POTENTIAL FOR AGRICULTURE IN COMBINATION WITH NATIVE PLANTS ON EXTENSIVE GREEN ROOFS

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ABSTRACT

As human populations continue to increase and degrade the environment, efficient and environmentally conscious utilization of space is becoming more imperative. With their myriad of benefits to humans and the environment, green roofs have the potential to alleviate this issue. Research was conducted to analyze the potential for agriculture in combination with native plants, on extensive green roofs, in an attempt to determine which of these benefits can be combined. Six green roof simulation boxes, three of which were 10.16cm in depth and three of which were 15.24cm, as well as three ground plots were constructed to compare four perennial native species and four perennial food crops grown both alone (food crops only or native plants only) and in mixture. Change in diameter (radial spread), change in height, above ground biomass, water content, and fruit count were analyzed after one growing season to determine growth trends for a green roof system. Results indicated that there is potential for agriculture on extensive green roofs. Food crops grew more (change in diameter, change in height, and dry weight) in mixture with native plants than alone, both food crops and native plants grew more (change in diameter, change in height, and dry weight) in deeper plots than in shallow boxes or the ground, food crops had a higher water content in shallow plots than deep plots, and more strawberry fruits were produced in deep plots. This research indicates that extensive green roofs, planted with food crops and native species, are a viable option to consider for reducing environmental degradation and adding to humans' quality of life.

INTRODUCTION

Benefits of Vegetation

From providing food to carbon sequestration to removing pollutants from the air to trapping minerals to increasing mental health, vegetation provides a myriad of benefits to humans and other organisms as well as playing an essential role within ecosystems.

More and more, nutritional guides are encouraging the consumption of leafy greens, fruits, and whole grains (Welsh et al. 1994). Plants provide humans with the calories that they need everyday to survive and even the meat humans consume originates from vegetation because the animals are fed various plant material. In ecosystems, vegetation provides the food necessary for a diversity of non-autotrophic organisms to survive.

Vegetation also influences its environment based on what it absorbs and emits. As carbon sinks, plants remove greenhouse gases from the atmosphere, helping mitigate anthropocentric greenhouse gas contributions to global warming (Pretty 2007). Waring and Running (1998) estimate that forest ecosystems contain about 80% of all carbon that is aboveground (Zierl and Bugmann 2007). However, carbon is not the only important element to consider. According to Loreto et al. (2004), plant leaves can also absorb ozone (S. Fares et al. 2008). This is significant because tropospheric ozone contributes to smog. Plants take up and store materials through below ground components as well as through aboveground components. Minerals, simple inorganic nutrients, are absorbed by vegetation (Campbell and Reece 2005). For example, heavy metals are absorbed by roadside plants (Bakirdere and Yaman 2008), thus reducing those heavy metals in soils surrounding the plants.

Finally, on more of a social level, according to Hartig et al. (1991), local green spaces have favorable affects on the well being of humans, both mentally and physically (Tratalos et al. 2007). These favorable affects include: enhanced contemplativeness, stress reduction (according to Ulrich 1981), mental restoration, and a sense of peacefulness and tranquility (according to Kaplan 1983: Chiesura 2004).

Vegetation changes atmospheric chemistry, reacts to environmental changes, shapes the land, and impacts ecosystem processes (Cornelissen 2003). This complexity in function and potential for far-reaching ecosystem effects necessitates a background on the subject of vegetation before manipulating or creating ecosystems.

Benefits of Urban Agriculture

As the human population increases, high densities of people are degrading the environment (Bloom 2008). This degradation has negative health effects on surrounding ecosystems (Lagro 1994) and the people who spend time in them (Nowak 2006). Furthermore, population increase is ending no time soon, with a predicted urban population increase of 20 to 30 percent by 2030 (Bettencourt 2007). Although population growth is hard to manage, changing the ways in which humans use the environment might be more possible. For example, environmental degradation can be ameliorated by planting vegetation in urban areas. According to Nowak and Dwyer (2000), the benefits of urban vegetation include energy conservation for buildings, water quality improvement, cooler air temperatures, air quality improvement, social benefits, and reduction in ultraviolet radiation (Nowak 2006).

