *Rhodiola rosea*, *Campanula rotundifolia*, *Danthonia spicata*, and *Sibbaldiopsis tridentata* and lesser species include, *Luzula multiflora*, *Festuca rubra*, and *Plantago maritima*. Treatments were 150 grams of kelp meal (K+) per m², 75 grams of kelp meal (k-) per m², 5 litres of mushroom compost per m², 30 grams of 10N:10P:10K slow release fertilizer (F) per m², and nothing added to the control (C). K+, k-, M, & F (*n=5*), C, (*n=4*). Significant differences are shown with an (a) or (b). 1st denotes highest number of leaf hits, 5th denotes lowest number of leaf hits.

Native species	**July 2013**	**Aug 2013**	**Sept 2013**	**May 2014**	**June 2014**	**July 2014**
1st	k-	M	C (a)	M	C (a)	K+
2nd	C	F	K+	F	M	C
3rd	M	C	k-	C	K+	M
4th	F	K+	M	K+	k-	k-
5th	K+	k-	F(b)	k-	F (b)	F

There were no significant differences between treatments in the *Sedum* plots. Table 7 shows Tukey's Pairwise Comparisons between the various treatments in the *Sedum* plots. A larger sample size may have produced more significant results.

Table 7: Canopy density for 24 *Sedum* plant plots on NSCC green roof. Treatments were 150 grams of kelp meal (K+) per m², 75 grams of kelp meal (k-) per m², 5 litres of mushroom compost per m², 30 grams of 10N:10P:10K slow release fertilizer (F) per m², and nothing added to the control (C). K+, k-, M, & F (*n*=5), C, (*n*=4). 1st denotes highest number of leaf hits, 5th denotes lowest number of leaf hits.

Sedum	July 2013	Aug 2013	Sept 2013	June 2014	July 2014
1st	F	K+	F	K+	M
2nd	C	F	C	k-	k-
3rd	M	C	K+	M	C
4th	k-	M	k-	C	F
5th	K+	k-	M	F	K+

Figure 12 shows the canopy density of the *Sedum* during the course of the study on the green roof. There were no significant differences between treatments. The plants showed a slight loss of canopy density in after installation in August, 2013 in all treatments except the K+ treated plots. Figure 13 shows the canopy density for all the native plots. All treatments grew steadily throughout the study with no significant differences.

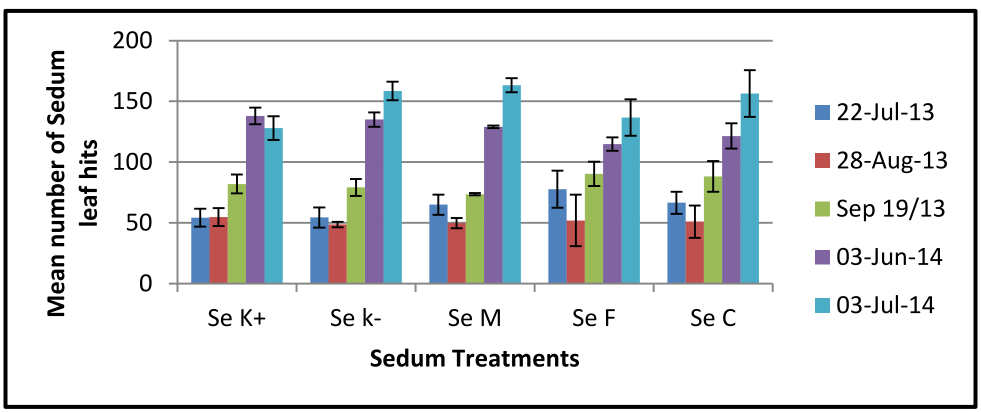


Figure 12: Canopy density of *Sedum* species on the NSCC green roof from July 2013 to July 2014. Treatments were 150 grams of kelp meal (K+) per m², 75 grams of kelp meal (k-) per m², 5 litres of mushroom compost per m², 30 grams of 10N:10P:10K slow release fertilizer (F) per m², and nothing added to the control (C). K+, k-, M, & F (*n*=5), C, (*n*=4). Error bars represent standard error.

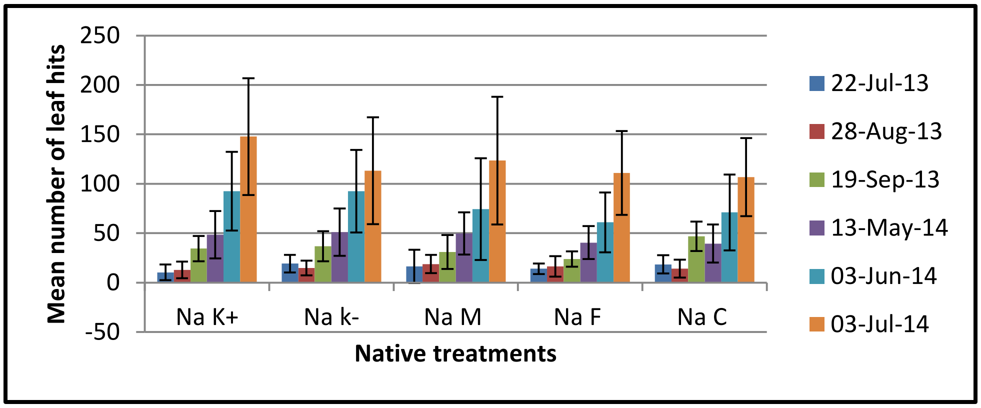


Figure 13: Canopy density for 24, 1m² native plant plots on NSCC green roof. Main plant species include *Rhodiola rosea*, *Campanula rotundifolia*, *Danthonia spicata*, and *Sibbaldiopsis tridentata* and lesser species include, *Luzula multiflora*, *Festuca rubra*, and *Plantago maritima* from July 2013 to July 2014. Treatments were 150 grams of kelp meal (K+) per m², 75 grams of kelp meal (k-) per m², 5 litres of mushroom compost per m², 30 grams of 10N:10P:10K slow release fertilizer (F) per m², and nothing added to the control (C). K+, k-, M, & F (*n=5*), C, (*n=4*). Error bars represent standard error.

Erosion

In the spring of 2014, geotextile was visible in many of the native plant plots. Since the geotextile was covered with soil during the installation of the vegetated mats in June 2013, the presence of geotextile showed that soil had eroded away. Pin frame measurement was used to evaluate soil, geotextile, and plant hits only in the native plant plots and visual analysis was used to evaluate visible geotextile only in the native plant plots.

Significant differences in the number of soil hits can be seen in Figure 14 and were found between the M and the K+ treated plots and the F treated plots. The F treated plots had less soil hits and more geotextile hits compared to the M and the K+ plots. The F treated plots had the lowest number of soil hits compared to all treatments and the highest number of geotextile hits compared to the other treatments. The M treated plots had the highest number of soil hits and the least number of geotextile hits (significantly lower than F treatments). The M treatment did help reduce erosion on the mat surface at a greater rate on the green roof compared to all other treatments. Both the K+ and the k- treated plots experienced less erosion compared to the C and the F treated plots.

The F treated plots had significantly higher plant hits compared to the K+ treated plots and more plant hits compared to all the other treatments. Even though the F treated plots had more plants, the soil still eroded at a higher rate than the plots with fewer plants. The plants didn't necessarily help to hold the soil on the top of the vegetated mat.

