THESIS

EXPANDED SHALE AS A SOIL AMENDMENT FOR THE ROCKY MOUNTAIN REGION

Submitted by

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ABSTRACT

Landscape soils are rarely ideal, consequently there has been abundant research about amendments for soil improvement. This research project focused on the use of compost, a long-standing successful amendment as well as expanded shale, an amendment that originated in the construction industry. Expanded shale is a shale rock that is heated to very high temperatures causing the material to fracture and create small pores. These pores make the material lighter in weight and those pores help to improve soil porosity and potentially can act to hold some levels of moisture and nutrients.

The study began in October of 2015 and data was taken in the growing seasons of 2016 and 2017 from April 2016 to October 2016 and from April 2017 through September 2017. In this project six different treatments of varying levels of compost and expanded shale were incorporated into a research site at Colorado State University. The treatments were **1**) 0 cm of expanded shale and 5 cm of compost (0 ES: 5 C), **2**) 2.5 cm of expanded shale and 5 cm of compost (2.5 ES:5 C), **3**) 5 cm of expanded shale and 5 cm of compost (5 ES:5 C), **4**) 7.6 cm of expanded shale and 5 cm of compost (7.6 ES:5 C), **5**) 5 cm of expanded shale only (5 ES:0 C), and **6**) 7.6 cm of expanded shale only (7.6 ES:5 C).

Soil moisture data was taken weekly in 2017 and physical measurements and photographic growth measurements were obtained during each growing season. A destructive harvest was performed in October and November of 2017 where top growth and roots were harvested separately and measured before being oven dried for weight analysis. Statistical analysis did not demonstrate significant differences between treatment types, however the soil

amendments were not detrimental to plant growth. There is a lot of room for potential

futurestudy of expanded shale as a soil amendment for rocky mountain region soils and beyond.

ACKNOWLEDGEMENTS

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CHAPTER I. INTRODUCTION AND LITERATURE REVIEW

1.1 Introduction

  With increasing urbanization and housing development, establishing and refurbishing of landscapes are common issues. Construction often destroys natural soil horizons and causes soil compaction; therefore, urban soils frequently do not support healthy plant growth. Soil amendments and conditioners to improve soil properties to maximize plant health are widely used. The current literature is lacking in the topic of inorganic soil amendments such as expanded shale when used as a landscape amendment. Soil amendments or conditioners are used to enhance plant growth not only in landscapes, but also in containers and green roof plots. Amendments can improve water use and nutrient absorption, in part due to changes in soil porosity, tilth and hydraulic conductivity (Sloan *et al.* 2010, Bousselot *et al.* 2010, Mechleb *et al* 2014.). Organic amendments are excellent for sandy soils while organic amendments and inorganic amendments will boost plant performance in heavy clay soils (Sloan *et al.*). Clay soils have low porosity and high potential for water logging as well as compaction. In containers, inorganic amendments may also reduce weight and bulk density improving porosity of the plant growth substrate. Green-roof construction relies on the addition of lightweight inorganic materials to provide substance and drainage while minimizing the weight imposed on the roof (Bousselot *et al.* 2011).

1.2 Literature Review

  The following discussion includes pros and cons of amendment materials, such as expanded shale, as well as other inorganic or organic amendments. I first address soil amendments used in landscapes (Section 1) and then amendments to substrate media used for

plant growth in green-roofs (Section 2). Finally, I focus on expanded shale as a soil amendment in a variety of applications (Section 3).

1.3 Amendments for landscape soils

Amending native landscape soils with materials can enhance-soil tilth, improving conditions for plant establishment and growth. Both organic and inorganic amendments are employed in management of landscape ground. For instance, Scheiber *et al.* (2007) tested the outcomes on growth in a sandy soil of an annual bedding plant, *Pentas lanceolata,* using organic compost versus an inorganic clay-based amendment in a simulated landscape setting. The work was performed to address the issue of concern for sandy soils, that the irrigation of landscape plants can place a significant drain on potable water supplies. Treatments that reduce the water needs of landscape plants, while maintaining aesthetic qualities, will be increasingly important as growing populations and urbanization interact with climate variability. The authors evaluated water use versus the growth and aesthetic qualities of plants raised in a sandy substrate amended with municipal compost or kaolinite clay, conditions that would mimic local homeowner landscapes.

For this study, lysimeters were packed with the local topsoil of the Apopka sand series (paleudult), without and with amendments of municipal compost or clay. Each lysimeter was planted with three seedlings of *Pentas lanceolata* "New Look Red". The lysimeters were irrigated daily for 21 days after transplant to establish the plants. From then on irrigation was regulated by tensiometer- controlled irrigation, so that the plants did not receive excess water. Growth was measured and aesthetic value determined by assessment of plant quality, density and flower coverage.

Amendment of the sandy soil with compost but not the clay increased ($P < 0.05$) shoot dry weight, total biomass and shoot-to-root ratios compared with growth in the non-amended soil. Also, evaluation of plant density and flowering potential were greater for growth with the compost amendments, whereas these properties with the clay amendment was not statistically different from the control grown plants. The compost also improved water usage. The plants from the compost-amended treatments had a greater shoot-to dry weight/L irrigation than for the plants grown in the control or clay amended soils. This was interesting since the soil amendment with clay at low water potential had a higher water content than the compost amended soil. Thus, compost amendment to the sandy soil rather than the clay was more beneficial for plant performance along with more efficient water use.

Various sources of organic amendments have been examined. As noted by Scheiber *et al.* (2007), not all organic amendments will be equal in their efficacies in soil, with longevity in soil due to different rates of degradation. Different products have been examined, especially where their use has an extra bonus of helping to defray environmental disposal issues. As an example, a byproduct of olive oil production, olive mill waste (not composted), is used as a potential resource. Currently, significant quantities of olive mill waste are discharged into rivers and the sea without treatment. Thus, an alternative use as a soil amendment would improve overall environmental impacts. Additionally, mill waste could function as a viable alternative to peat moss in horticulture.

Ntoulas *et al*. (2011) examined the use of olive mill waste in establishment of turf with *Cynondon dactylon* (bermudagrass). The study involved 24 plots in a randomized design, with wood barriers between each treatment. Plots were fertilized monthly with a 12-12-17 fertilizer and planted with *C. dactylon.* Evaluation involved visual quality ratings with a scale from 1-9,

one being dead, 9 ideal, and 6.6 being the minimum acceptable turf quality. Other assessments included clipping yields, root growth and vertical detachment force measurements. The authors also measured bulk density, pH, EC and soil moisture.

Three different volumes of amendment were added: low = 12.5 %, medium = 25 % and high = 50 % by volume to a depth of 0.25 m. With increasing levels of olive mill waste, there was reduced soil bulk density, reduced pH and improved moisture retention. Beneficial changes in the physical characteristics of the soil influenced visual quality ratings of the grass during the cold periods of the study. The authors concluded that amendment with the higher levels of olive mill waste were important for speed of turf establishment and maintenance under limited water supply. For longer-term sustainable growth, the lowest level of olive mill waste was adequate. This is an excellent use of a byproduct of an existing industry.

The addition of organic amendments, tillage and aeration are all touted as methods to improve soil conditions for plant growth. Erickson *et al.* (1982) sought to determine the effects of tillage on soil aeration. Their study determined whether the addition of compost, with or without tillage or aeration, would improve the physical and chemical properties of the soil to assist in plant growth and development. Plot-site soils were primarily sandy. The five soil management treatments were: 1) tilling, 2) addition of composted animal manure, 3) addition of compost with tillage, 25-35 cm deep 4) soil aeration, and 5) addition of compost with aeration. Plots were established with turfgrass and four common ornamental species. Plant growth measurements and tissue nutrient content were taken after 13 and 40 weeks. The plots were fertilized with complete fertilizers recommended for each plant. The turf was mowed as needed, mostly during the summer months.

Addition of the compost significantly increased soil field moisture capacity compared with the unamended soils. As expected, the soil organic matter content increased with compost amendment. Plant response varied amongst species although overall plants performed better in the compost-amended soils. The authors suggested several reasons for enhanced growth of ornamentals and turf with compost addition: compost improved the field capacity of the soil to promote root and shoot growth; the compost provided materials that enhanced soil fertility, therefore improving plant nutrition; and composted animal manure altered the physical and chemical properties of the sandy soil to favor better growth. In sandy soils aeration is less of an issue than in clay soils so tillage and aeration had little effect on the physical properties of the soil resulting in little effect on plant growth. These findings on soil aeration compare to that of Scheiber *et al.* (2007) where an amendment of compost but not clay improved aeration of a sandy soil. Erickson *et al*. (1982) noted that the results of amendments would likely vary in a clay soil. Also, Erickson *et al*. (1982) proposed the needs for study of the long-term effects of the amended sites once plants had established.

Amendment for larger and more permanent fixtures in the landscape such as trees can be a difficult subject to study because of their longevity. However, in 1995 Smalley and Wood examined the effect of backfill on red maple (Acer Rubrum). They used four different organic containing amendments. The treatments were: 1) native soil, 2) a 50:50 mix of aged pine bark and soil, 3) a proprietary mix called Mr. Natural Concentrated Landscape Media (CLM) mixed with soil, and 4) 100% CLM. The CLM was composed of both inorganic components of granite sand, crushed granite and expanded shale, and with organic components of pine humus and composted poultry litter. The backfill mixes were homogenized with native clay soil in a cement mixer before filling around tree root balls. Planting holes were mulched with 10 cm of pine

needles after planting. The mixture of CLM with soil (3) produced trees with the largest number of small roots (<2 mm) but with no effect for the larger roots (>2 mm). The authors concluded that for these trees there was no advantage observed in using amendments for backfill for transplanting red maples even if the backfill was potentially superior to native soil. Thus, there are examples where amendment does not improve plant growth.

1.4 Amendment applications for substrates for Green Roofs:

Green roofs are considered valuable for aesthetics as well as practical uses. For instance, a roof garden can reduce temperature and solar irradiance, thus, lowering building heat load and creating significant energy savings. Green roof initiatives are growing throughout the USA and the world. For instance, in 2017, the city of Denver, Colorado USA, passed a green roof initiative requiring every building over 25,000 square feet to include a green roof on a percentage of their roof in a sliding scale as the building size increases. The primary obstacle for green roof acceptance is a combination of high initial cost, and the need to build to accommodate the increased mass on the roof when compared to a traditional roof.

There are two types of green roofs: "intensive" and "extensive." A green roof is termed an "intensive roof" if it provides deep rooting areas, to allow planting of shrubs and trees and other ground cover (Dunnet and Kingsbury, 2004). Such an intensive roof garden would have a heavier load and greater water need than an "extensive roof garden" defined as featuring plants with shallower rooting requirements (Dunnet and Kingsbury, 2004).

Construction of a green roof requires several layers as shown in Fig. 1. (presented by greenerheights.wordpress.com). Uppermost is the plant bed growing in a contained, formulated substrate.
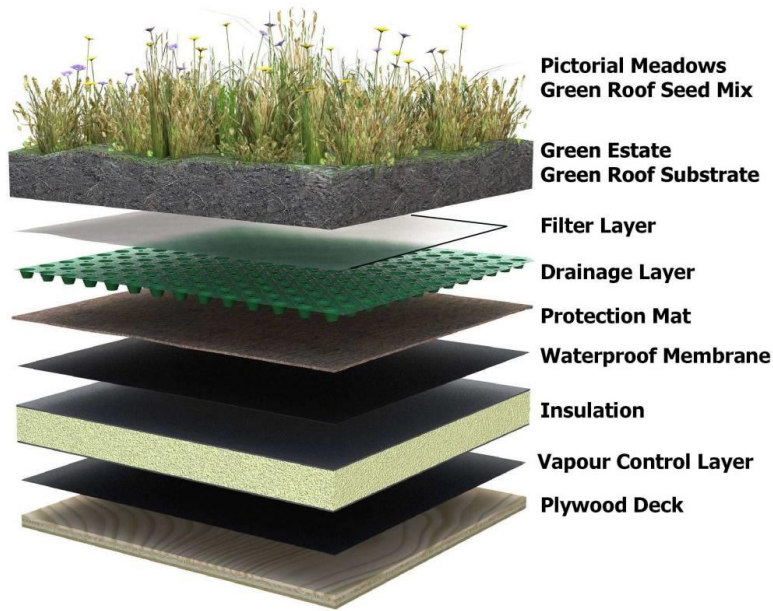
Figure 1. Construction of a green roof. (greenerheights.wordpress.com)

Subsequent underlayers include a barrier limiting invasive root growth, a drainage layer to accommodate excess wetness and a waterproof layer to prevent seepage into the building. These requirements raise the need for use of materials with the least weight. Consideration must be made so that the roof structure will support the weight of the growth containers. Slope, wind, temperature, and water runoff also are to be considered in the design of the roof. The following discussion addresses published findings pertinent to amendments for green roof growth substrates.

Dunnet and Kingsbury (2004) provide a basic examination of the processes behind a successful green roof system, as well as presenting the requirements for living walls. This review focus on the "components of green roofs" (Dunnet and Kingsbury, 2004) with attention to growth substrates and water supply through controlled irrigation, but also with uncontrolled

additions by precipitation. They highlight why standard topsoil is ineffective and special formulations are required.

Typical green roof substrate materials include: pumice, brick, sand, topsoil, water, lava, perlite, vermiculite, zeolite, and expanded materials. The expanded materials are expanded clay, expanded shale and expanded slate. The process of "expanding" involves heating to high temperature the parent material of clay, shale, or schist so that gases in the material expand and create pores in the material. Consequently, expanded materials are lightweight, with pore spaces that can be filled to act as water reservoirs, which could contain soluble nutrients. The pore surfaces additionally increase available habitat for microbial communities that could promote plant health. Such channels would limit the impact of overwatering while lessening weight concerns. Kingsbury and Dunnet (2004) stress that the total weight of the whole infrastructure when wetted is the most important consideration when planning.

The issue of substrate weight is addressed in Panayiotis (2003) through examination of four materials. The goal of this study was to determine the benefits of a variety of soil amendments especially for weight reduction and an ability to maintain plant growth under defined irrigation conditions. The four growth substrates examined were 1) a sandy loam soil, 2) a sandy loam soil amended with urea- formaldehyde resin foam, 3) a sandy loam amended with peat and perlite and 4) peat amended with the urea - formaldehyde resin foam. The materials were placed in transparent pots 28 cm deep. The pots were expandable to allow for better growth as plant roots reached the edge of the pot wall. The initial pot diameter was 20 cm with expansion in 10 cm increments up to 50 cm. The study with 60 *Lantana camara* plants involved measurements of shoot length, number of shoots, number of buds and flowers and the diameter of the main shoot.