When urban vegetation includes food crops, even more quantifiable benefits arise. These benefits include food security, reduction of food transportation costs, and additional sources of income (Zeeuw et al. 1999). Many city dwellers, especially those of low income, do not have adequate access to fresh food. According to Patel (1996), a 10x10 meter plot can provide many of the vegetable and nutritional needs of a household in a climatic zone with a 130-day growing season (Bellows et al. 2003). Southeast Michigan's growing season, or frost free period, occurs from mid May to early October, about 135 days (World Agricultural Outlook Board 1994). Not only does urban agriculture provide a source of dependable fresh food, it can also be a source of employment (Nugent 2002).

Reducing monetary costs and environmental degradation associated with the transportation of food by growing food locally is also beneficial. The average American's meal travels 1500 miles from the field to the plate (Kortright 2001). Therefore, urban agriculture, if implemented on a larger scale, has the potential to reduce significantly carbon emissions related to transportation of food. Further, chemicals are sometimes applied to crops when they are produced on a large scale and when they need to be preserved for long periods of time. Promoting the growth of a diversity of crops, in order to suit multiple fruit and vegetable needs, might create a system in which less of these inputs are necessary (Gliessman 2007).

One of the inhibiting factors in installing more urban agriculture plots is a lack of space. In many cities the cost of land is high, so buying land specifically for gardening is not realistic. Rooftop gardens provide an alternative option that could provide employment opportunities in the form of rooftop construction, garden maintenance, harvesting, and farmers market sales.

Benefits of Green Roofs

If properly constructed and utilized to their full potential, green roofs could provide a multitude of benefits to people and to their environment. In terms of physical benefits, green roofs aid in extension of roof life, storm water management, energy use reduction, flora and fauna preservation, air pollution reduction, the reduction of the urban heat island effect, and food production (Getter and Rowe 2006). Green roofs also have aesthetic appeal and qualities that contribute to mental health (Villarreal 2007)

Green roofs act as a protective layer against the elements, therefore extending the life of a roof by as much as 20 years or more (Oberndorfer et al. 2007). Ultraviolet radiation and extreme temperatures put stress on the materials that roofs are made from, thus, adding a green roof protects the structure against these elements (Oberndorfer et al. 2007). Although installing a green roof is initially more expensive than a non-vegetated roof, a green roof has the potential to be more cost effective in the long term because it reduces maintenance and replacement costs (Wong et al. 2003).

In the past, people have not looked to roofs for methods of reducing storm water runoff, but with the high cost of land in cities this is becoming a more practical option to explore. Much of city land is impermeable, covered with pavement and roofs. According to Frazer, up to 32 percent of urban impermeable surface is roof (Oberndorfer et al. 2007). Hardening of the earth is meaningful when one considers that as water runs across impermeable surfaces it collects oils, pesticides, heavy metals, salts, and animal wastes, which are carried to local streams and groundwater (Getter and Rowe 2006). Runoff degrades stream quality and facilitates eutrophication (Getter and Rowe 2006). A way to curb stream degradation is through the use of green roof systems. Green roofs reduce significantly storm water runoff, especially for smaller storms (Carter and Jackson 2006). Various vegetation and soil mediums have different effects on the rate of runoff and the depth of the soil and size of the roof will impact the volume of roof runoff, but the positive effect of green roofs is evident throughout (Villarreal 2006). In an experiment comparing rainwater retention for gravel roofs and vegetated roofs, retention rates ranged from 48.7 percent for gravel roofs to 82.8 percent for vegetated roofs (VanWoert et al. 2005 A).

Since green roofs act as an extra insulation layer for the roof, heating and cooling costs for the building are decreased (Teemusk 2006). Plants on green roofs can shield as much as 87 percent of solar radiation while non-vegetated roofs are under 100 percent direct exposure (Wong et al. 2005). Green roof vegetation keeps buildings cooler in the summer (Alexandria and Jones 2008). Although the benefits for winters are, thus far, not as conclusive as for summers, the overall increase in energy efficiency throughout the year is significant (Santamouris et al. 2007). Reductions in heating and cooling costs are desirable for economic reasons and for savings in the use of fossil fuels.