Organic matter was added on top of the vegetated mats when the mushroom compost and kelp meal were applied and would have affected the number of soil hits. The data does show that it is beneficial to top dress amendments onto vegetated mats to help reduce soil loss compared to applying slow release fertilizer (F) or nothing (C).

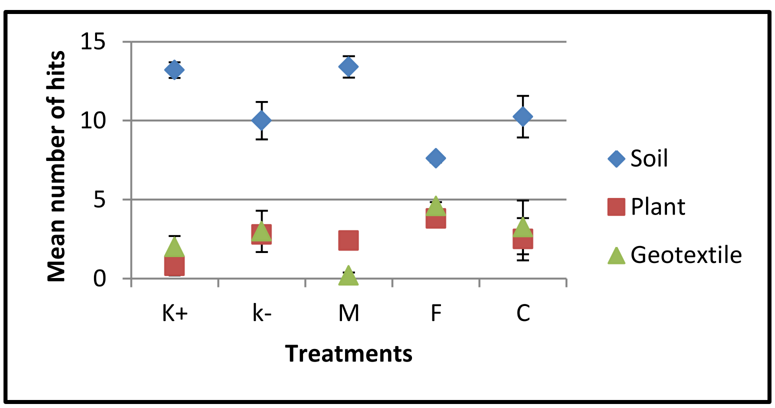


Figure 14: Substrate erosion on April 18, 2014 on the NSCC green roof native plant plots, recognizing soil, plant, or geotextile that was visible on the surface of the green roof. Treatments were 150 grams of kelp meal (K+) per m², 75 grams of kelp meal (k-) per m², 5 litres of mushroom compost per m², 30 grams of 10N:10P:10K slow release fertilizer (F) per m², and nothing added to the control (C). K+, k-, M, & F (*n=5*), C, (*n=4*). Error bars represent standard error.

Percent erosion was also visually estimated on the same day as the pin frame erosion and can be seen in Figure 15. The M treated plots were significantly different from the k-, F, and C treatments. The F treated plots had the highest amount of geotextile visible and the C plots had the second highest amount of geotextile visible.

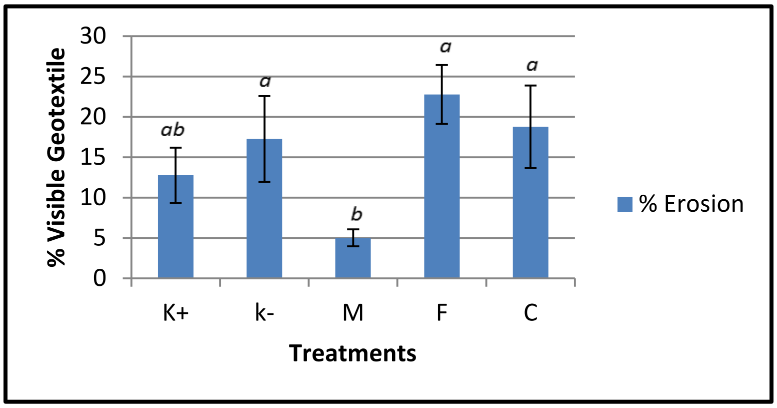


Figure 15: Percent visible geotextile on NSCC green roof native plant plots. Treatments were 150 grams of kelp meal (K+) per m², 75 grams of kelp meal (k-) per m², 5 litres of mushroom compost per m², 30 grams of 10N:10P:10K slow release fertilizer (F) per m², and nothing added to the control (C). K+, k-, M, & F (*n=5*), C, (*n=4*). Error bars represent standard error. Means that do not share a letter are significantly different.

Winter survival of native plant species

There were no significant differences between treatments in the number of native plants that survived through the winter study period. There were not large native plant numbers to begin with and a bigger sample size may have shown significant differences. The F treatments had the lowest plant numbers in both the fall and the spring for all species while the K+ treatments had the highest plant counts for all species in both seasons. Figure 16 shows native plant survival for three species. It was decided that the data were not suitable to use for *Rhodiola rosea*, due to the growth pattern, the variable plant numbers at the start of the experiment, and the process of counting the plants in the fall (the plants had died back to the ground at the time of counting), instead see Figure 17 for photos of *R. rosea* plant crowns in the spring of 2014. All *Sibbaldiopsis tridentata* plots showed an increase in the number of individual plants from fall to spring. This result is interesting due to the fact that the *S. tridentata* plants had showed yellowing among almost all plants in all plots the previous year. The species increases from underground runners and these were very evident in some of the plots. *Danthonia spicata* showed a mean loss of about one plant per plot from the fall to the following spring with little difference among treatments. *Campanula rotundifolia* had mean losses of less than one plant per plot with little difference among treatments.

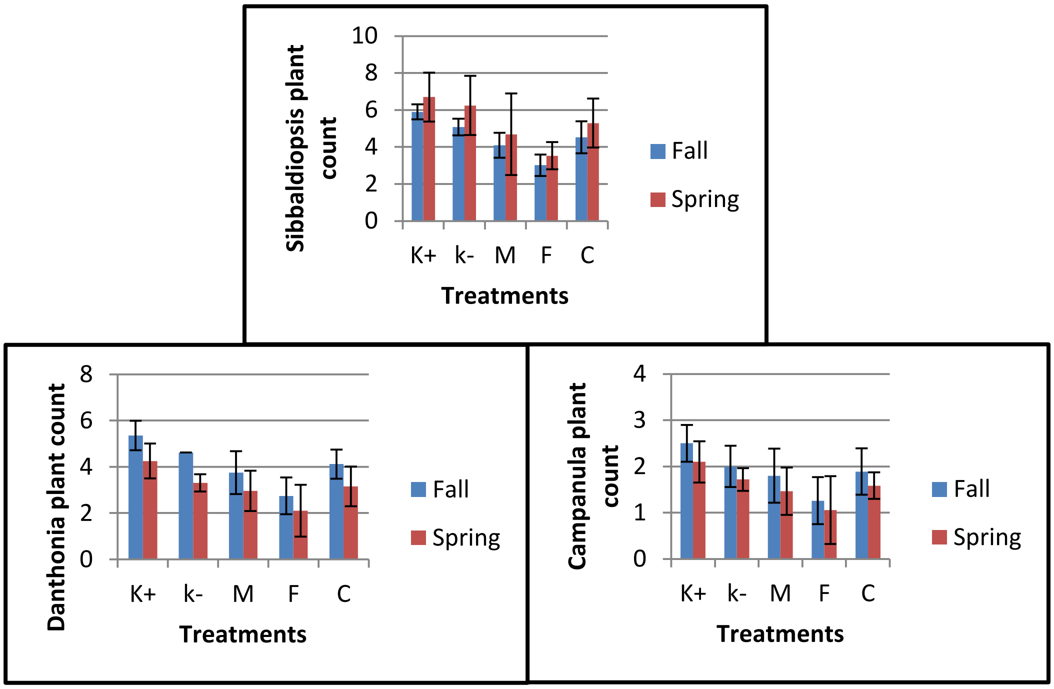


Figure 16: Native plant survival on $1m^2$ plots on the NSCC green roof in a vegetated mat green roof system in the fall of 2013 and the spring of 2014. Plant species are *Sibbaldiopsis tridentata*, *Danthonia spicata*, and *Campanula rotundifolia*. Treatments were 150 grams of kelp meal (K+) per m^2, 75 grams of kelp meal (k-) per m^2, 5 litres of mushroom compost per m^2, 30 grams of 10N:10P:10K slow release fertilizer (F) per m^2, and nothing added to the control (C). K+, k-, M, & F (*n=5*), C, (*n=4*). Error bars represent standard error.