The urea-formaldehyde resin foam was added to reduce bulk density. A target of 17 %, reduction was shown to be the best option for the green roof application. The peat/perlite mix provided the best growth at the lightest weight, reducing bulk density by about 24 %. However, the best plant growth resulted from the unamended sandy loam soil and the sandy loam amended with the foam. Unfortunately, because the sandy loam soil had a high bulk density, its use was not an effective option as a green roof substrate. So, although the lighter substrates reduced bulk density they did not grow plants as well as more traditional materials under the conditions of this study. Thus, this study again shows that some amendments can be detrimental.

The roof environment is challenging for plants. How the plants tolerate and recover from severe water stress is important. However, because the growth substrate for a green roof must be lightweight and well drained, it is likely that the plants selected will be able to adapt to conditions of low moisture. Bousselot *et al*. (2011) sought to broaden the spectrum of plants available for green roof use. At the time of their study, succulents, especially species of *Sedum,* were the most common plants for green roofs. *Sedum* sp. cope well with water limitations due to their ability to close stomata during hot and dry periods to reduce water loss. However, the authors pointed out that increasing plant diversity on green roofs would be beneficial, both aesthetically and functionally. The authors also discussed that there is a need for a more diverse palette of plants for green roofs. Such plants should be adaptable to a variety of climatic conditions, such as those of the western states of USA.

The authors examined the ability of 15 potential green roof plants, both herbaceous and succulent, to tolerate and grow in increasing levels of dryness plus their ability to recover after a period of dryness. The project used a substrate composed of expanded shale, sphagnum peat moss, perlite and vermiculite. The study examined 24 plants of each species which were planted

in containers and established for 10 weeks in a greenhouse before being exposed to drought stress.

The volumetric moisture content (VMC) of the growth substrate was taken daily for each container using a ThetaProbe until the VMC value remained constant at about 18 days after initiation of the dry down period. Once the top of the plant had died back, the plant was rehydrated to determine whether the plant had gone into dormancy or had died. If plants did not die during the length of the study, they were watered again to evaluate their revival rate after the extended period of drought. There was no clear distinction between succulent and herbaceous plants in the dry down curves. However, the substrate supporting succulents generally retained more moisture than when planted with the herbaceous plants, i.e., water use was lower for the succulents than the herbaceous plants. Succulent plants retained viable foliage about five times longer than herbaceous plants at the end of the dry down period, and were twice as likely to revive on rehydration. These finding illustrate the difficulty in identification of aesthetically pleasing plants with adaptions to survive under periods of low water supply.

To assess effective plant growth on the roofs it can be valuable to examine the leaf area of the plants as they grow over a season. Bousselot *et al*. (2011) examined the leaf area in a green roof setting by using a digital image analysis program: SigmaScan Pro 5.0. The project examined six different species of plants and compared data from physical measurements with that of the digital imaging analysis. Species evaluated were *Antennaria parvifolia*, *Bouteloua gracilis*, *Delosperma cooperi*, *Eriogonum umbellatum*, *Opuntia fragilis*, and *Sedum lanceolatum*. *E. umbellatum* was not recommended from the study because of poor overwintering. However, the other five species were good candidates for green roof analysis because they grew throughout the study.

Digital image analysis involved adjusting images to remove the background and calibration with the ruler in each photograph. The accuracy of such findings was reported to be greater than for physical measurements. The authors concluded that digital image analysis is a reliable substitution for physical measurements and can also be helpful in determining biomass accumulation.

Significant research has also been done at Michigan State on topics ranging from watering practices for green roofs (Durham *et al* 2006), impact of the depth of the substrate (Durham *et al* 2007), to the impacts of stormwater retention (VanWoert *et al* 2005). Research from these areas has helped to bring green roofs a lot more popularity in many regions as the research has been able to examine them from a wide variety of angles.

1.5 Expanded Shale

Inorganic amendments hold a strong place in amendments for both green roof, container and landscape applications. Expanded shale is lightweight, possesses large water-holding pores and has permanence in the substrate. Because transportation is a very significant cost concern in landscape management, the use of an amendment that is low in mass is commercially attractive (Ferguson, 2005). Expanded shale, clay, or slate, termed ESCS, have been used in permanent landscape structures since the 1980s. Ferguson examines throughout his book, "*Porous Pavements*," the role that such ESCS can play in urban landscape amendments. ESCS have greater porosity than most other expanded substrates. Thus, ESCS is a common component of planting media because of its ability to aerate and hold water in the soil substrate. Some varieties of ESCS also have a high, cation exchange capacity (CEC), thus having high potential to function as reservoirs for mineral nutrients for the plants.

Expanded products are potentially very useful amendments especially for poor-draining, clay soils. The poor hydraulic conductivity of fine clay soils is a factor to be improved to maximize plant growth. Mechleb *et al*. (2014) examined the effects of expanded shale on hydraulic conductivity in clay deposits from Austin, Texas. The expanded shale was non-toxic and inert, lightweight, inorganic and durable and with the potential to aerate soil for better root development. The fact that the expanded shale had half the density of more traditional fill materials was an attractive feature.

The researchers worked with three types of soils that varied in swelling with applied water: 1) a non-swelling clay soil with a plasticity index (P.I.) under 20, 2) a swelling clay soil with a P.I. between 20-35 and 3) a swelling clay soil with a higher P.I. over 35. The effects of amendments with expanded shale were contrasted to controls of limestone additions. The amendments were added at rates between 0 % and 50 % by volume. Prior to the experiments the clay soils were air dried, sieved in a 4.75 mm sieve and mechanically crushed before being compacted into rigid wall permeameters to perform the test.

Overall, hydraulic conductivity improved with increased expanded shale amendments for all three soil types. The authors found that the 35-50 % rates of ES amendment significantly increased the hydraulic conductivity of the three clay soils. The interpretation of these studies is that addition of expanded shale theoretically could improve drainage of a compacted clay soil. Improving drainage would reduce water logging and, thus, enhance oxygen supply to plant roots as well as promoting root penetration. While the amendment with limestone also improved hydraulic conductivity, it also decreased the bulk soil density of the sample to a greater extent than the ES. Mechleb *et al.* (2014) concluded that this successful laboratory test should be followed by *in-situ* field tests.

The geotechnical properties of expanded shale have been utilized in the construction industry before its development as a soil amendment. The strength and weight of expanded shale is compared to traditional structural materials by Stoll *et al.* (1990). Compression tests were performed on both "loose" and "compacted" samples to determine whether compaction would improve or reduce the structural integrity of samples of five different types of expanded shale derived from shale, clay or slate from sources within the United States. The authors concluded that although the expansion process lowered density, resistance to pressure was not reduced. This tolerance to pressure is an important feature contributing permanence to the changes endowed in an amended soil.

As mentioned by Ferguson (2005), some expanded materials have a higher CEC and thus higher nutrient storage capacity than others. The moisture and nutrient storage capacity of calcined expanded shale is the focus of research by Sloan *et al.* (2011). These authors examine the physical properties of expanded shale in the context of its use as a soil amendment, whether in-ground or in containers. Previous work by Sloan *et al.* 2010 and Forbes *et al.* 2005, showed the inorganic expanded shale is inert in its reactivity with plants or soil chemistry, plus its prolonged structural integrity justified the study. The effects of expanded shale amendment on soil pore water were evaluated with measurements of pH, electrical conductivity (EC), element dissolution, calcium carbonate equivalent (CCE), water uptake, maximum water holding content, water adsorption rate, and nutrient release after fertilizer treatment and bioavailability of adsorbed nutrients.

Sloan *et al.* (2011) measured EC by suspending expanded shale with particle size of 1-6 mm in deionized water for 60 min. The resulting suspensions had EC value of 1.6 dS m-1, which would have little effect on plant growth, where the threshold value is < 2 dS/m. Thus, the amendment of expanded shale to soil or to a potting substrate does not elevate salinity. The pH

of the expanded shale suspension was 8.25, showing that Ca, Fe, Mg, K and Na would be present as hydroxides but at levels that would not affect substrate pH. However, the pH of the suspensions likely would vary with sources of the shale (Sloan *et al.* 2011). Release of soluble levels Ca, Fe, Mg, K and Na from the ES were negligible.

At room temperature, the expanded shale accumulated 15 % of its weight as water within 10 minutes, with an increase to 20 % in 2 hours. Subsequent uptake slowed to a maximum of 36 % at 150 hours. Most of this water, about 80 %, was held in large pores but with a low surface tension making it easily available for root and microbial uptake, but also susceptible to evaporation. However, approximately 16-21 % of the water was held in smaller pores. Although the pore size was not provided, the ES used had pores that were well dispersed across the particles' surfaces (Sloan *et al.,* 2011).

Sloan *et al.* (2011) found that the expanded shale functioned as an effective slow-release source of fertilizers. The expanded shale absorbed soluble P from a solution containing three forms of N, NH_4^+, NO_3^- and urea, as well as P and K. This nutrient-loaded expanded shale was incorporated into planting media with ratios of 100:0, 75:25, 50:50, 25:75, and 0:100. The expanded shale was covered with a thin layer of acid-washed sand. The amount of P, measured as the phosphate ion, released from the loaded particles decreased linearly with extractions and K. Growth of lettuce in the nutrient-soaked expanded shale was supported for 45 days before additional fertilization was required. Both the shoot and root mass of lettuce increased with higher doses of the fertilizer-treated expanded shale. These findings demonstrate that the amendment with expanded shale allowed slow-release fertilization and acted as a water reservoir in soil and soilless media.
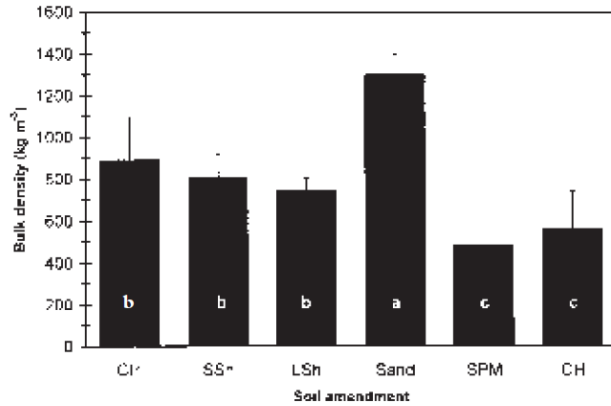
Fig. 2. Effect of 1 to 3 mm (0.039 to 0.118 inches) small diameter expanded shale (SSh), 3 to 6 mm (0.118 to 0.354 inches) large diameter expanded shale (LSh), sand, sphagnum peatmoss (SPM), and cottonseed hulls (CH) on bulk density of Austin silty clay (Ctrl) soil 7 months after application. Columns with the same letter are not statistically different at $P = 0.05$, n = 6; 100 kg·m^{-3} = 6.2 lb/ft^3.

Figure 2. Effects of different amendments on bulk soil density. Figure is from Sloan *et al.* (2011) Moisture and Nutrient Storage Capacity of Calcined Expanded Shale 2011. Performed by flushing with clean water. The release of P was much slower than the release of N.

In an earlier paper, Sloan *et al.* (2002) examined the effect of particle size of the expanded shale as an in-ground soil amendment. For two growing seasons (1997 – 1998) they used 1 m by 1m plots of an Austin silty clay soil (haplustoll) amended to 15-cm depth with two small sizes of expanded shale, 1-3 mm and 3-6 mm, large size expanded shale, or quartz sand, or sphagnum peat moss or cottonseed hulls. A winter crop of 'Crown Azure Blue' (Pansy Viola wittrockiana Crown 'Azure') pansies was grown from December to June followed by a planting of scaevola, 'New Wonder' (Scaevola aemula 'New Wonder'), from June to November.

Plants were rated on growth, foliage quality and bloom quality. Plants received a complete (21:3.1:11.6) fertilizer treatment at the beginning of each planting. Plants were watered by hand as needed because the natural rainfall provided most of the watering requirements.

They found, as shown in Fig 2, that there was no effect of the shale on bulk density of the soil, although this was increased by sand and reduced by the moss and cotton seed hulls, An ideal bulk soil density is between 1100 to 1300 kg/m^3 and the unamended soil had a density

about 900 kg/m^3. Although there were changes to the soil density there was no consequence to the root growth for either the pansies or scaevola.

The experiment assessed pansy root weights and above-ground biomass at the end of each growing season. Although none of the amendments had a sizable effect on pansy foliage or pansy bloom, the smaller diameter expanded shale and sphagnum peat moss decreased pansy nitrogen content the first year, although not in the second. However, the authors suggested that this result was in part could be due to high rainfall in the first season potentially leaching some of the available soluble nitrogen. The larger diameter expanded shale significantly improved the survival rate of the transplanted scaevola plants and the quality of the blooms during both growing seasons. There was no significant impact on blooms for the pansies.

They concluded the larger diameter expanded shale most consistently improved overall plant performance (survival, bloom and biomass) more than all other amendments. It is possible that the expanded shale improved the ability of the roots to gather resources such as water and oxygen sufficiently to help this generally sensitive plant perform better. The authors concluded that soil amendment with expanded shale could be effective in highly visible and intensively utilized planting beds, those that are replanted every year. The benefit of expanded shale in comparison to its organic counterparts was in its comparative permanence in the ground; expanded shale does not degrade over time like organic amendments and, thus, would retain effectiveness for long-term plantings.

Sloan *et al*. (2010) examined expanded shale as a lightweight amendment in a greenhouse setting with four different other complex organic matter amendments. The authors highlight the problem that organic-based soilless media can result in nitrogen deficiencies due to a high carbon: nitrogen ratio. To assess the feasibility of expanded shale as an addition to these organic

materials the authors used four different treatments: 1) 75 % bark + 25 % Sphagnum Peat Moss, 2) 50 % bark + 50 % biosolids, 3) 100 % municipal waste compost and 4) 65 % bark + 35 % cottonseed hulls. They blended expanded shale with each mixture at rate of 0, 15, 30 and 60 % vol. by vol. The expanded shale used in the study had a negligible Cation Exchange Capacity, (2.8 cmol kg).

The study examined three different plants: vinca (*Catharanthus roseus*), verbena (*Verbena hybrida*), and shantung maple (*Acer truncatum*), by their growth in #1 containers filled with each growth substrate; each treatment was replicated four times. After planting each pot received a 14:6.1:11.6 fertilizer treatment. The plants were watered based on water content in the upper 2 inches of each growth medium.

Assessment of the physical properties showed that the expanded shale increased the bulk densities of each organic-based media. The authors discuss that the addition of expanded shale brings these media to a density that is higher than ideal for potting mixes but could be ideal when used for planters or raised beds outside.