Implementing green roofs also can aid in protecting flora and fauna. There has been some concern over the disjointedness of green roof habitats in relationship to surrounding ecosystems, but many species still manage to establish themselves on green roofs (Getter and Rowe 2006). They reduce the physical distance between other ecosystems that support diversity. Birds can be found nesting on green roofs, while butterflies and bees make their homes there (Brenneisen 2006). Beyond protecting flora and fauna for the inherent value of protection, organismal diversity is crucial to ecosystem functioning (Tilman et al. 1997).

Green roofs can also improve air quality. The increase in atmospheric carbon dioxide concentration is identified as the largest contributing factor of global warming (Chaudhari et al. 2007). The green plants on roofs exchange carbon dioxide for oxygen, thereby reducing the overall levels of carbon dioxide in the atmosphere. On a more tangible level, exposure to high levels of air pollution contributes to diminished lung function and heightened susceptibility to asthma and acute respiratory illness in children (Bateson and Schwartz 2008). The risk of lung cancer also increases (Nyberg et al.

2000). The vegetation on green roofs filters out air-born particulates. According to Liesecke and Borgwardt (1997) green roofs can reduce air pollution from diesel engines (Getter and Rowe 2006), which is especially important in urban environments. The benefits of reducing air pollution contribute to quality of life.

Another benefit is that green roofs have the potential to decrease significantly the urban heat island effect. The heat island effect explains how urban areas are heated up more than surrounding areas because of the prevalence of heat absorbing building walls and roofs, dark colored pavement, and hot air coming from cooling systems (Rizwan et al. 2008). The USEPA (2003) has reported that temperatures can be as much as 5.6°C warmer in urban areas due to the heat island effect (Getter and Rowe 2006). A green roof acts to moderate these high temperatures (Saiz et al. 2006).

Although not a focus of current green roof literature, food has been produced on green roofs for centuries (Kortright 2001). Places in the world that have already run into density problems are experimenting with innovative ways of using their space. Making this a common practice in the United States is something to strive toward. As discussed earlier, cities are consuming resources that reach far outside of the land that they occupy. A significant amount of these resources could be reduced if even a portion of food production becomes local. There is no lack of space for this change either. According to Ferguson (1998), in the United States, 71 to 95 percent of shopping centers and industrial areas are covered by impermeable surfaces (Getter et al. 2007). Not only are there environmental benefits to having food crops on roofs. Food waste is also a problem in cities. On a green roof, if the infrastructure can support it, food waste can be composted and used to grow the roof's crops further benefiting the surrounding environment (Kortright 2001).

All of these benefits, with varying levels of efficiency and sustainability, have been seen and will continue to be seen in green roofs around the world. However, it is not common that all of these benefits are seen in one green roof site. This distribution of benefits has to do with the varying purpose and types of green roofs.

Variation in green roof performance depends in part upon whether their construction is intensive or extensive. Intensive roofs have deeper and richer soil, are more costly, and are generally more accessible to people as roof gardens (Kortright 2001). The design of these roofs must be incorporated into the building construction planning because the weight demands are so significant (Oberndorfer et al. 2007). They can have the appearance of being a garden that is raised up off the ground (Kosareo 2006) and have clear aesthetic appeal. Extensive roofs, on the other hand, do not weigh very much, (according to Dunnett and Kingsbury, usually within standard roof weight-bearing parameters of 70-170 kg per m^2 (Oberndorfer et al. 2007)) require less maintenance, and are more cost efficient (Kosareo 2006). Extensive green roofs, generally, serve more of a functional purpose than an aesthetic one (Oberndorfer et al. 2007). Due to their high costs and significant weight restrictions, intensive roofs are generally less feasible to implement than are extensive roofs (Gettter and Rowe 2006) although they can provide great aesthetic appeal when viewed from adjacent buildings or other tall structures.