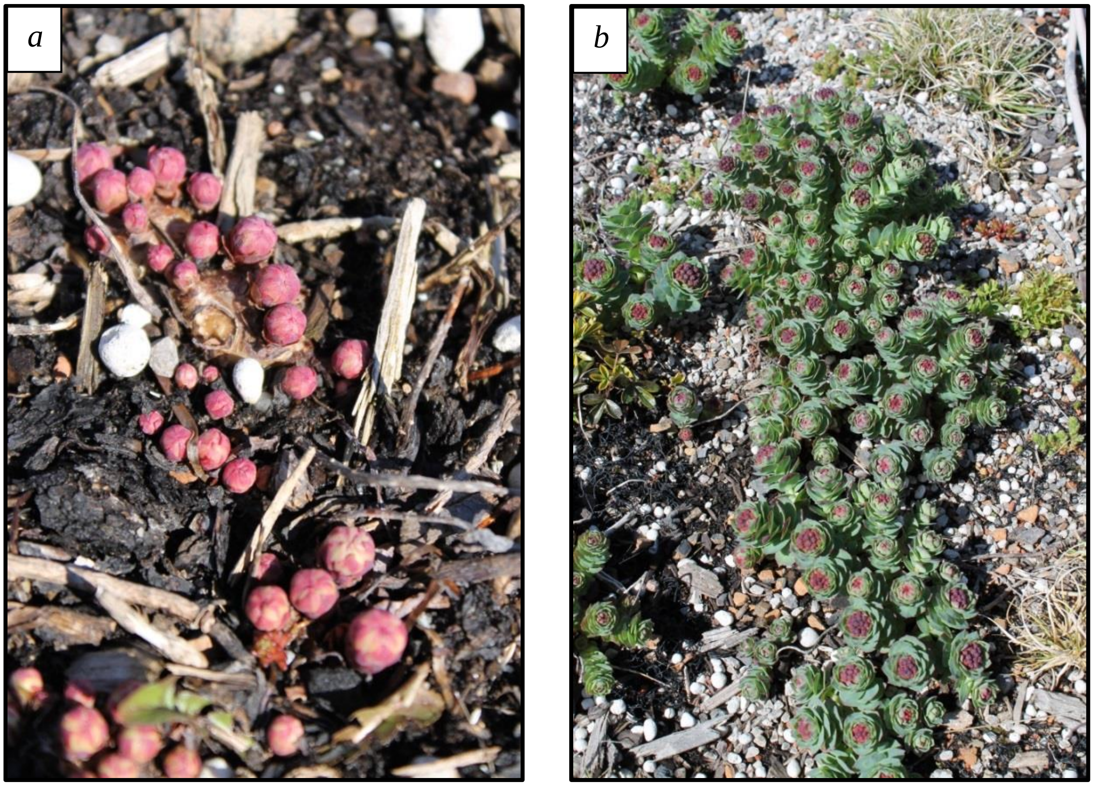


Figure 17: *Rhodiola rosea* plant crowns in April 18, 2014 (a) and May 6, 2014 (b) on the NSCC green roof show the successful survival over the winter.

Plant health

The FLL Guidelines (2002) recommend pH of green roof substrate to be 6.5-8.0 for multiple-course construction. Multiple course construction contains both growing media and a separate drainage layer (Philippi 2006) and the green roof substrate provided by the industry partner had a mean pH of 8.38 (*n=3*). The FLL document also lists that a lower pH is acceptable for special plants (humus rooting plants), recognizing the fact that there are plants that will benefit from a lower pH. One native species, *Sibbaldiopsis tridentata* showed signs of nutrient deficiency because of the high pH. Figure 18a shows an example of what the majority of this species looked like in 2013 and Figure 18b is a picture of a healthy plant. There were 240 *S. tridentata* plants installed in June, 2013. On August 12, 2013, yellow plants were counted and 192 out of the 240 plants were yellow and showing signs of deficiency due to an inability to take up essential nutrients. According to http://www.wildflower.org, *S. tridentata* requires soil with a pH of <6.8. In Nova Scotia, rain and snow events can cause acidification when soil water that contains a lower pH combines with inorganic aluminum (Campbell et al. 2005). The population of *S. tridentata* increased in 2014 despite the yellow plants and the new plants were a healthy green colour.

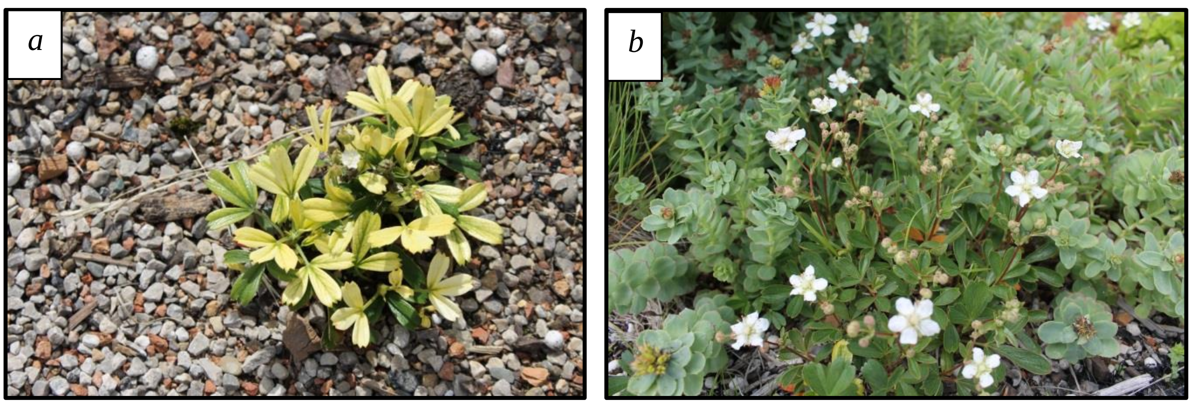


Figure 18: One of 192 out of 240 *Sibbaldiopsis tridentata* showing nutrient deficient symptoms (*a*) and a healthy *S. tridentata* (*b*) on NSCC green roof.

In 2013, many of the big leaf *Sedum* (*S. kamtschaticum* and *S. spurium*) showed evidence of *Septoria sedi* (leaf blotch) highlighting the risk of planting large quantities of one or two species on green roofs. Figure 19 shows evidence of disease on the green roof plants. The disease was not present on the smaller leafed *Sedum*.

Figure 19: *Septoria sedi* infecting *Sedum kamtschaticum* on the NSCC green roof 2013.

Substrate temperature

The extreme high and low mean temperatures all took place in the native plant plots. The highest mean bottom temperature was 28.38 °C and the lowest was -16.75 °C. The highest mean surface substrate temperature was 40.48 °C and the lowest was -17.54 °C. The native plot bottom temperatures were significantly hotter than the bottom temperatures in the *Sedum* plots. The native plots did not have complete canopy cover. The exposed substrate could have become hotter than the *Sedum* plots which had almost complete coverage from the creeping stems of the *Sedum* plants. Average high and low bottom and surface temperatures for all plots together can be seen in Table 8. While not significantly different, the *Sedum* plots had the lowest average bottom and surface temperatures.