The results of plant growth varied. Vinca showed a significant decrease in biomass and enhanced symptoms of chlorosis as the content of expanded shale increased in any of the substrate mixes. These findings suggested that nutrients became limited due to their sequestration into the pores of the shale particles and these effects were not offset by any of the organic materials. Effects on the verbena were mixed. Growth decreased in all treatments except for increases with the municipal compost waste containing additions of up to 30 % expanded shale. The authors posited that the expanded shale at this level of amendment increased the porosity of the compost to promote release and plant availability of soluble nutrients. Growth with the other three organic amendments was less affected by the expanded shale. Maple growth

did not change with the 15 % and 30 % expanded shale treatments but was decreased with the 60 % treatment. The inference was that the high expanded shale content reduced available nutrients and /or water to the maple.

These findings revealed there was a strong effect of the type of organic material used with the expanded shale. Supplements of biosolids or composted municipal waste outperformed the traditional bark and peat moss amendments. However there appeared to be an upper limit in the effective mixes with the potential for water and nutrient availability possibly being compromised. The inclusion of expanded shale with these organic substrates had no real advantage and was dependent on the mixture. The expanded shale was beneficial only when the material had insufficient drainage and aeration.

Conclusions

Soil amendments, whether organic or inorganic, can improve soil structure, hydraulic conductivity, and moisture retention. Some are also capable of reducing the weight of a growth substrate, with improved conditions for plant growth. Therefore, their inclusion in soils, whether in containers, on a roof, or in the landscape is an important facet of an approach to enhance plant performance under defined growth conditions.

CHAPTER 2: MATERIALS AND METHODS

2.1 Plant Selection

The primary criterion for plant selection was that they were typical of herbaceous perennials used by the public in Colorado for home landscape use in the intermountain west. Plants listed in the Plant Select® program (www.PlantSelect.org), have been proven to be well adapted to the region's climate and soils. Additionally, the plants chosen for this study from Plants Select® had to be successful in partial shade. The selected study site, on the north side of a greenhouse (Fig 1 A), would be partially shaded during the growing seasons. An initial planting of *Osteospermum* 'Avalanche' PP 22,705 (www.PlantSelect.org) , Avalanche white sun daisy, was unsuccessful. When transplanted, in fall 2015, from number one container grown stock plants which were very root bound in the container, they did not overwinter. Consequently, in spring 2016 *Penstemon x mexicali* P008S Red Rocks® penstemon (www.PlantSelect.org) (Figure 3) was used as a replacement. This plant complemented the *Heuchera sanguinea,* 'Snow Angel' Snow Angel coral bells (www.PlantSelect.org) that had survived transplanting in fall 2015 and successfully overwintered (Figure 3). Both plants do well in partial shade and low water conditions (Pretty Tough Plants, 2017).

Figure 3. Examples of the flowering stage of the *Penstemon x mexicali* and the *Heuchera sanguinea* used in the study.

Snow Angel coral bells (*Heuchera sanguinea* 'Snow Angel') is a low-growing mounding perennial that has variegated green and white leaves. The plant excels in climates with variability in rainfall and is hardy in USDA zones 3-9 (Pretty Tough Plants, 2017). Pink/red flowers form on spikes from late spring into the summer (Fig. 3). They are also attractive to a variety of pollinators, such as moths and hummingbirds, and in this experiment provided excellent shelter to a few resident toads.

Penstemon x mexicali, Red Rocks® 'P008S', (Red Rocks penstemon) (Pretty Tough Plants, 2017) is a hybrid *Penstemon* selected from crosses between Mexican and American species. It blooms in June with continual flowering through the rest of the season upon deadheading. The plant reseeds readily, and the dead shoots can be cut back for visual appearances and to promote new growth after overwintering. This particular *Penstemon* tolerates a wide variety of growth conditions in USDA hardiness zones 4b-8. The plant has attractive red colored flowers that attract a variety of pollinators (Kimball and Wilson 2009) (Fig 3).

2.2 Site characteristics.

The study was designed to test the effect of soil amendment with expanded shale on a site that represented home owners' landscape and care. A site that mimics a less than optimal landscape features was used. The study was established on the north side of a greenhouse at the Colorado State University (CSU) Horticulture Center located at 1707 Centre Avenue, Fort Collins, Colorado (Fig. 4 A and Fig 5). The USDA hardiness zone for the site is Zone 5b: -15°F to -10°F. The site is a strip of landscaping soil abutted with a pavement that was adjacent to a road. There was a slope of approximately 10% at its most extreme from the pavement down to the level of the greenhouse (Fig. 4 A).

Figure 4. Images from plot site. (A) Image of plot on north side of greenhouse with irrigation in progress. (B) Image of plots designated with colored lines. (C) Image of plot soil amendment with a layer of compost before incorporation into soil.

2.3 Soil and weather characteristics at site

Soil samples were taken prior to any amendments in October 2016 to assess soil texture, pH and chemistry. Soil samples were taken from the center of each replication of each treatment, the treatments were thoroughly mixed together. Additionally, the October 2016 soil samples were assessed for soil-pressure moisture release data. Soil moisture measurements were taken on site for each plot using a ThetaProbe moisture meter (Delta-T Devices Ltd., Cambridge, UK), from a position in the middle of each plot. Two measurements were taken and values averaged

per plot. Measurement of soil moisture was recorded in October 2016, resumed in June 2017,

and continued weekly through September 19th, 2017.

Climate data was retrieved from the archives of the Western Climate Center and values

for precipitation and air temperature for the growing seasons of 2016 and 2017 are shown in

Table 1. The 2016-2017 winter was dry and windy.

Table 1. Precipitation and air temperatures at the plot site during the growing seasons. Weather
data from: https://wrcc.dri.edu/cgi-bin/cliMAIN.pl?co3005

2015		2016		2017	
Precipitation	**Average daily temperature C**	**Precipitation**	**Average daily temperature C**	**Precipitation**	**Average daily temperature C**
November: 2.24 cm	2.78	April: 6.99 cm	9.4	April: 5.38 cm	10
December: 1.63 cm	-1.67	May: 4.67 cm	12.2	May: 11.28 cm	13.9
		June: 0.13 cm	21.7	June: .36 cm	20.6
		July: 2.31 cm	23.3	July: 2.41 cm	23.9
		August: 1.93 cm	21.1	August: 6.04 cm	20.6
		September: .48 cm	17.8	September: 5.31	17.2
		October: .79 cm	13.3	October 4.27 cm	9.8
		Total:17.3 cm		**Total**: 35.41 cm	

2.4 Site Establishment

Site establishment began in October 2015 by marking out the plots in the research area

with spray paint and using string secured down by garden staples (Fig. 4 A, B). The final plot

sizes measured 2.4 m long by 1.7 m wide and reached a total length of 37 m long by 3.4 m wide.

Digging of the compacted clay soil began on October 12, 2015 and required two weeks for

completion. The heavy soil compaction was the result of recent construction at the site. Digging

in Fall 2015 to mix the soil for the plots was aided by fall rainfall after a hot and dry summer (see Table 1). Digging was performed by hand to a 45 cm depth. An irrigation system was already installed that precluded deeper digging.

2.5 Irrigation

Precipitation at the site differed monthly and between the two years of the study. Noticeable was the much higher levels of rain in Aug, Sept and October in 2017, totaling almost 16 cm versus 2 cm in 2016 (See Table 1). In anticipation of inconsistent rainfall, water supplied to the plant was supplemented by an irrigation system. This practice also would be expected for homeowner's landscapes. The installed irrigation system allowed even water distribution through Rainbird (Rainbird Corporation, Azusa, CA USA) pop-up sprinklers (Fig. 4 A). The frequency of watering was regulated and monitored. During the 2016 growing season, the sprinkler system provided water every other day for two 8 min intervals. Watering started in April 2016 and stopped in late September 2016. In 2017, the sprinkler system was on the same time frame throughout the cool and moist spring, starting in April and stopped mid-September. A subsequent rapid increase in temperature in the first week of June resulted in watering for three cycles of 8 minutes every other day. Irrigation began in May 2016 and ended in late September 2016. For the 2017 season irrigation began in April 2017 and ended in late September 2017.

2.6 Site summary

The site used for the studies mimicked a householder's landscape: a site with a slope, northern exposure with partial shade, an automated irrigation system and growth of ornamental flowers. This site was created with soils initially compacted due to construction.

2.7 Soil amendments

The plots were designed to test the effects of expanded shale amendments on plant performance. The expanded shale used in this study was from Trinity Shale and Clay in Golden, Colorado (Fig. 6).


Figure 5. The expanded shale used in the plot amendments.

Research performed at Texas A&M (https://aggie-horticulture.tamu.edu/newsletters/hortupdate/hortupdate_archives/2003/nov03/Expdshale.html) reported that 3 inches (7.6 cm) of shale incorporated with 3 inches (7.6 cm) of compost was most beneficial. However, because many landscapers and homeowners are under budget restraints, we examined the effects of lower amendment levels. The following six treatments, 1-6 (Fig. 5) for the clay soil were:

1) 0 cm of expanded shale and 5 cm of compost (0 ES: 5 C)
2) 2.5 cm of expanded shale and 5 cm of compost (2.5 ES:5 C)
3) 5 cm of expanded shale and 5 cm of compost (5 ES:5 C)
4) 7.6 cm of expanded shale and 5 cm of compost (7.6 ES:5 C)
5) 5 cm of expanded shale only (5 ES:0 C)
6) 7.6 cm of expanded shale only (7.6 ES:5 C).

The compost was a commercial blend, Organics from Platteville, Colorado, and contained a mixture of poultry manure, sphagnum peat moss, composted wood chips and a small amount of pumice. Fig. 4 C shows a plot spread with compost before manual incorporation.
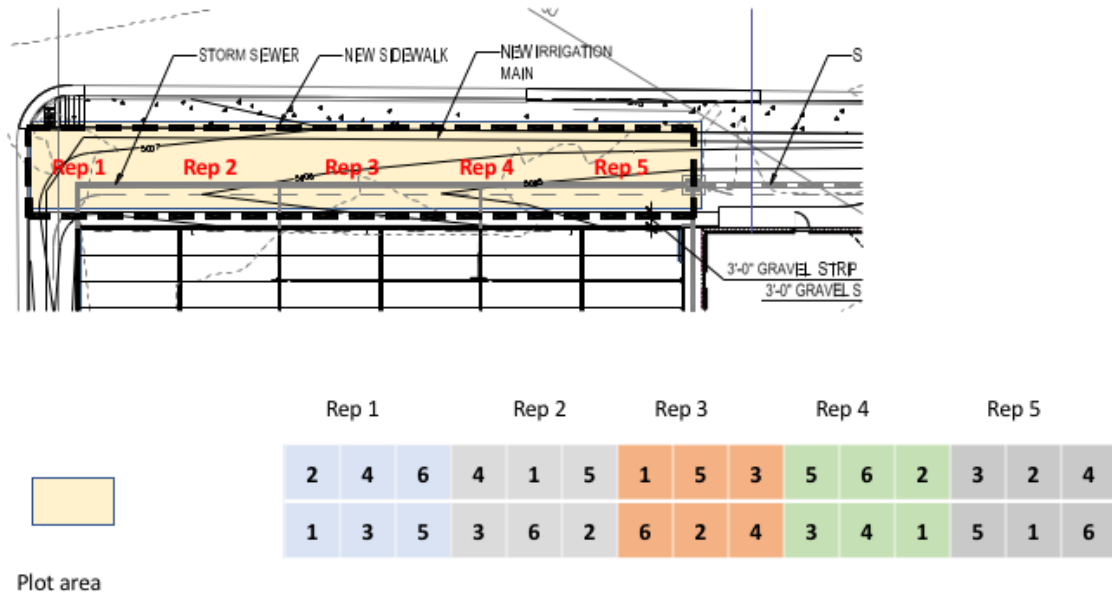
Figure 6. Site plan showing replication and treatment positions.

The quantities of amendments necessary to achieve the desirable treatment amounts were derived from use of the online calculator from the University of Minnesota (http://www-users.math.umn.edu/~white004/personal/compost.html).   An input of the area of soil to be covered and the depth of the amendment provided the cubic yard measurement. Six cubic yards of compost was delivered and incorporated into soil at the relevant quantities for the treatments. Thus, for a treatment with 5 cm compost, 0.3 cubic yards of compost per plot was added by manual transfer from ten 19 L buckets. The compost was spread on top to an even layer before being dug 30 cm deep into the prepared soil profile. A total of 7.2 cu meters of expanded shale needed for incorporation with 4.5 cubic meters arrived on November 6th and 2.7 cubic meters on

November 9th. Treatments with 2.5 cm expanded shale needed 0.09 cubic meters of expanded shale/plot. The 5 cm expanded shale plots received 0.2 cubic meters and 7.6 cm expanded shale used 0.31 cubic meters. The expanded shale was measured and spread evenly over the soil surface before being incorporated 30 cm deep. Each of these treatments had five replicates in a randomized complete block form. The treatments and plot design were determined after consultation with a statistician at Colorado State University. The site plots are illustrated in Figs. 4 and 5.

Each plot received the same fertilization so that it was not a variable within the experiment. The plants were fertilized once at a medium rate in June 2016 with a standard 10 N-10 P-10 K Osmocote granular slow- release fertilizer (The Scotts Miracle-Gro Company Marysville, OH USA). No fertilizer was applied in the 2017 growing season.

2.8 Planting Dates

On Monday November 16th, 2015, 60 *Osteospermum* Avalanche and 60 *Huechera sanguinea* Snow Angel, a total of four plants, two of each variety, were transplanted into their designated sites within the plots with the six different soil treatments (Fig. 5 and Fig 7). The *Osteospermum* were large, established plants in number 1 pots and the *Heuchera* were in 10 cm pots. At planting, the *Osteospermum* were observed to be heavily rootbound and, thus, attempts were made to break up the roots before transplanting into the soil. Two of the *Osteospermum* plants were already dead.

Figure 7. Study site on the north side of the greenhouse showing partially planted plots in fall 2015.

Each plot received two of each plant taxa (Fig. 7). Likely due to the late planting date, early freezing temperatures and poor root structure, over 50% of *Osteospermum* plants died during the winter of 2015/2016. Consequently, these plants were removed in early April 2016 and were replaced with 60 *Penstemon x mexicali '*Red Rocks' plants. These established healthy plants were grown in 10-cm pots and were not root bound or overgrown.

2.9 Plant growth: site measurements

Plant growth during the 2016 and 2017 growing seasons was measured by two different methods, physical measurements and digital imaging, on the calendar dates shown in Table 2. This time table was designed so that these were two methods to assess plant growth were performed each month.