Table 8: Average highest and lowest bottom and surface substrate temperatures in control plots (C) for native and *Sedum* plants species on the NSCC green roof *(n=4)* from August, 2013-February, 2014. Significant differences comparing species are shown with an (*a*) or (*b*).

Species	**Average Highest Bottom Temperature**	**Average Lowest Bottom Temperature**	**Average Highest Surface Temperatures**	**Average Lowest Surface Temperatures**
Native	27.7 *a*	-14.2 *a*	37.0*a*	-14.8 *a*
Standard error	0.3	1.0	1.5	0.8
Sedum	25.9 *b*	-15.1 *a*	31.9 *a*	-15.7 *a*
Standard error	0.6	0.6	1.5	0.8

Sedum species were affected by the edge in Plot 31 and all of the extreme high and low temperatures on the substrate surface and bottom were in this plot. The plot was at a windy edge of the roof. The native species in Plot 32 had extreme low temperatures in both the top and bottom surface. This plot was also on the edge and in the same windy corner as Plot 31. The highest surface temperature for the native species was in Plot 22 which was an inside plot, but on the central path. The rubber pavers may have affected the temperature of this plot. The highest bottom temperature of the native plots was in Plot 15 in the upper right hand quadrant of the roof. There was no outside edge for this plot; it was surrounded on two sides by mushroom compost. These factors may have affected the bottom temperature. Table 9 shows the highest and lowest bottom and surface temperature means for each separate native and *Sedum* species.

Table 9: Average highest and lowest bottom and surface soil temperatures from each temperature probe in control plots (C) on the NSCC green roof. Data was taken from August 2013 to February 2014 approximately every ten minutes. Bolded numbers are the highest and lowest readings.

Species	**Highest Bottom Temperature**	**Lowest Bottom Temperature**	**Highest Surface Temperatures**	**Lowest Surface Temperatures**	**Plot Number**
Native	26.9	-14.9	**40.5**	-16.0	22
Sedum	24.9	-13.6	29.5	-13.8	36
Native	28.0	**-16.8**	34.2	**-17.5**	32
Sedum	27.6	-16.4	36.5	-17.4	31
Native	**28.4**	-12.1	39.0	-13.8	15
Sedum	25.1	-15.3	31.8	-16.4	25
Native	27.6	-14.1	34.9	-14.5	35
Sedum	26.3	-15.5	31.1	-16.1	9

There were a number of freeze-thaw cycles that took place in the control plots on the green roof. These cycles can be seen in Figure 6. The incidences of these events were higher at the top of the substrate compared to the bottom of the substrate. The native plant plots had a higher number of times where they were either frozen or thawed compared to the *Sedum* plots which showed less fluctuation in temperature.

Volumetric water content

Snapshots of the volumetric water content (VWC) were taken twice in 2014 and can be seen in Figure 20. On May 7, there was one significant difference where the M treated *Sedum* plots were significantly drier than the C *Sedum* treated plots. On June 3, the M treated plots were the driest treatment (not significant). The *Sedum* plots treated with M also showed the highest canopy density in July 2014. These larger plants may have been using more water compared to the other treatments. There were no significant differences in the native plots when treatments were compared in May or June.

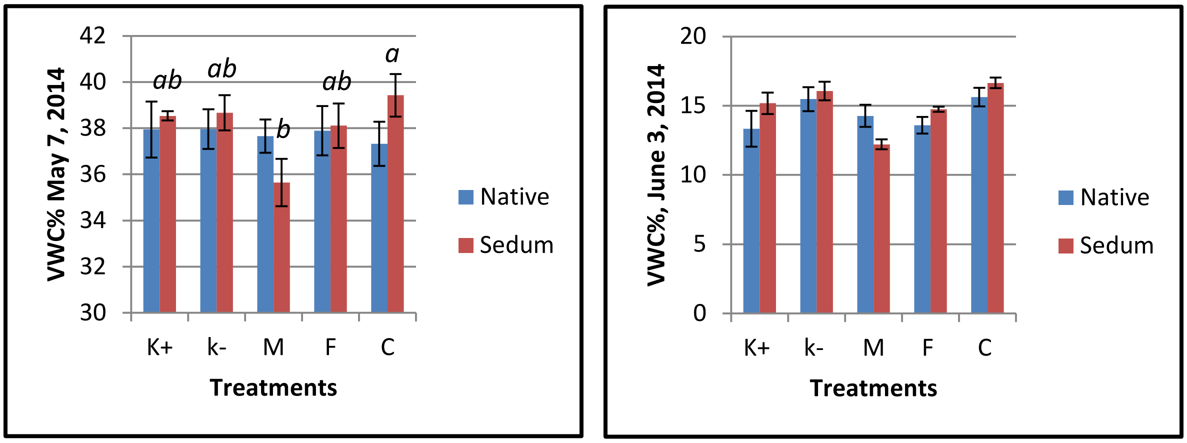


Figure 20: Volumetric water content of green roof substrate in *Sedum* and native plots on NSCC green roof on May 7, 2014 and June 3, 2014. Treatments were 150 grams of kelp meal (K+) per m^2, 75 grams of kelp meal (k-) per m^2, 5 litres of mushroom compost per m^2, 30 grams of 10N:10P:10K slow release fertilizer (F) per m^2, and nothing added to the control (C). K+, k-, M, & F ($n=5$), C, ($n=4$). Error bars represent standard error.

Discussion

Amendments

Plant growth was measured using percent visual cover in 2013, canopy density in 2013 and 2014, and relative canopy change from 2013 to 2014. There were few significant differences when comparing plant growth and amendments. There were two incidences where the C treatment was significantly larger than the F treatments for native plants (see Table 6) and one case where the C treatment was significantly larger than the F treatments for *Danthonia spicata* (see Figure 10). Measuring the plant growth in real conditions on a green roof where there is free root run and shared soil water created less controlled conditions compared to testing pot culture or a modular system and this could have affected results. A larger sample size may have resulted in a different outcome.

Thirty out of forty eight of the green roof plots were treated with organic amendments. While these parameters were not tested, the literature shows that the organic amendments are likely improving the physical aggregate structure, the chemical properties, and the microbial populations of the green roof substrate (Elliot & Coleman 1986; Bulluck et al. 2002; Ferreras et al. 2006; Shepherd et al. 2002).

The mushroom compost provided nutrients for microorganisms that benefit the populations. This soil microbial activity improves soil functioning (Bonilla et al. 2012). Increased fungal hyphae can improve the soil structure and help to bind soil particles together (Lucas et al. 2014). These processes in soil formation and maturation are integral steps to developing a sustainable green roof substrate.

The abundance of the big leaf *Sedum* on the NSCC roof provides ideal conditions for *Septoria sedi* to cause leaf damage and possible plant loss on the roof. Control recommendations of this disease include plant removal (Hong 2014) which would be difficult. The addition of organic amendments could have a positive effect in controlling disease on the green roof. Bulluck et al. (2002) found that by adding organic amendments, the incidence of plant-pathogenic organisms was reduced in agricultural soil.

Kumari et al. (2012) found that kelp meal was superior for overall improvement of soil structure compared to kelp powder. It was the biomass of the kelp meal that improved the physical, chemical and biological soil properties that in turn improved plant growth. Haslam & Hopkins (1996) tested another species of kelp, *Laminaria digitata*, and found that by including kelp in the soil, total pore volume and aggregate stability of the soil was improved. The K+ treated plots had the first or second highest canopy density at the end of each of the growing seasons. It is possible that the K+ treated plants were putting on root growth at the beginning of the year (and this could have been due to improved substrate properties) which enabled leaf production to take place through the growing season. This experiment did not measure root growth, however research does show that the application of kelp aids in root growth (Crouch & van Staden 1992).

The dried kelp meal differs from compost which has gone through a process where nutrients are stabilized by microbes and humification has taken place (Hadas et al. 1996). It would be useful to test composted fresh kelp, or dried kelp that has been combined with compost to see if these amendments will benefit plants growing on a green roof.

Monterusso et al. (2005) used slow release fertilizer for their experiment that included *Sedum* and native plant species. While the *Sedum* survived, the majority of the native plants died during the three year experiment. Emilsson & Rolf (2005) tested establishment methods on vegetated mats and applied slow release fertilizer. Clarke & Zheng (2014) recommended that some green roof systems should not be fertilized at installation due to leaching of nutrients that can be a source of pollution. They tested a vegetated mat system and concluded that higher fertilizer rates led to plant injury over the winter. Nutrients were leached from some mats at unacceptable levels in the study. Leach et al. (1999) tested *A. nodosum* to measure leaching in two different soil types (a sand/compost mix and a sand/peat mix). There was significantly less nitrate leaching (20%) from the sand/compost soil treated with *A. nodosum* compared to the control. Applying *A. nodosum* to green roof substrate could help to alleviate this problem.

The growth of the *Sedum* in the F treated plots during the first year was not apparent the second year of the study as the fertilizer was not applied in 2014, so the nutrients were no longer available while the organic amendments were still benefiting plant health and growth due to the slow release of this type of biofertilizer.

The above ground native plant material either incorporated into the soil or could have been blown away throughout the winter. See Figure 21 of the NSCC green roof on April 17, 2014. Some researchers think that green roof ecosystems should not have inputs but rather be left to reach a state of homeostasis (Sutton 2009). A green roof is a contained system where the soil water and plant roots are not able to reach out to nutrients and areas that may be available for plants in a landscape at ground level. Nutrient losses may be permanent on a green roof and planning a regular nutrient program is a sensible way to protect the green roof ecosystem.

Figure 21: NSCC green roof on April 18, 2014. Dark coloured plots are *Sedum*, lighter plots are native species.

Plant Growth

The conservation of native plant species that live on the coastal barrens has been successful on this roof. The native species are colonizing and new seedlings of *Plantago maritima*, *Campanula rotundifolia*, *Rhodiola rosea*, *Sagina procumbens,* and *Luzula multiflora* were observed in 2014. After one year on the roof, the native mats have surpassed the minimum recommended 60% coverage at installation in FLL (2002) green roof guidelines.

The roots of *Rhodiola rosea* are used as a nutritional supplement with claims that it helps to normalize body functions, such as metabolism and hormonal glands by stimulating biochemical and functional reserves (Tasheva 2011). The species is dioecious (separate male and female plants) and the rhizomes, which smell like roses, are edible (Rohloff 2002) as are the leaves of the plant. In Norway, the plant has a long history of being used on turf roofs and is thought to help protect houses from fire (Alm 2004). The interesting history, medicinal properties, opportunity for plant conservation, and the species successful establishment on the NSCC roof, make this a plant worth researching more for use on green roofs in Nova Scotia.

The *Sedum* mats began the experiment with just under 90% cover and have surpassed that when looking at the canopy density and photographs of each plot. *Sedum* species observed on the roof were: *S. kamtschaticum*, *S. spurium*, *S. album*, *S. acre*, *S. aureum, S. sexangular*, and at the edge of the path, *S. reflexum*. *Sedum pulchellum* was observed (one plant in the field) but was not present on the roof. When the vegetated *Sedum* mats were first installed on the green roof, the plants had been growing in very little substrate and had undergone drought conditions. At the time of installation, the dominant species observed were *S. album* and *S. acre*. See Figure 22 for a visual look at the plant mats immediately after installation. Although we did not measure *Sedum* beyond genus, it was observed that *S. kamtschaticum* and *S. spurium* were progressing as more dominant species and were taking over the plots on the green roof. Starry et al. (2014) found that *S. kamtschaticum* used water more efficiently under well-watered conditions and gained more carbon than *S. album* which was a more efficient water user in lower water conditions. The water availability on the green roof may be why there has been a change in the *Sedum* community.

Figure 22: NSCC green roof plots immediately after installation on June 26, 2013 showing abundance of red *Sedum album*.

The central path in Figure 23 provided an edge and was colonized with *S. reflexum*, *S. acre*, and *S. album* in 2014. This was the only plant community of *S. reflexum* on the roof.

Figure 23: A portion of the central path on NSCC green roof showing diversity at edges of plots.

Erosion

Getter & Rowe (2006) recommend that as part of maintaining a sustainable green roof, eroded substrate should be replaced and twice yearly visits will help to determine the need for fertilizer. In this study, the mushroom compost and the kelp meal protected the open soil and reduced erosion on the native plots. Organic amendments can improve soil structure and increase the water holding capacity of green roof substrate (Graceson et al. 2014) which in turn leads to improved plant performance. Cavagnaro (2014) found that the addition of compost improved plant and root growth and root structure may help with the reduction of erosion. The binding properties found in kelp partly come from alginates (Temper & Bomke 1990). These alginates could be increasing aggregate stability of green roof substrate in the kelp treated plots.

It's been established that plants are physiologically active even in the winter months (Steenberg et al. 2007). Knowing this, the fall application of mushroom compost not only provides protection from erosion of the substrate, it also inputs microbes and humus into the system. The nitrogen quickly becomes available for plant use as it is mineralized while some is stored in the system (Seiter & Horwath 2004). Further research exploring plant growth, nutrient run off, and erosion using different volumes of mushroom compost in green roof research could produce a more distinct picture on what may be the most beneficial frequency and volume of applications for green roof plants and substrate.

Substrate temperature

During freeze, thaw cycles, Kreyling et al. (2010) stated that nitrogen losses are often used by plants in a nitrogen transfer from the soil to the plants thus capturing the nitrogen and immobilizing it in the system. The native plants on the NSCC green roof went through a number of freeze-thaw cycles and more so than the *Sedum*. A deeper root system and adaptation to the cold Nova Scotia winters on the coastal barrens may be part of what is enabling the native plants to survive the extreme conditions on the green roof. Recognizing Lundholm's (2006) habitat template approach reinforces the importance of choosing the right plants for the environment which they are being placed.