Table 2. Calendar Dates for Physical and Digital Measurements of plant growth

Physical Measurements		Digital imaging	
2016	**2017**	**2016**	**2017**
April 24	April 25	May 21	May 9
May 21	May 21	June 7	June 3
June 21	June 16	July 4	July 1
July 18	July 14	July 30	July 30
August 13	August 12	August 24	August 26
September 9	September 9	October 7	September 9

.

Each method for growth assessments was performed once a month, alternating between physical measurements and digital imaging every two weeks. The first physical measurements were taken April 24, 2016 and April 25, 2017 with final measurements being taken September 9, 2016 and September 9, 2017. Two widths and one height physical measurements were obtained for each plant. The width measurements were always taken parallel (East-West) to the greenhouse first and then perpendicular to the greenhouse (North-South). They were taken to assess the overall widest part of the plant.

The second assessment of growth involved digital determination of the green leaf area for each plant. Digital images were recorded two weeks after the physical measurements on the dates shown in (Table 2). The digital imaging technology, Easy Leaf Area, developed at University of California at Davis was used as the software to generate relative values of the green leaf area (http://www.plant-image-analysis.org/). This program uses 4 x 4 cm red square to calibrate the number of pixels within a defined area of the digital image to normalize the

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measurements of green leaf area obtained from the plants. The digital overhead images of the plants were generated using a FujiFilm FinePix S3000 (6x optical zoom 3.2 mega pixels lens) camera mounted on a Bogen Manfrotto 190xprob tripod. Each field of view showed the whole plant, a ruler, a card with the plant identification (treatment, plant #) and the 4 cm by 4 cm red calibration square (Fig. 8). The height of the tripod was adjusted to accommodate these items. Before imaging all weeds were removed from around the plant. All images were stored in the software computer files that were Excel compatible.

Figure 8. Images showing the visual data imported into the Easy Leaf Area Program for both *Heuchera* and *Penstemon* plants for one sample date, July 30th, 2016.

Accurate assessment of the green leaf areas of each plant through the Easy Leaf Area software required modification to the raw digital images. First the photographs were sorted by plant type *Heuchera* or *Penstemon* for each two-week period. Due to variability in the natural light, from intermittent sunlight and shading from the greenhouse, and the slope of the plot where photographs were taken, the color and extent of recognition of the calibration pixels recorded from the red squares was inconsistent. The program struggled to effectively pick up the total pixels in the calibration square with its block of 4x4 red color. The problem also was problematic once the plants bloomed, as both plants had pink flowers. Therefore, each of the

photographs was cropped to fit around the plant and the red square was evenly colored with the program paint.net. For the *Penstemon*, because they had an even dark green leaf, only the modification of the red square was sufficient to get pixel values indicative of the leaf areas. For the *Heuchera*, the plant leaves were pale green with cream to white leaf variegation. Thus, initially when using the Easy Leaf Area Program with the raw digital images of the *Heuchera* plants, no consistency in leaf area readings was observed because of problems with recognizing the leaf green color accurately. Consequently, the paint.net program was used to recolor the *Heuchera* leaves in each photograph with green so all leaves would be recognized as green by the Easy Leaf Area program. This manipulation of each *Heuchera* plant for green leaf color plus the modifications to the calibration square generated leaf surface areas that were acceptable with the Easy Leaf Area software.
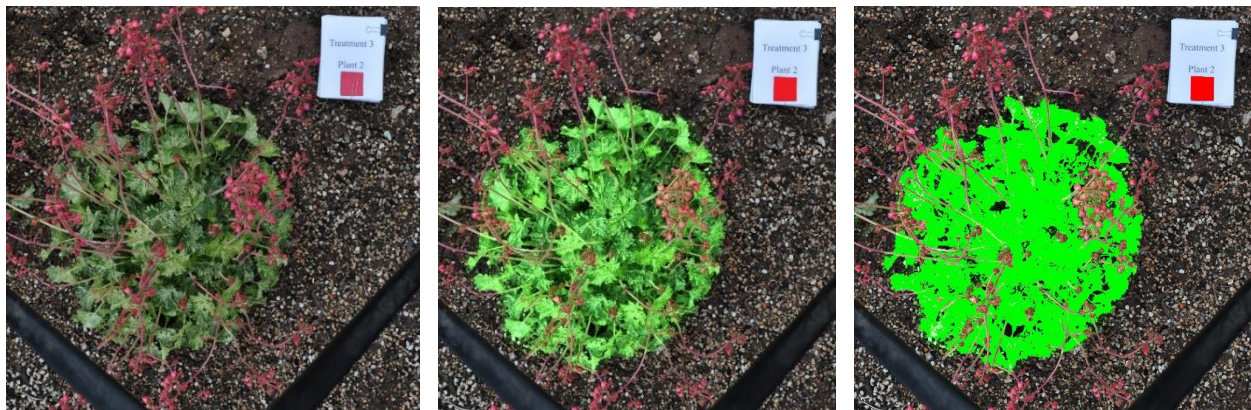
Figure 9. Photographic manipulation of red calibration square and leaves to get a reliable analysis result. First photo is unaltered. Second had red square and leaves uniformly colored. The final photo shows the results after Easy Leaf area analysis.

2.10 Plant destructive harvest

In March 2017, the tops of the *Penstemon* were harvested by cutting 5 cm above the soil line, bagged and dried to determine any growth differences via dry weight between the soil amended treatments. No green material already being produced by *Penstemon* was removed. No

plant material was removed from the *Heuchera* plants at the onset of 2017 growth. Flower stalks from 2016 were removed in July 2016.

On October 27, 2017 growth of both plant taxa was terminated. The tops were harvested and placed into paper bags to be dried and weighed. For the *Penstemon,* the tops were cut by hand at soil level with hand pruners. The *Heuchera* was cut with hedge clippers also at the soil level. The root systems were dug carefully for all plants, *Penstemon* on November 3rd, 2017 and *Heuchera* on November 4th, 2017. The amended soil in each plant root area was loosened by carefully digging to about 25 cm depth around the circumference of a 60-cm diameter hoop placed over each plant. The roots were carefully lifted. Cutting of the roots by the spade and root breaking upon lifting was not an observed problem. The soil was friable, and soil particles adhered to the roots came easily off the roots so that no root washing was necessary. Root samples were tagged and placed into paper bags. Samples were all dried in a Despatch v-series drying oven (ITW EAE, A division of Illinois Tool Works, Inc. Lakeville MN USA). Dry weights were determined for both the roots and tops of the plants after drying the materials in the oven for 48 hours at 70 °C and weighing each separately.

2.11 Statistical evaluation of data

The experiment was established with complete randomized block layout for the plants grown with six different soil treatments and five replications of the treatments. Statistics on the data generated in the study were run using SAS version 8.2 (SAS institute Inc., Cary, NC). Statistics were run using Proc Mixed, which is analogous to ANOVA, using Least Square Means and Type 3 test of mixed effects. The analysis was performed using t-tests ($\alpha = 0.05$) for a comparison of means to show differences in plant growth between treatments for either the *Penstemon* or the *Heuchera* plants. Means for the growth measurements, the leaf areas and dry

weight data were averaged for the plants grown with the same treatment from each plot. The

standard error bars indicate a 95 % confidence interval for the mean.

2.12 Soil texture and chemistry

Analysis of the compost confirmed that this slightly acidic mix was high in organic

matter (OM) and trace-metal cations, and K (Table 3). Addition of the compost to the soil for

four treatments increased the level of OM as anticipated. The OM value of the soils in two

treatments amended only with expanded shalewas not higher than the OM of the control soil

(Table 3).

Table 3 Texture and soil chemical properties of soil and compost used at the site, treatments can
be read as level of expanded shale: level of compost.

Sample			Lime	%	--------------------ppm----------------------------							Texture
Treatment	pH	EC mmhos /cm	Estimate	OM	NO$_3$-N	P	K	Zn	Fe	Mn	Cu	Estimate
0 ES: 5 C	7.6	1.0	very high	5.3	0.9	120	348	8.9	50.1	12.2	2.8	sandy loam
2.5 ES:5 C	7.9	1.1	high	4.0	1.4	77.4	231	5.4	37.4	5.9	2.0	sandy clay loam
5 ES: 5 C	7.8	1.2	high	4.8	2.2	93.1	270	6.9	37.8	6.4	2.9	sandy loam
7.6 ES: 5 C	7.8	1.0	high	5.7	1.4	74.5	242	6.6	35.0	6.1	2.4	sandy clay loam
5 ES: 0 C	7.9	1.3	very high	3.0	11.7	91.4	266	5.0	31.4	4.3	2.3	sandy loam
7.6 ES: 0 C	8.2	1.1	very high	2.4	7.7	52.6	237	3.3	27.8	3.2	2.8	clay loam
Untreated	7.6	2.0	high	3.1	63.8	89.3	374	5.3	36.8	13.0	3.2	sandy loam
Compost	6.5	2.1	low	30.0	412	528	2415	40.7	174	34.3	5.5	Loam

Unexpectedly the texture classification of the original, unamended site as a sandy loam

were not indicative of problem clay soils, possibly because previous modifications to this site

had occurred to improve its potential use as a landscape site. The pH of the soils was slightly

alkaline consistent with the soil classification.

3.1 Soil moisture 2016 and 2017:

Treatments:
1) 0 cm of Expanded Shale and 5 cm of Compost (0 ES: 5 C)
2) 2.5 cm of Expanded Shale and 5 cm of Compost (2.5 ES:5 C)
3) 5 cm of Expanded Shale and 5 cm of Compost (5 ES: 5 C)
4) 7.6 cm of Expanded Shale and 5 cm of Compost (7.6 ES: 5 C)
5) 5 cm of Expanded Shale Only (5 ES: 0 C)
6) 7.6 cm of Expanded Shale Only (7.6 ES: 0 C)

Soil moisture (Fig. 9) for samples obtained 24 hours after an irrigation period *in situ* using the ThetaProbe moisture meter, showed variability with date and with treatments. The treatment with 7.6 cm ES and no compost (green bars) generally had the least moisture 24 hours after watering compared to other treatments. This finding would be consistent with greater water movement through the soil due to loss of compaction due to addition of expanded shale. The presence of compost alleviated loss of moisture at some of the sampling times. These measurements do not reflect the heavier rain periods experienced in July, August and September (Table 1) suggesting that none of the plot soils have problems with water retention. The measurements also show that soil moisture % approached wilting point with levels about 10 % for all treatments, July 15th, 2017. This wilting point threshold also was observed for the amendment of 7.5 ES:0 C with the October 2016 sample date. Overall these data values indicated that water availability was not a problem for the plants during the two growing seasons.
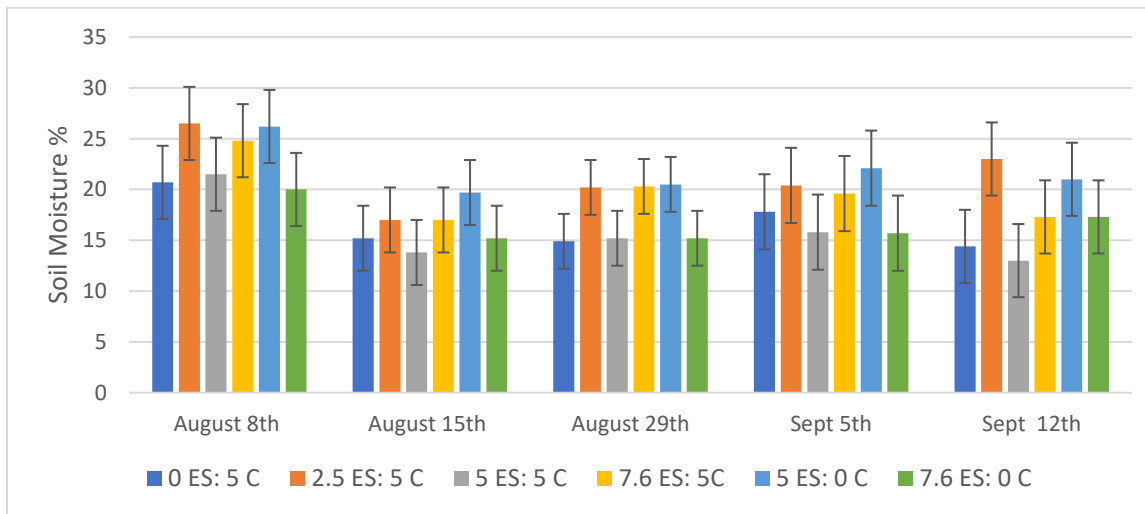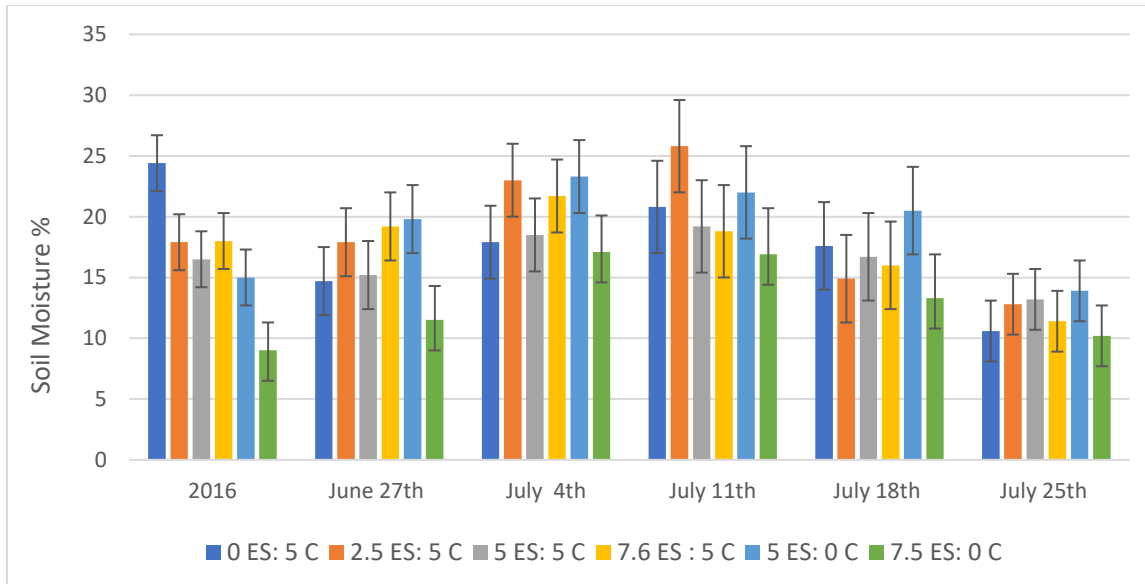
Figure 10. Soil moisture percentage from the plot areas. October 2016 and weekly readings June -September 2017. The soil moisture measurements were taken on site with a Theta Probe moisture probe for each plot using from a position in the middle of each plot. Two measurements were taken and the mean and standard deviations of these data are shown.