Kreyling et al. (2010) found that in a grassland community, freeze-thaw cycles resulted in an increased plant biomass the following year. The premise was that the grassland community (due to the need to uptake enough nutrients and regrow from the ground up) would respond differently due to uptake of nutrients that became available during the freeze-thaw cycles compared to dwarf heaths (that don't die back completely). In this study, the native plants increased in size during the second season after undergoing a number of freeze-thaw cycles that were different compared to the *Sedum* species. Microbial activity is increased during these cycles and microbial respiration generates heat which can cause a rise in soil temperatures (Campbell 2005). The high organic matter in the green roof substrate coupled with the larger root biomass of the native plants could have been a factor in the higher temperatures of the native plots.

Volumetric water content (VWC)

While not significant, the plots that were treated with mushroom compost grew larger plants compared to other treatments. These plots were drier when VWC was measured. Soil moisture was sufficient for the plants to grow well, even without irrigation during the second year (2014). Butler & Orians (2011) established that *Sedum* could act as a facilitator to higher water using plants during periods of drought conditions on a roof. Designing a green roof with a combination of native plants and *Sedum* may be one way to improve the growing conditions for native plants on extensive green roofs. The alternating design of *Sedum* plots with native plots may be allowing some facilitation on the NSCC roof, improving the growth and survival of the native species.

Vegetated mats

The vegetated mat system has been designed by the green roof industry to supply a ready-made product that provides instant greening and is ideal for growing and transporting *Sedum* species to green roofs. The quick coverage provided by some species

(*S. acre* and *S. album*) hold the substrate in place enabling the mats to be rolled up and easily transported. Other species typically in a *Sedum* mix (*S. kamtschaticum*, *S. spurium*) are present in smaller amounts and, depending on the growing conditions, these species can become the dominant ones over time (MacIvor et al. 2013; Moritani et al. 2013; Monterusso et al. 2005; Emilsson 2008). Available soil moisture and organic matter content appear to have an effect on these plant populations showing that each green roof is unique and each roof presents different growing conditions that can affect the plant populations.

The vegetated mats on the NSCC roof started with large quantities of *S. album* and lesser amounts of *S. acre*. *Sedum kamtschaticum* and *S. spurium* appear to be taking over the plots after the second year on the roof. A substrate rich in organic matter and plentiful soil water could be driving this plant population change.

The native plants had difficulty germinating and establishing on the vegetated mats in the field. This resulted in transporting the mats with one native mat stacked on top of a *Sedum* mat so as not to lose substrate and crush the *R. rosea* plants that were easily broken. Transporting the mats this way was bulkier than the industry partner's product which was rolled and stacked on one pallet. Low cover led to transplanting native plants into the vegetated mats thus altering the installation compared to the *Sedum* mats, yet positive results on the roof show that it is feasible to grow the native species within a vegetated mat system on a green roof. While this may be a different use of the vegetated mats compared to growing *Sedum* species, the mats are a good choice for windy (Snodgrass & McIntyre 2010) or sloped sites because they protect the bottom soil layer from erosion and reduce particle loss. Soil depth and soil moisture must be adequate in order for this type of native plant installation to be successful.

Ecosystem services

The green roof at NSCC is providing a number of ecosystem services that would otherwise be unavailable from a conventional roof. Aesthetic beauty was evident with the combination of grasses, perennial forbs, and *Sedum* providing a variety of plant forms and flower colour. Flowers that provided both nectar and pollen started in early May and included (in approximate blooming order) *Rhodiola rosea*, *Sibbaldiopsis tridentata*, *Sagina procumbens*, *Plantago maritima*, *Houstonia caerulea*, *Sedum* species, *Campanula rotundifolia*, *Danthonia spicata*, and *Festuca rubra*. Figure 24 shows a portion of the green roof in July, 2014. A large number of bees were observed on the roof. The decline of pollinators in recent years is due to a loss of habitat (Jansson 2013), particularly in urban areas and this green roof is one way to counteract the negative effects of urbanization by providing floral resources.

Figure 24: Flower abundance on the NSCC green roof, July 17, 2014.

Green roofs can offer a relief for urbanites as a source of nature. Ulrich (1984) found that by viewing nature through a hospital window as opposed to viewing a brick wall, a patient's recovery from surgery could be influenced. While Ulrich's study looked at views of trees, other studies have shown that views of fields and grasslands can provide positive physiological benefits (Velarde 2007). Lee et al. (2014) concluded that restorative green roofs were taller, green, and contained both grasses and flowers. These and other species are flourishing on the NSCC roof. The NSCC green roof can be viewed from the windows of the Dartmouth General Hospital and may offer some nature relief to those working at and visiting the hospital.

Hundreds of *Coccinella septempunctata* (seven-spot ladybird) larvae were observed in 2013 and 2014 eating aphids that were mainly on the *Sedum* and *R. rosea* on the roof. While not quantified, this introduced species from Europe was abundant and could be seen on the white posts around the green roof going through metamorphosis in the 2014 season providing evidence that the green roof is a source of habitat for this species. Figure 25 shows larva in 2014.

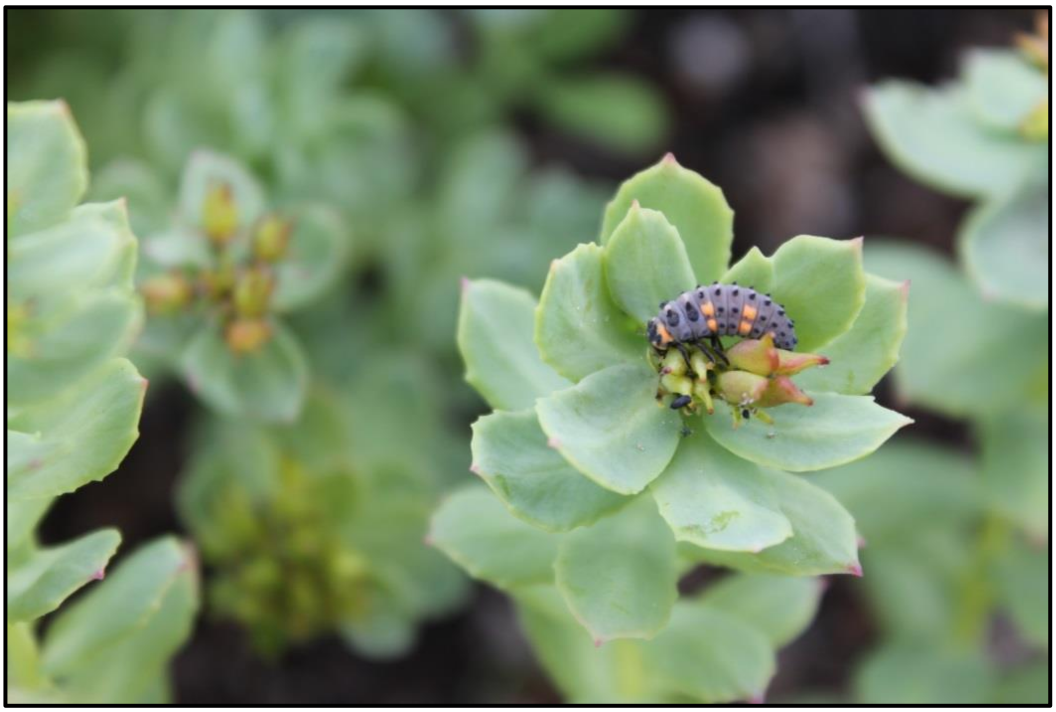


Figure 25: *Coccinella septempunctata* (seven-spot ladybird) larva feeding on aphids on *Rhodiola rosea*, NSCC green roof, June 13, 2014.

The installation of the vegetated mats on the NSCC green roof can be considered a success. Figure 26 shows the roof in July, 2014. The diversity and health of the plant species is evident. It would be beneficial to continue to monitor plant populations on this roof since many green roof studies are short term, there are few published papers that show long term research, and as each green roof is unique, the roof can offer insight into plant survival on green roofs in Halifax region of Nova Scotia.

Figure 26: NSCC green roof in July 2014 at the end of the study period.

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CHAPTER 4

Synthesis: "Evaluating the effects of kelp (Ascophyllum nodosum), mushroom compost, and slow release fertilizer amendments on the growth, health, survival, and drought tolerance of plants growing on extensive green roofs."

Chapter 4: Thesis synthesis

Green roofs offer us an opportunity to reduce impervious surfaces on conventional roofs by creating an ecosystem in an area which would otherwise be uninteresting, wasted space. Green roof research and the green roof industry have enabled us to expect and predict how a green roof may perform. Geographical location, wind speed, solar radiation, precipitation, building materials, substrate, plant species and planting design can all have an effect on green roof performance. Conducting research that measures individual green roof elements along with field studies that measure real green roofs can be important additions for expanding green roof knowledge (Dvorak & Volder 2010). Green roofs are long-term ecological experiments with expected life spans of 30-40 years and there are some green roofs that are still in existence after 100 years (Köhler 2006). A green roof can last much longer than a conventional roofing membrane while providing environmental benefits and ecosystem services. The two experiments presented here are short-term when considering the potential life span of a green roof. The greenhouse experiment took place over a four month period (one growing season) and the green roof experiment encompassed a year of research (two growing seasons). Green roofs are a sustainable technology and it is through research and testing of different plants, products, and substrates that we may discover new ways to create healthy, unique green roof ecosystems in Nova Scotia.

The first manuscript (Chapter 2) of this thesis began with exploring seed germination and plant biomass in a greenhouse experiment at Saint Mary's University, Halifax, Nova Scotia using an industrial green roof substrate while testing liquid *Ascophyllum nodosum* (kelp) amendment and synthetic, slow release fertilizer. The experiment continued further, measuring plant health on the Saint Mary's green roof and analyzed how plants and substrate treated with different amendments reacted to a six day drought. A third phase of the experiment took place back inside the greenhouse and measured plant health, growth, and survival in a two month, prolonged drought. Plant species tested include four non-native plants provided by an industry partner, Vitaroofs, three species native to the coastal barrens of Nova Scotia, and three annual flowers from a local seed supplier.

The second manuscript (Chapter 3) was an in depth green roof project that was a collaboration of industry and science. Vegetated mats that are commonly seeded with a variety of industry standard *Sedum* species were tested along with four main species of plants that are native to the coastal barrens of Nova Scotia. The 75 m^2 extensive green roof was installed on the Centre for the Built Environment at the Nova Scotia Community College in Dartmouth, Nova Scotia. The green roof contains 48 m^2 of research plots and has a 15 m^2 demonstration site for the industry partner's vegetated mat product. The substrate was custom made in New Brunswick. Soil amendments tested in this project include *A. nodosum* meal (kelp meal), mushroom compost, and synthetic, slow release fertilizer.

Green roof plants need to grow well, so they can become established quickly on a roof. This is often done with the use of synthetic fertilizers. The lesser kelp treatment in the greenhouse experiment showed promising results for seed germination, plant growth, and survival during drought, while the fertilized treatments grew large plants, but died sooner and had lower health scores than the kelp treated plants during the droughts. The mushroom compost and kelp treatments tested in the green roof experiment, grew healthy plants that were comparable in size to the fertilized treatments. This was different compared to the greenhouse experiment where the fertilized treated plants grew significantly larger compared to the controls and the kelp treated plants.

Many of the plants in the greenhouse experiment experienced a reduction in health when exposed to drought in the second month and again in fourth month of the growing season. The plants in the green roof experiment grew well (regardless of treatments) with irrigation in the first growing season. Irrigation was withheld the second season and the plants in all treatments continued to show steady growth in the canopy density. The added organic amendments (kelp meal and mushroom compost) on thirty plots could have improved the water holding capacity of the green roof soil. The combination of native plots alternating with *Sedum* plots could also have been a factor in the plant survival with the *Sedum* facilitating the native plants in times of low water availability. Since the green roof was a whole system, compared to the individual pots in the greenhouse experiment, soil water and nutrients were shared. This reduced the amount of control in the experiment and likely affected the results.

Plants that have sufficient moisture and nutrients to meet their growing needs will be healthier. The native plants on the green roof had low mortality through the winter of 2013-2014. They survived fluctuations in the substrate temperatures from summer to winter months (57 °C in surface temperatures) and extremely low bottom and surface temperatures in the winter months (-17 °C). Though there were few significant differences among treatments when comparing the growth of the plants, the health of the plants was apparent when analyzing their canopy density as it steadily increased over two growing seasons. The growing conditions on the roof would have played a part of this survival. Monterusso's (2005) experiment where the majority of the native species tested, died, took place over three years. There were some losses the first winter. When irrigation was withdrawn in the second season, many plant species died and further losses happened through the second winter. Unlike Monterusso's native, prairie species, there was not a loss of the coastal barrens native species in the NSCC green roof trial when irrigation was stopped in 2014. The canopy density of all the native species continued to increase throughout the growing season. It would be useful to continue monitoring the green roof to see if the native plants survive through subsequent Nova Scotia winters.

Retaining substrate while plants are growing (whether in the field or on a roof) is an essential part of providing the plants with appropriate medium for rooting, stability, taking up nutrients, and providing sufficient moisture. Wind and rain splash erosion are two ways that substrate is lost from a green roof system. The kelp meal and the mushroom compost on the green roof significantly reduced the amount of erosion that took place during the winter of 2013-2014 compared to the fertilizer. The native plants had not covered the substrate completely and have a different growth habit compared to *Sedum* that leaves substrate open. Using mulch such as mushroom compost or kelp meal annually would help to reduce erosion, build soil with the input of organic matter, and could be considered part of best practices maintenance.

The variety of plants tested in both experiments represents a diverse mix of genus' and species. Each species had different results when analyzing germination, drought tolerance, growth, and winter survival. Creating green roofs that are diverse in species, plant morphology, life cycles, nutritional needs, and water requirements can result in a more flexible ecosystem than a green roof that is comprised of one plant genus. We tested perennials on the NSCC green roof. The annuals tested in the greenhouse experiment could be a practical addition to the plant palette on the roof. Some species did self-seed in the few months of the greenhouse experiment and could offer later floral resources for both aesthetics and pollinators when the perennial species have finished blooming for the season. *Portulaca grandiflora* tested in the greenhouse experiment was a drought tolerant succulent that did not die in a two month drought. This annual has a variety of flower colours and could offer another option for diversity on a green roof.

The *Sedum* genus is comprised of a number of species that provided cover, flowers, and structural diversity on the green roof. The vegetated mats were easily installed on the roof and did provide instant colour. The *Sedum* could be helping to provide moisture to the higher water users on the roof (Butler & Orians, 2011). Including plants in the *Sedum* genus provides reassurance since the genus is a proven performer for green roof culture.