3.2 Soil moisture release curve

A soil moisture tension release study was performed to aid in understanding the influence of the expanded shale on water availability to the plants. The findings are shown in Fig. 10. The Bar value 0.1 corresponds to a water saturated soil and Bar 0.33 is field capacity. At Bar 15 permanent wilting point for the plants would occur. At field capacity, 0.33 bars, the highest

moisture was seen with the four treatments containing compost. Moisture % in the soils was consistently lowest in the treatments with ES at 5 and 7.5 cm amendments. At wilting point, 15 Bar, the soils with least moisture were those with only expanded shale amendments. Thus, the expanded shale aided in soil drainage whereas compost promoted moisture retention.
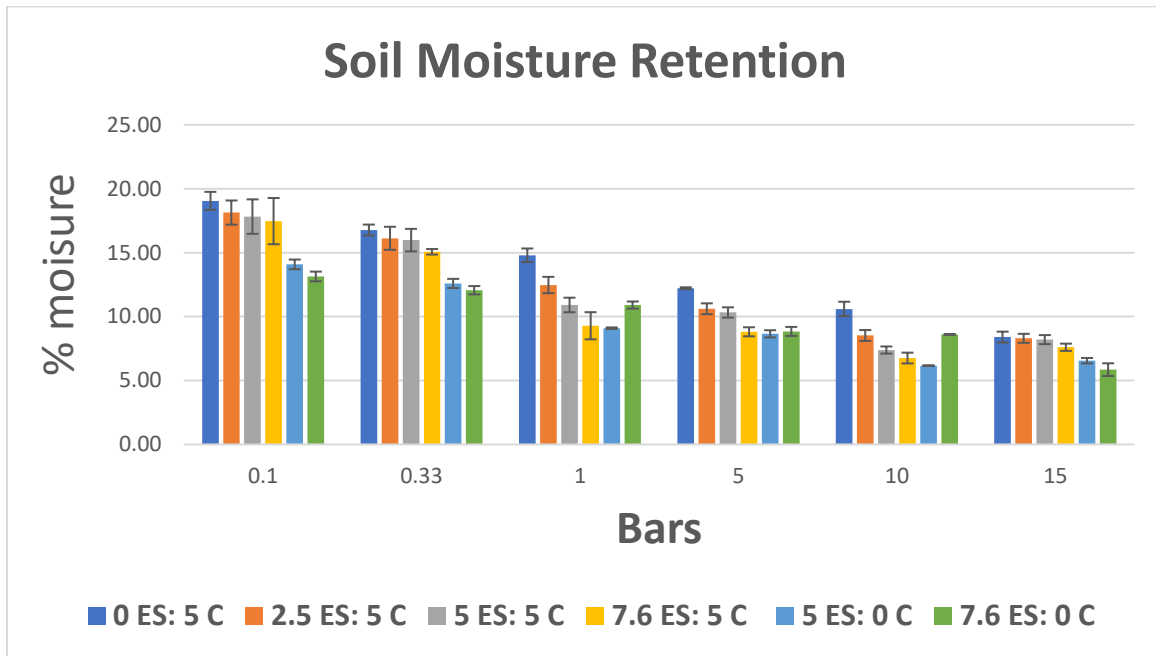
**Figure 11**. Soil moisture release curves determined by pressure plate technique. Pressures used were 1/10, 1/3, 1, 5, 10, and 15 bars.

3.3 Plant growth evaluation

Plant growth problems were observed in the outermost east and west plots at the site, due to uneven watering patterns and other problems such as slope and exposure. Replication 1 was at the western side of the building with the most direct exposure to an adjacent road. This replication had poor plant growth in comparison to the same treatments in reps 2, 3, and 4. Most likely this was due to increased exposure as the replication was not protected from wind and sun by the building as were the other replications. Plants also did not establish well in rep 5. The

slope of replication 5 led to problems with runoff after rain events and, to a lesser degree, after irrigation. The plants in these replications overwintered poorly and these plants grew more slowly in both seasons (2016 & 2017) than the plants in reps 2-4. Consequently, the west replication and the east replication were eliminated from the statistical analysis, meaning that data sets presented in the following sections are for replications 2, 3, and 4.

3.4 Plant growth: *Heuchera*.

In 2016, the *Heuchera* established from planting without any plant loss from overwintering 2015-2016. Their width increased steadily after May throughout the 2016 growing season (Figure 11).
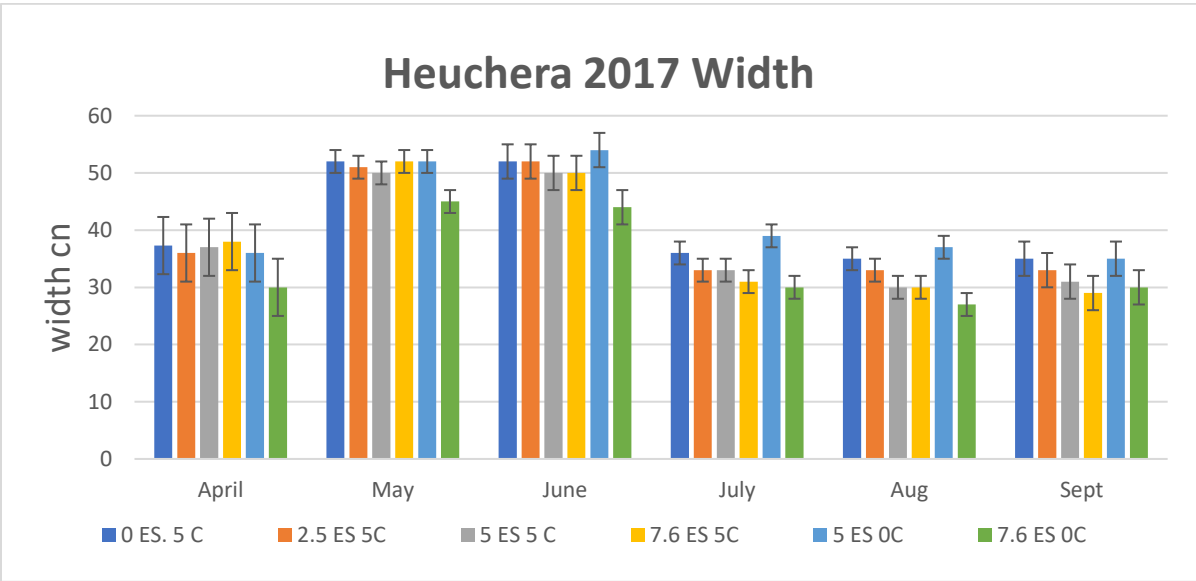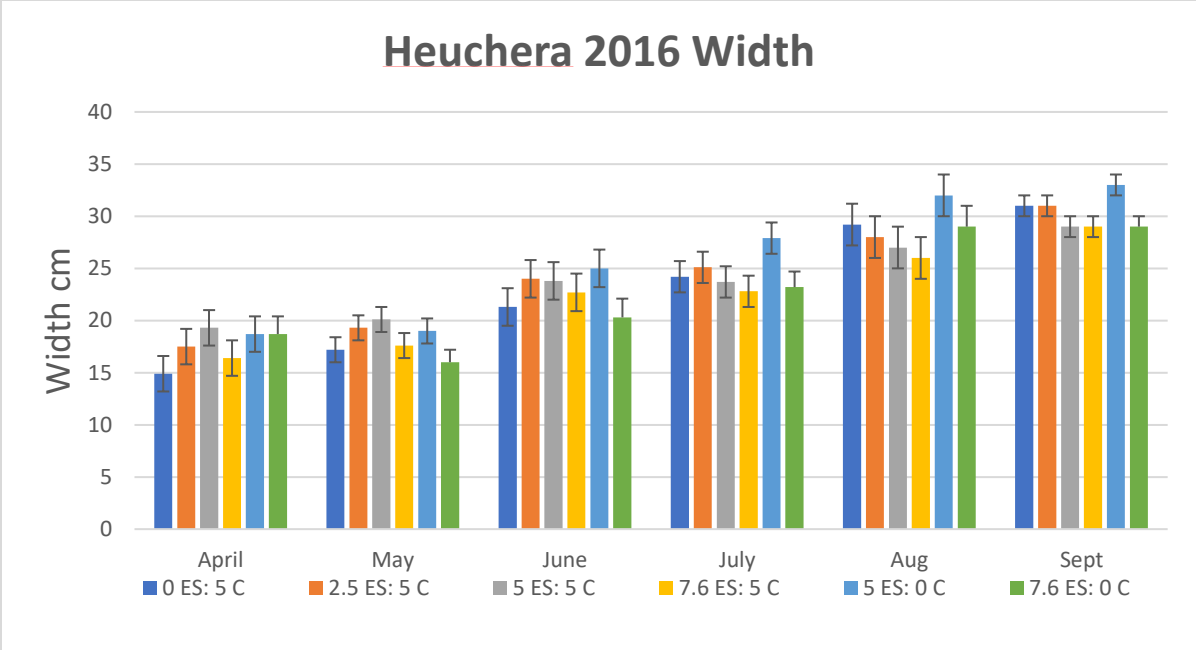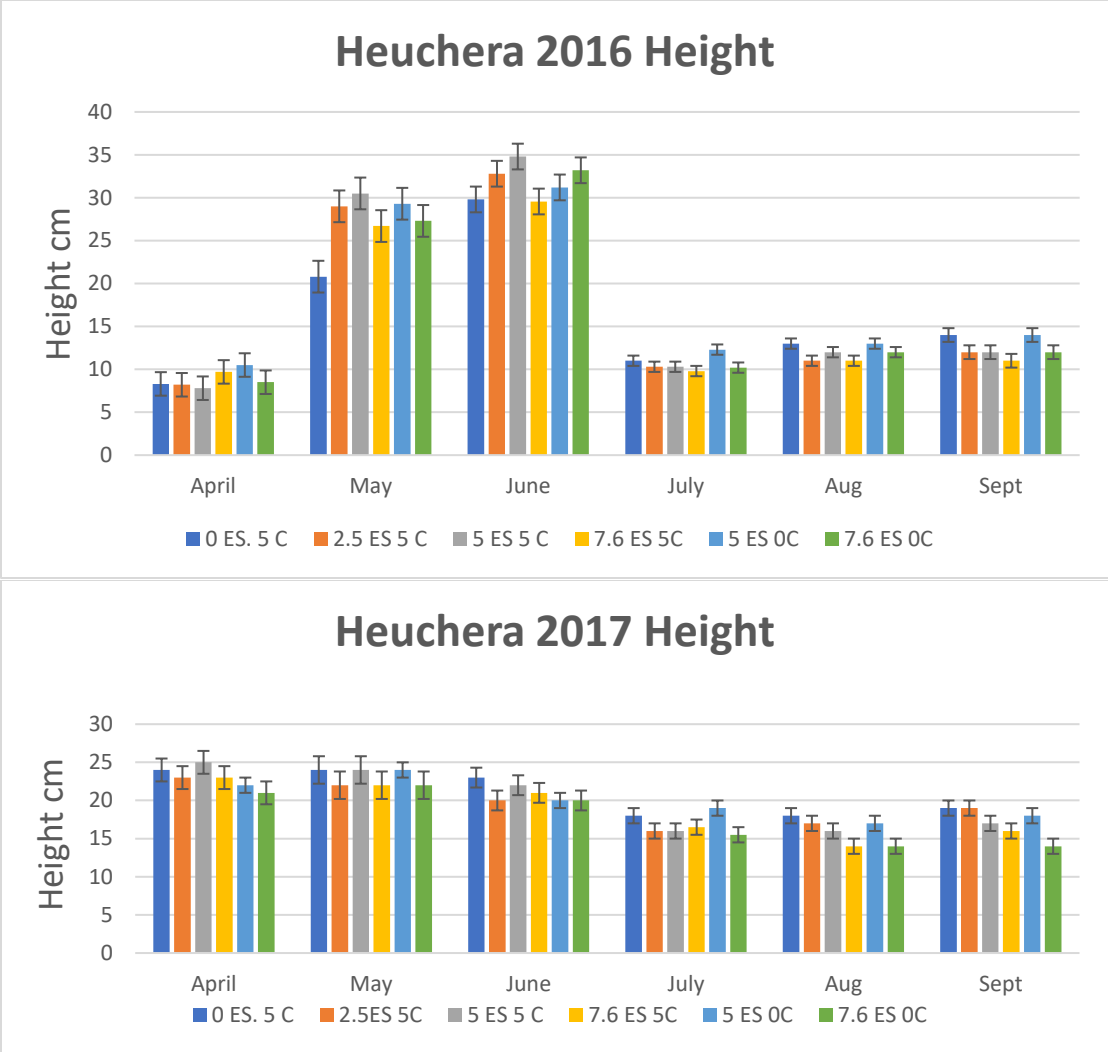
Figure 12. Width of *Heuchera* during the 2016 and 2017 growing seasons. Bar graphs of mean widths and heights for each treatment combination, the standard error bar indicates as 95 % confidence interval for the mean. Measurement data was taken at the same time of the month each month, see Table 2 for specific dates.

Heuchera plant width maintained during the 2016-2017 winter with the plants showing strong increases in width in May and June of 2017 (Fig 11 B). By July reduction in width had occurred and no increases were observed through September. The changes in width coincided

with air temperatures increasing and less rain by June (see Table 1 in Materials and Methods). In 2017 and in the earlier months of 2016 the weakest growth measured as foliage spread was observed in treatments with highest shale and no compost (7.6 ES and 0 C). Because these conditions heightened water flux in the soil as illustrated in Table 1, this factor may have impaired foliage formation. Thus, the presence of compost appeared to attenuate soil water availability, indicating that a combined treatment of expanded shale with compost was preferable. (Scheiber *et al.,* 2007, Ntoulas *et al*., 2011, Erickson *et al*., 1982, Smalley and Wood, 1995).

     Heuchera plant height measurements are shown in Fig. 12. The data in May and June 2016 included measurements to the tips of the blossoms. In 2017, the data was only for the height of the foliage. The data in July, August, and September 2016 were for foliage height not including blooms and showed little increase compared with the growth in width (Fig. 11). Plant height increased about 10 cm through the 2016 winter. There was a trend in April 2017 for the plants with the two treatments without compost to have gained least height (Fig, 12). However, the findings from the Fort Collins site are like those of Sloan et al (2002) where the amendments did not have significant impacts on plant growth.