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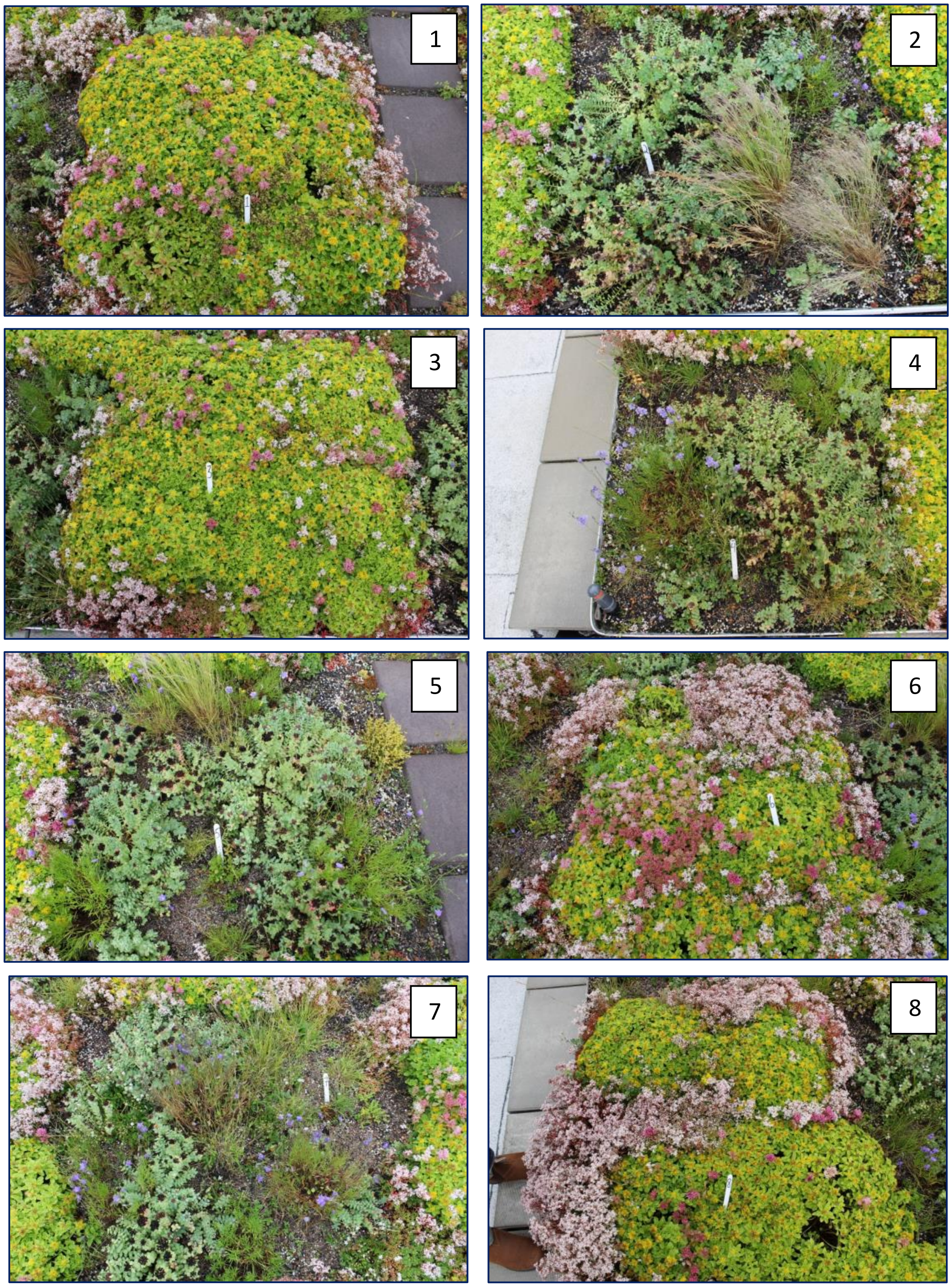
Appendix: Final canopy cover of 48 plots on NSCC green roof. July 17, 2014.

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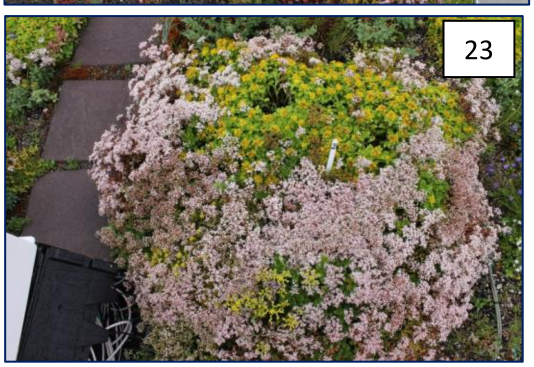
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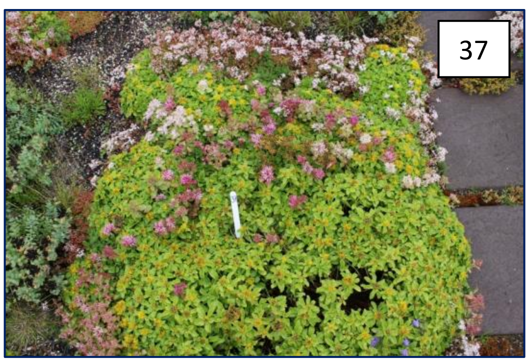
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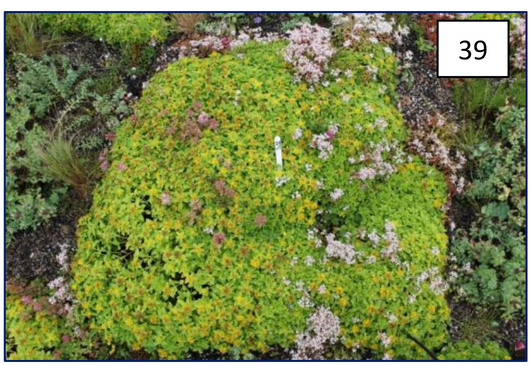
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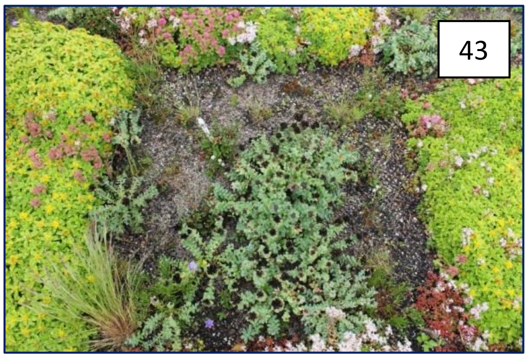
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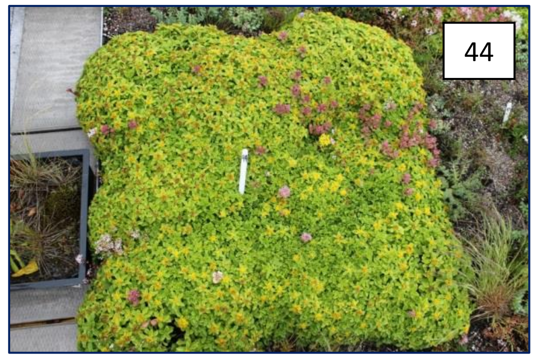
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