Figure 13. Height of *Heuchera* during the 2016 and 2017 growing seasons. Bar graphs of mean widths and heights for each treatment combination, the standard error bar indicates as 95% confidence interval for the mean. Measurement data was taken at the same time of the month each month, see Table 2 for specific dates.

3.5 Heuchera Leaf Area 2016 and 2017

Leaf area assessments generated using the Easy Leaf Area program show more variability with the different treatments than direct physical measurements (Fig. 13 vs. Figs.11 and 12). In 2016, leaf surface area increased markedly, almost doubling, between July and August and from August to September (Fig 13) in contrast to the more modest increments displayed by just width measurements. This set of data showed more dramatic monthly change than that of just width

measurement and thus has provided useful information. The data obtained from the digital imaging suggested that *Heuchera* rather than growing in width or height developed more leaf surface area. Treatments with low ES and compost (0 and 2.5 ES with 5 C) as well as 5 ES without compost, resulted in the greatest increases in leaf surface area in August and September confirming the findings with the data sets for the physical growth measurements. This pattern may reflect a shift in energy use from flowering, which ended in June, to develop photosynthates to produce the storage metabolites in the roots to promote overwintering survival (Sloan *et al.,* 2010). Indeed, the leaf surface area was maintained through the 2016 winter. However, the pattern of an increase in leaf surface area in August and September was not observed in 2017 as occurred in 2016. This likely was due to the heat stress on the heuchera that occurred in June of 2017. The plant had to regrow leaf tissue that was lost due to scorch and was unable to increase its leaf surface area later in the season.
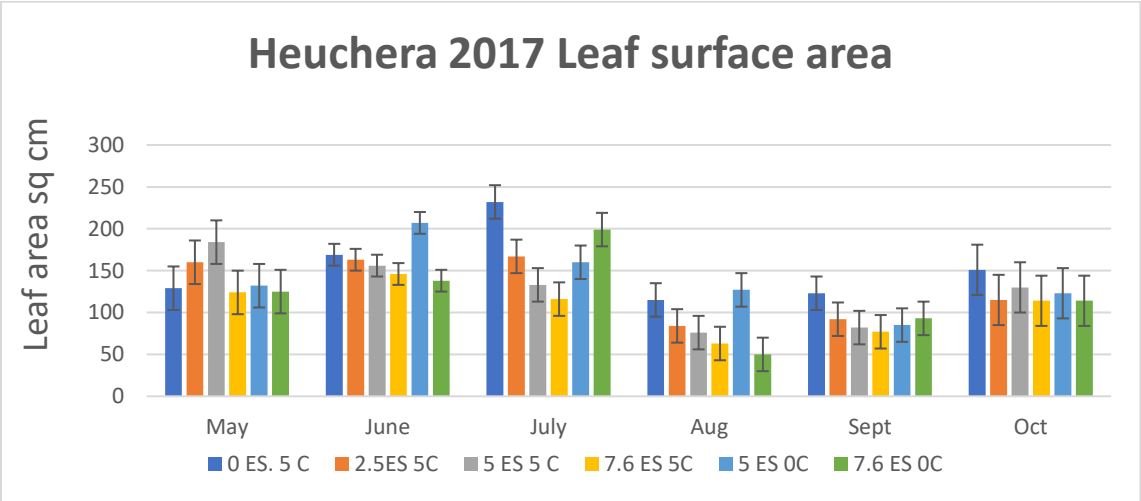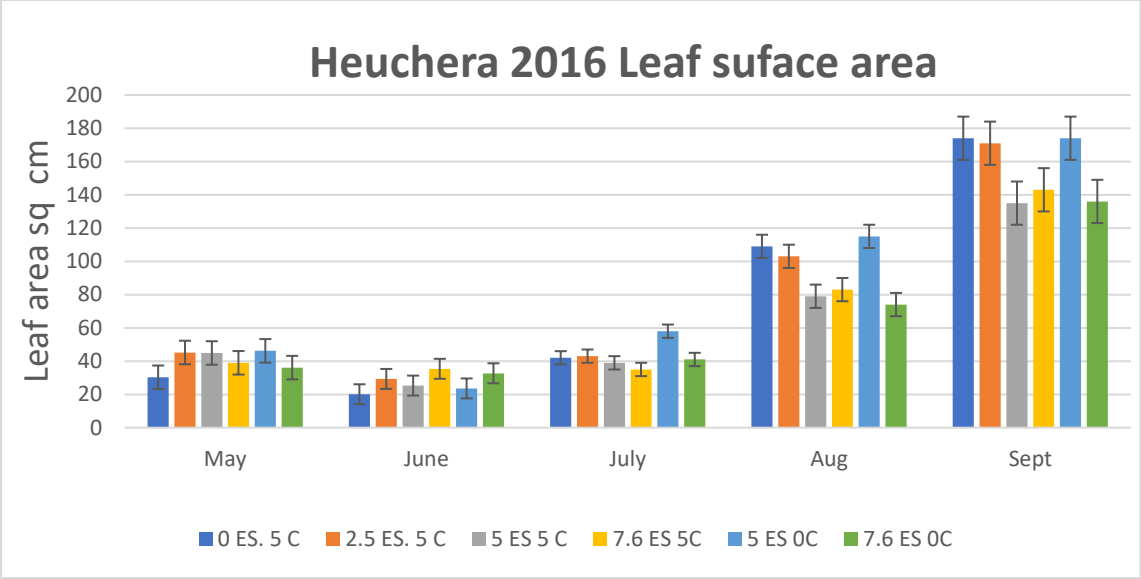
Figure 14. Leaf surface areas as determined by the Easy Leaf Area program for 2016 (A) and 2017 (B). Bar graphs of mean leaf area for each treatment combination, the standard error bar indicates as 95 % confidence interval for the mean. Measurement data was taken at the same time of the month each month, see Table 2 for specific dates.

3.6 Plant Growth: *Penstemon*

In 2016, the width of the transplanted *Penstemon* plants did not increase from April to

May but was observed to increase and peak in June, and plateau at lower values from July

through September. Width was reduced during winter 2016 (Fig. 14). There were no significant

media treatment effects (Fig. 14). There was a slight trend for best growth in 2017 May through September for treatments containing both ES and compost.
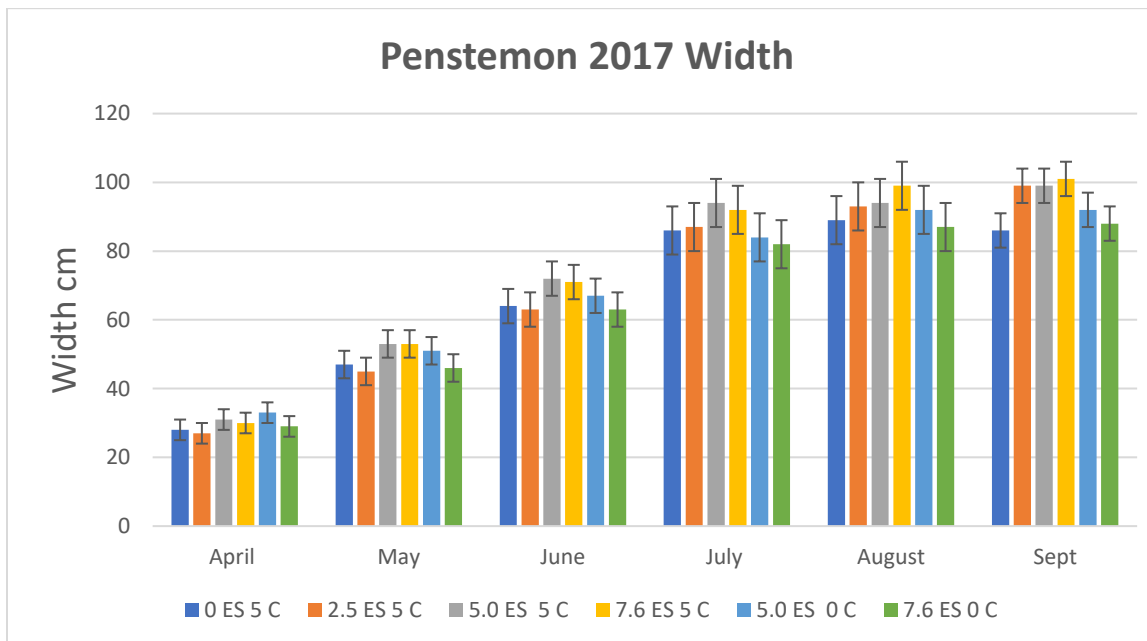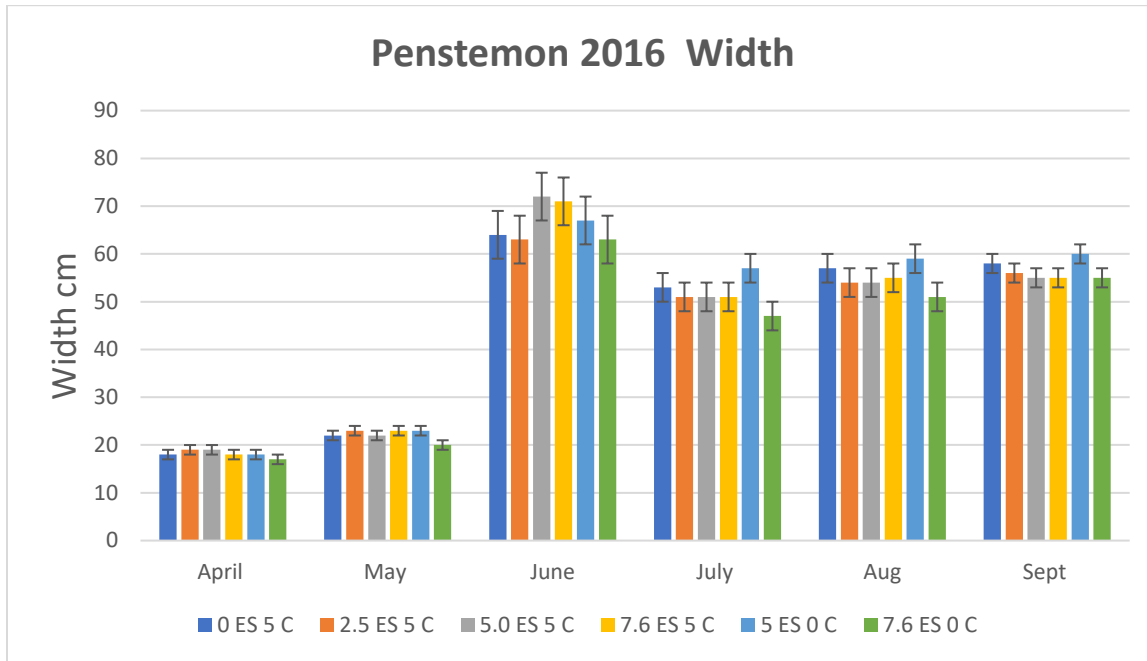
Figure 15. Width of *Penstemon* during the 2016 and 2017 growing seasons. Bar graphs of mean widths and heights for each treatment combination, the standard error bar indicates a 95 % confidence interval for the mean. Measurement data was taken at the same time of the month each month, see Table 2 for specific dates.

The height measurements of *Penstemon* were taken to the tip of any leafy flowering shoot, when present. A small increase in height of the *Penstemon* was observed between April and May for both 2016 and 2017 when plants were without flower shoots. Height then greatly increased in June coincident with onset of flowering. Flowering continued but with less consistency between the plants through the growing season. There was no significant effect of treatment in 2016 but lowest values for plant heights were observed for the treatment with high ES (7.5 cm) plus no compost (Fig 15, green bars). Overall again the findings of little influence of treatment on *Penstemon* height in this study agreed with the observations of Sloan *et al.* (2002). Flowering over a longer period may have affected the width and height of the penstemon over the growing seasons. As Figure 14 A and B both show there is not a lot of growth after June for 2016 and July for 2017; possibly the plant is putting more energy into flower production than increases in size.
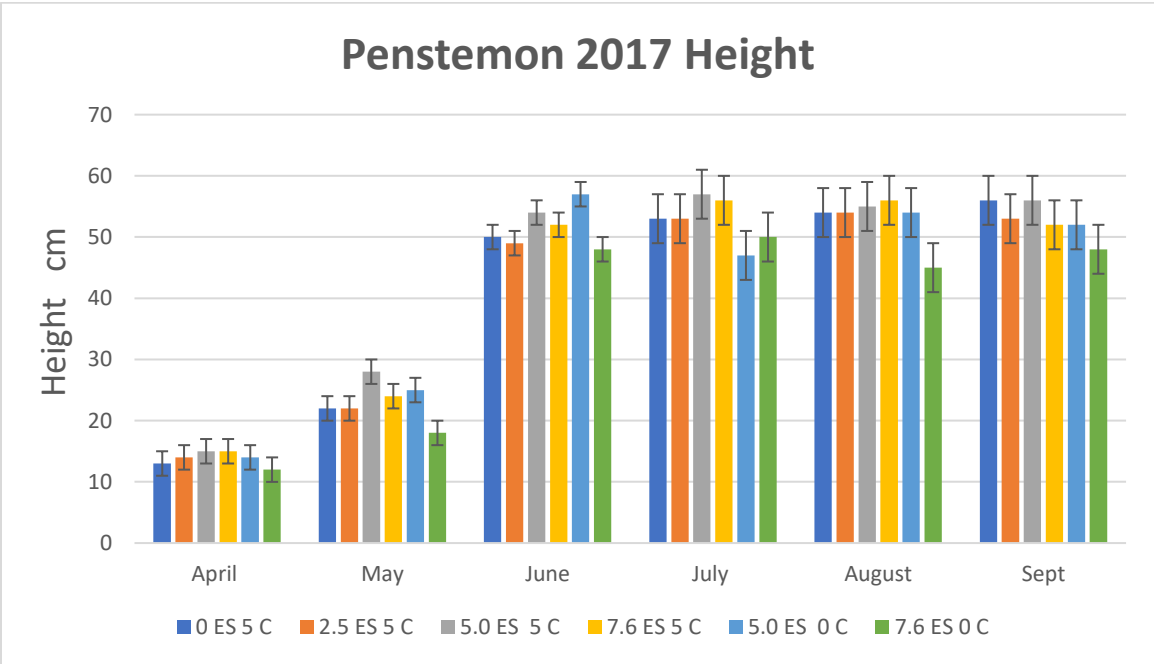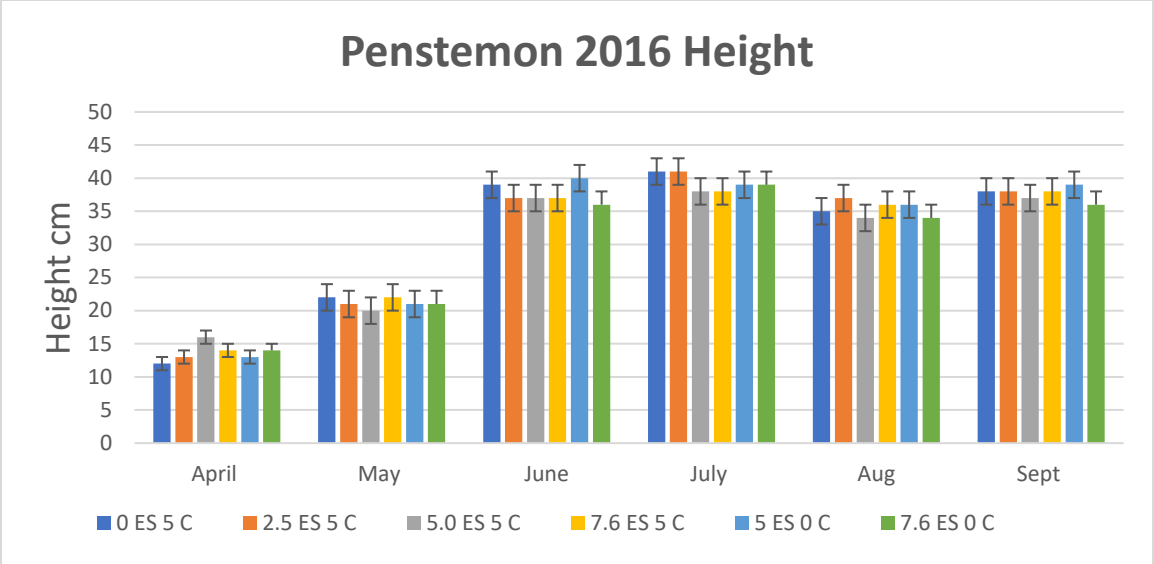
Figure 16. Height of *Penstemon* during the 2016 and 2017 growing seasons. Bar graphs of mean widths and heights for each treatment combination, the standard error bar indicates as 95 % confidence interval for the mean. Measurement data was taken at the same time of the month each month, see Table 2 for specific dates.

3.7 *Penstemon* Leaf Area 2016 and 2017

     In 2016 the *Penstemon* leaf surface, area increased steadily over the course of the season and did not plateau as was observed in the height and width measurements (Fig. 16). Thus, these measurements suggest that the foliage of the *Penstemon* plants became denser over the course of the season. In 2016 the least surface area for most months was for the treatment with high shale and no compost. More variability in treatment in leaf surface area was observed in 2017. There was a trend in May through September for lower leaf surface area from plants growing in the soils amended with just expanded shale and no compost and the treatment with ES 2.5: 5. Thus a positive effect of compost with the higher levels of shale (ES 5 and 7.5) was observed from the assessment of leaf surface area compost. This finding suggests that the organic component of the soil interacts with the expanded shale such that there are optimal ratios of compost and expanded shale to achieve greater growth, something that could be pursued in further research. Thus, this study does not support the concept raised by Sloan *et al* (2010) that ES would promote biomass increases with the plant species. This *Penstemon* study shows the importance of organic amendments.
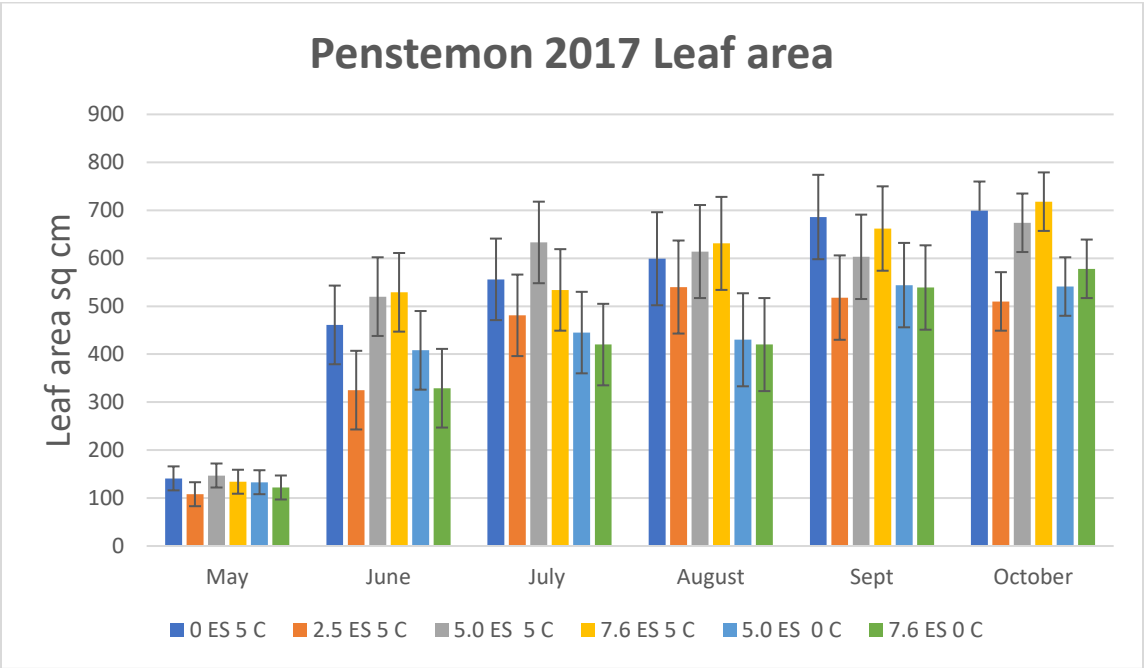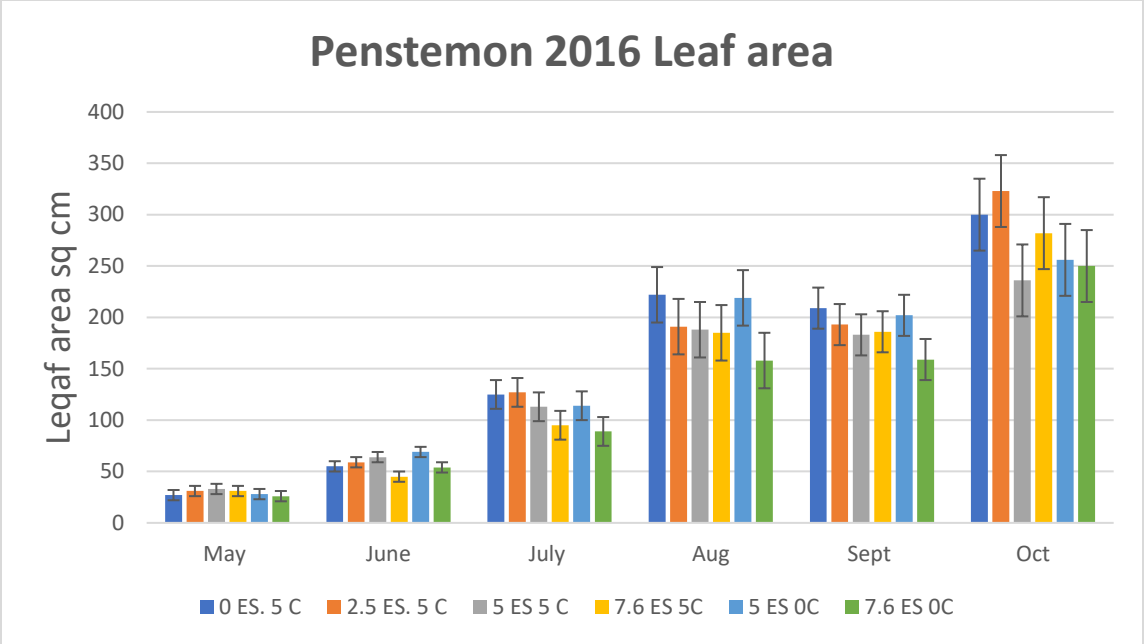
Figure 17. Leaf surface areas as determined by the Easy Leaf Area program for growth of *Penstemon* 2016 (A) and 2017 (B). Bar graphs of mean widths and heights for each treatment combination, the standard error bar indicates as 95 % confidence interval for the mean. Measurement data was taken at the same time of the month each month, see Table 2 for specific dates.

3.8 Destructive Harvest
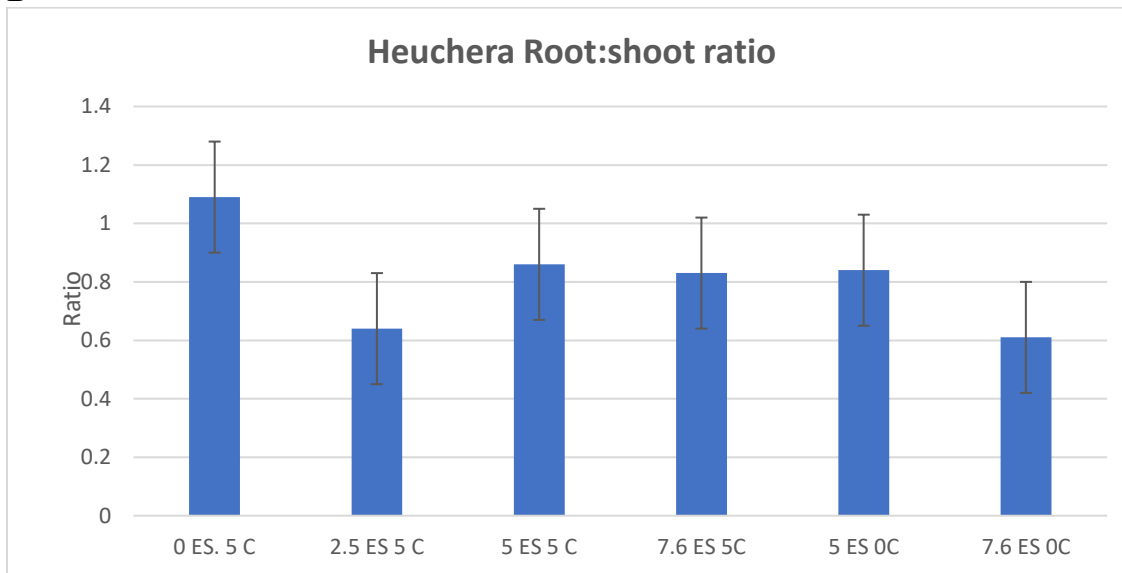
3.9 *Heuchera*:

      Comparison of the foliage and root dry weights of the *Heuchera* plants harvested in the fall of 2017 showed little significant differences between treatments (Fig. 17). The greatest root weights were for treatments 0 ES: 5 C and 5.0 ES: 5 C, and these same treatments and also the treatment 7.6 ES: 0 C were highest for foliar mass. Thus, there was no support for the concept that ES amendments would boost plant growth, especially for the roots through increasing root growth, Treatment with no expanded shale but with compost had the highest root to foliage ratio and the highest total plant biomass. These finding again illustrate that the combinations of ES with compost were important in influencing plant growth rather than just considerations of growth effects as a function of ES amendment (Sloan *et al.,* 2010).
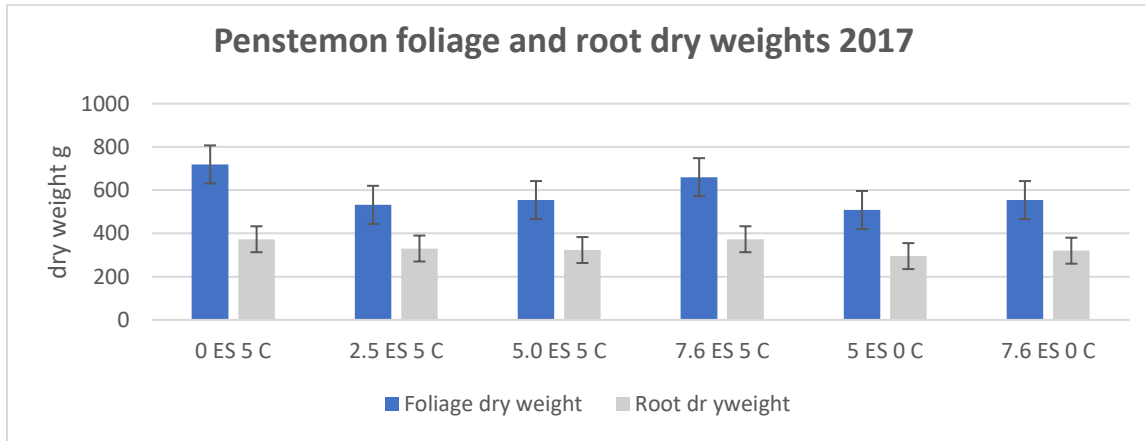
A
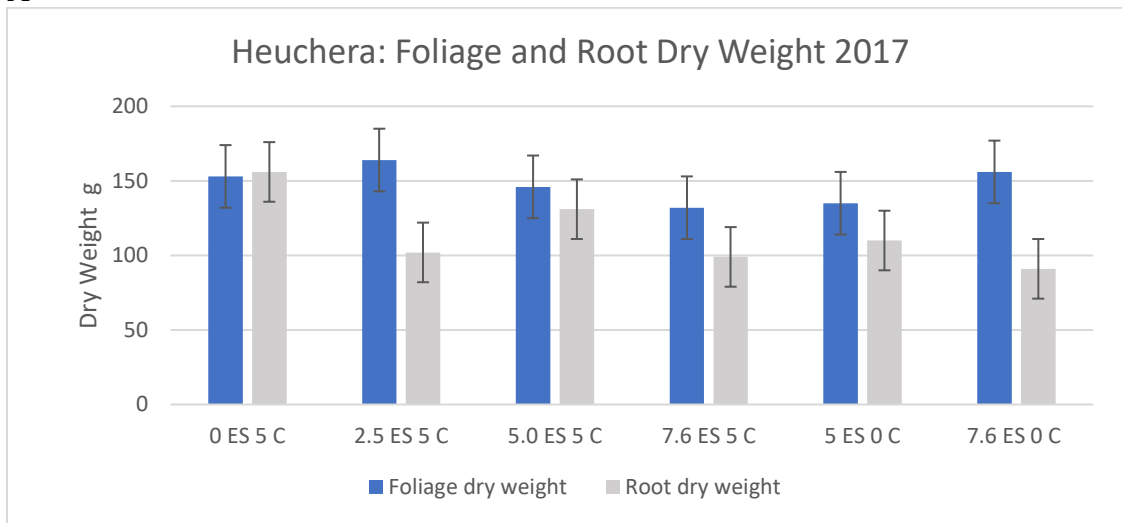
B

Figure 18. Effect of treatment at harvest on *Heuchera* foliage and root dry weight. A) dry weight data. B) Root:shoot ratio. Bar graphs of mean widths and heights for each treatment combination, the standard error bar indicates a 95 % confidence interval for the mean.
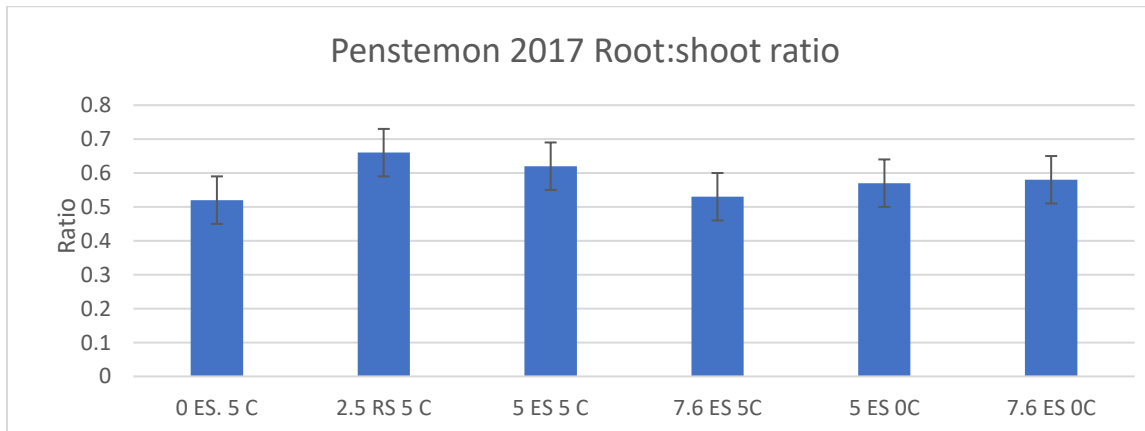
3.10 *Penstemon*:

Penstemon showed less variability in root than foliage dry weights than *Heuchera*, and there were no significant differences between the shale/compost treatments (Fig. 18). The toot to shoot ratio for the dry weights was highest when the compost (5C) was amended with 2.5 and 5 ES, but without significance. Overall the root to shoot ratios for *Penstemon* were lower than observed for *Heuchera*. These differences between the *Penstemon* and the *Heuchera* are possibly due to differences in the climates they evolved in, each performed more ideally with flowering one to two times (*Heuchera*) or continually throughout the season (*Penstemon*).

A

B

Figure 19. Effect of treatment at harvest on *Penstemon* top and root dry weight. A) dry weight data. B) Root:shoot ratio. Bar graphs of mean for each treatment combination, the standard error bar indicates a 95% confidence interval for the mean.

3.11 *Heuchera* harvest root length and width

Root measurements were taken to determine whether the roots grew more vigorously by depth or by spreading laterally in the presence of ES. There were no significant differences between root length and width of the *Heuchera* harvested after growth with the six treatments (Fig. 19). Root width and length did not show the same patterns with the various treatments. There was a trend for soil treatments of 0 ES: 5 C. 7.6 ES; 5 C and 7.6 ES; 0 C. to promote greatest root depths versus width.
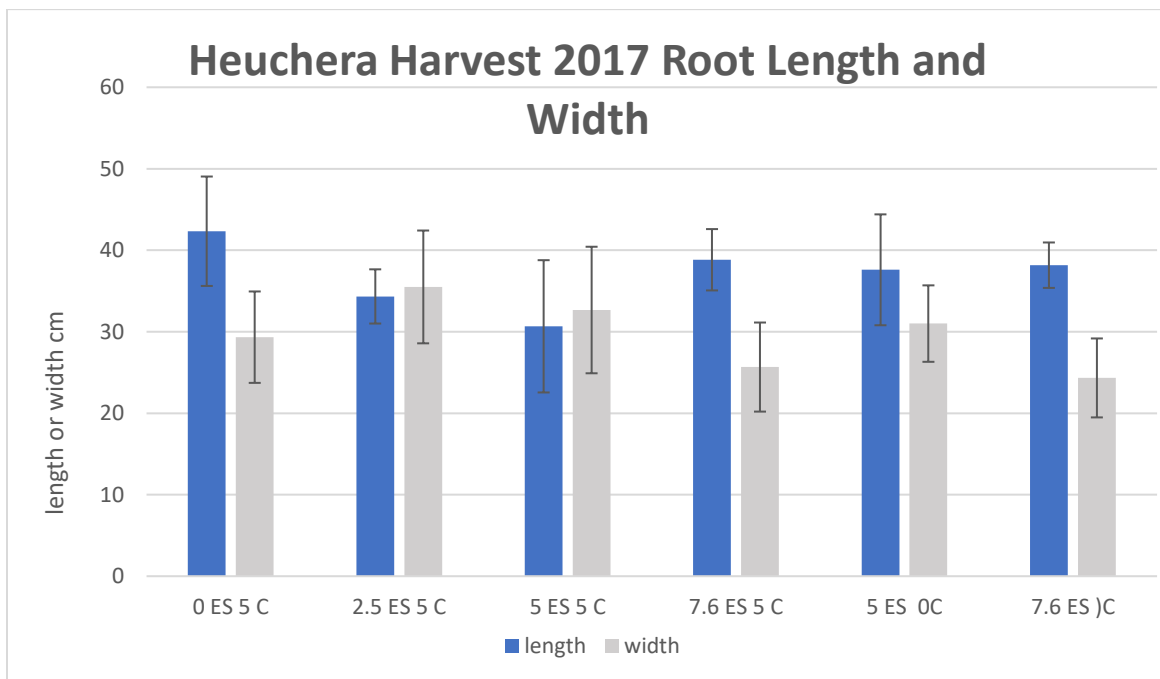
Figure 20. Effect of treatment on root length and width for *Heuchera*. Bar graphs of mean widths and heights for each treatment combination, the standard error bar indicates a 95% confidence interval for the mean.

3.12 *Penstemon* harvest root length and width

For *Penstemon* there was no statistical significance between the different soil treatments for the measurements of root length or width. Soil treatments 7.6 ES; 5 C and 7.6 ES; 0 C

promoted the deeper rather than wider growth. *Penstemon* roots grew differently than those of

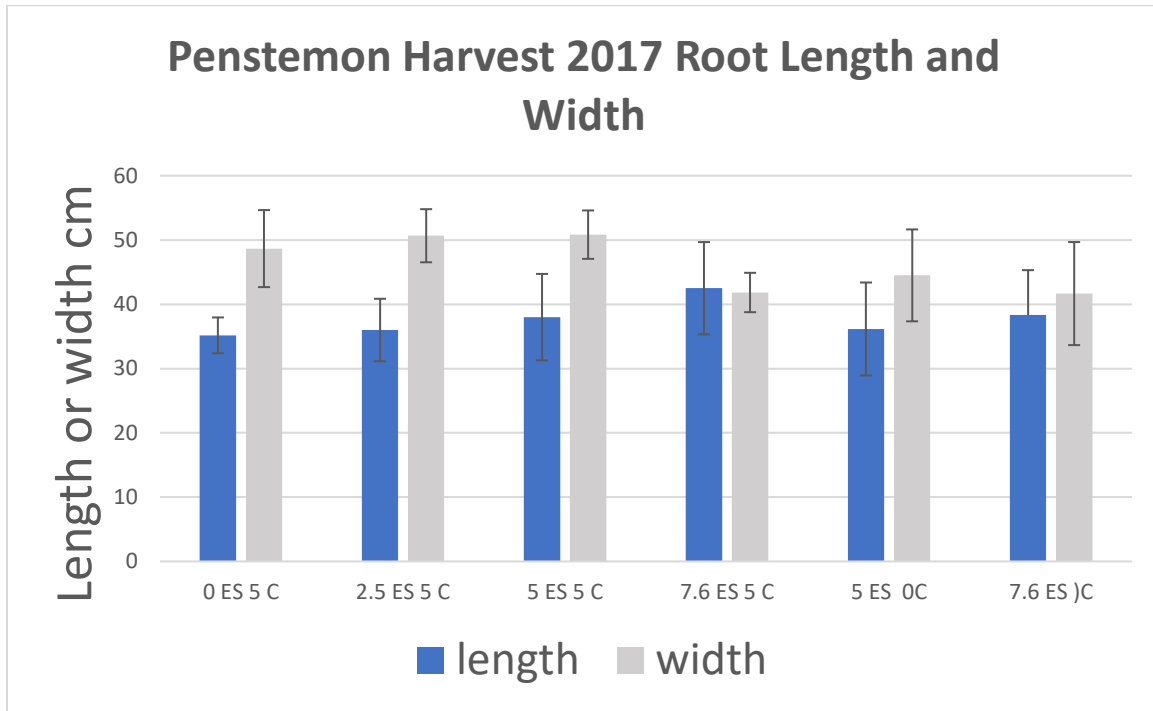the *Heuchera* with root length being less than the root width as illustrated in (Fig. 21).

Figure 21. Effect of treatment on root length and width of *Penstemon*. Bar graphs of mean widths and heights for each treatment combination, the standard error bar indicates a 95% confidence interval for the mean.

Figure 22. Example of the different root forms for *Penstemon* and *Heuchera*.

3.13 Discussion

The inclusion of expanded shale had no significant detrimental effects on the growth of these two genera. Nor was there a statistically significant effect showing a negative association between the ES and composts amendments. For some measurements, there was a trend for positive interactions between the ES and compost. In this study only one type of compost and one application of slow release Osmocote was used. The pores in the ES are proposed to act as a reservoir for nutrients in solution. One study discusses the role of ES as a long-term P source (Sloan *et al.* 2011, Forbes *et al.* 2004). Consequently, studies could be performed with composts of different composition to compare their efficacy with ES on plant performance.

The consistency of all growth performance data derived from the study illustrates the robustness of the measurements. The findings illustrate that the *Heuchera* and *Penstemon* could overcome the environmental stresses imposed by transplant, the climate and the soil properties during the two-year study. These findings are consistent with the fact that both *Heuchera* and *Penstemon* are genera native to the intermountain west and, consequently, have already adapted to the environmental conditions of the site, mainly alkaline soils and intense sunlight during the summer (Pretty Tough Plants 2017). Effects of erratic rainfall were likely minimized by the irrigation system used to mimic that of a typical homeowner landscape.

The growth data through two full growing seasons were robust enough to show although there were no significant and consistent effects of the amendments with expanded shale and compost treatments for either *Heuchera* or *Penstemon.* The data revealed differences in growth potential of these two plants. For instance, growth of *Heuchera,* but not of the *Penstemon* in 2017, was negatively affected by the onset of heat that shocked the plants and set growth back substantially in June 2017. Both taxa showed increased leaf density over increased height or

width as the growth season progressed, a process that could provide roots with reserves for survival through the winter.

There was no statistical trend that root growth for these plants were affected by ES. Thus, establishment of plots with the goal of scrutinizing root development is suggested, and would involve destructive harvest at more time points than the single measurement at project termination, as used in this study. Mechleb (2014) published that there was a trend that the expanded shale aided deeper root development. Understanding any relationship between soil ES amendments and root growth for maximum performance would have relevance to rooftop gardens and the decisions on depth of the growth matrix (Bousselot *et al.,* 2011).

One feature of the ES amendments of uncertain consequence from the evaluation of the plant measurement data was the improvement in water movement in the soil with the addition of expanded shale. This effect was illustrated by the soil moisture studies indicated that the ES alone promoted water drainage out of the soil profile. The analysis of the soil at the study site revealed that it was compacted but did not consistently have the characterization of a clay texture rather of a sandy loam. Thus, another site with compacted clay soil could be selected for a repeat study.

Another approach for future studies would be to repeat with plants that are less tolerant of clay soils with their problems of compaction and water retention. The manual digging of the soils to mix in the compost and the ES likely overcame compaction in the soil penetrated by the roots during the two-year growth study. A longer-term study for these perennial plants where roots may grow to greater extents could give valuable data on the longer term effects of ES amendment.

Another potential study would be to examine how plants would grow without programmed irrigation applications. A dry-down study would be of interest to determine whether the ES treatments would speed up or slow down the process of reaching permanent wilting point. The study could be extended to investigate growth to wilt followed by rehydration and scoring for viability. Such a study by Bousselot *et al.* (2011) showed differential effects of soil applications. The results from such studies would be valuable not only for landscape sites but also for containers and roof gardens.

Observed throughout the experiment was an ease of weed removal in the plots treated with the higher levels (5 and 7.5 cm) of expanded shale. This would be consistent with ease of soil penetration for plant roots. Thus, a study based on assessment of whether weeds are more easily removed would be very interesting, especially when considering the homeowner market where weeds are often the most troublesome problems in their landscape.

The manipulations to the digital images to allow their processing by the Easy Leaf Area program was a breakthrough. The direct use of the program with the original digital images had problems because they were taken in the field. Variable sunlight and slope of the land were environmental factors that resulted in problems in using the original images. These problems mainly impacted imaging of the red square used for normalization. The need to remove all weeds from the field of view was essential so that only foliage from the plant of interest would be recognized as green-colored pixels. Post imaging green color manual manipulation of the leaves of the plants under study on each digital image was required. First, the processing eliminated problems with measurement of red coloration of the flowers during the bloom especially for the *Penstemon*. Second the fact that the *Heuchera* variety used had a variegated cream/green coloration was not appropriate because the light-colored areas of the leaves were not recorded

from the original images. However, the study illustrated the value of the digital imaging and

processing because the data added to the information gained from physical measurements of

width and height. Thus, the use of imaging of the field data and its processing through such

software would be a strong approach when studies focusing on the visible above ground effects

of ES were to be studied. Overwintering potential, time of growth onset and timing of flower

initiation etc would be valuable properties to examine in more detail for soil amendments with

expanded shale.

CHAPTER 4: CONCLUSION

The expanded shale and compost amendment treatments did not have clear effects on the performance of the two selected genera of plants. The six treatments did have variability between them, but not enough consistently to statistically demonstrate a significant difference between the treatment types. Over the two and a half years of the study a wide variety of measurements were taken to assess this data. At the onset the plants were measured physically and photographs were taken from above to assess the growth over each season. Each season was assessed separately for significance from April 2016 to October 2016 and from April 2017 through September 2017. Soil moisture tests were performed weekly starting in June 2017 and a destructive harvest was performed in October and November of 2017 to assess top and root weights after drying in an oven. Although the statistical analysis did not show a significant difference in these treatments there is a lot of potential for future study of expanded shale as a soil amendment. Expanded shale is a product that could have a lot of potential in the landscape, and already is in use in many other areas. Further research could prove beneficial.

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