Variation in green roof performance also stems from the types of plants used on the roofs. Many green roofs in temperate U.S. climates are planted, primarily, with *Sedum* because it is an incredibly hardy genus of over 400 leaf succulent species, many of which can withstand extreme weather conditions as are seen in places like Michigan (VanWoert et al. 2005 B). This planting program has worked thus far. However, any planting approach that relies on a single genus of plants is more vulnerable to diseases and other pests (Speight et al. 2008). If a disease were to infect the *Sedum* genus in a debilitating way, entire green roof systems would be left dead and ineffective. This is why there has been some research done by Bob Grese, Joel Perkovich and Brian Chilcott, at the University of Michigan, to encourage the use of a diverse assortment of native plants (Grese 2007). The biodiversity of plants is necessary for sustainability in an ever-changing and unpredictable ecosystem. The use of a variety of native species on roof environments can create a more resilient plant community and can connect more to surrounding native areas and animal and insect species (Grese 2007). Further, biodiversity is important because of functional complementarity amongst terrestrial plants, which leads to healthy ecosystems of greater carbon and nitrogen accumulation and biomass production (Fornara and Tilman 2008).

More research is needed

Residents of the United States still need to overcome some barriers before fully accepting and implementing green roofs (Getter and Rowe 2006). In the United States interest in green roofs and urban agriculture is expanding. However, action is sometimes premature because effective construction, growing techniques, and species choices have not been sufficiently researched for the specific climates in which the roofs are being built (Kortright 2001). More research needs to be done in order to more thoroughly understand the potential for human and environmental benefits.

KEY THESIS QUESTIONS

Creating a well-researched green roof that is both appealing to humans and beneficial to the environment is what will encourage green roof construction in the United States. Therefore, merging as many human desires and needs with ecological benefits without compromising either is the ultimate goal. In order to observe a portion of which of these positive attributes can be combined the following questions will be addressed:

1. Can native Michigan plants and food crops be effectively integrated into extensive green roof systems?

   More specifically:

   a. Does the presence of native plants enhance or decrease the performance of food crops in green roofs? In planning a green roof that combines the benefits of native species biodiversity and food crop yield, understanding species interactions is imperative.
   b. Does soil depth in green roof design influence the growth of food crops and their interaction with native species? Growth potential and competition dynamics might vary based on depth of soil medium.

There are several reasons why food crops are not as common as non-crop plants on extensive green roofs. Fleshy crops rely on a deeper taproot system than grasses for example, which have a fibrous, shallower, root system (Campbell 2005). Roots bring water and nutrients to plants and may not be supported under the conditions of the typical green roof. Also, when there is not regular irrigation there are only a subset of food crops that will survive and produce a yield. In addition, the soil media that is commonly used on green roofs is based mostly on lightweight mineral content and is not particularly high in organic matter or nutrients (Grese 2007). Based on these factors, it is no surprise that *Sedum*, which has fibrous roots (Monterusso et al. 2005), and is a succulent (VanWoert et al. 2005 B) has tended to do well and has become the primary species of choice. There is a clear need for more research on which kind of food crops can grow in the kind of soil media found on green roofs since there are so many complex factors to consider. Aesthetics, soil composition, soil depth, installation methods, and maintenance methods all need to be considered when deciding which plants to grow (Getter and Rowe 2006).

METHODS

Research Design

The green roof research was performed in a fenced-in work yard at the Matthaei Botanical Gardens in Ann Arbor, Michigan. The experiment was conducted using four 1.22m by 1.22m and two 2.44m by 1.22m green roof simulation boxes—special planter boxes raised 0.91 meters off the ground—rather than on a real roof due to the lack of available roof space (see Appendix A, Figure A1: picture of plots). Using boxes rather than ground plots allowed for the appropriate green roof layers to be installed in the bottoms of the boxes, just as they are on typical extensive green roofs, and also barred the chance of the plant growth being skewed due to relatively cooler ground temperatures. The materials installed include: a waterproof membrane, a root barrier, a drainage/aeration/water storage layer, the growing medium and the vegetation itself (see Appendix A, Figure A2: Diagram of green roof layers).

The experiment compared the growth of native species and the growth of food crops when grown alone or in mixture, in green roof simulation boxes of different depths and in ground plots (see Appendix A, Figure A3: plot layout). A group of four perennial native species and four perennial food crops were compared. This design was chosen because, in planning what plants to grow on a green roof, it would be useful to know not only what plants thrive, but also if certain plants thrive in combination with other plants. Green roofs can typically support anywhere from 7.62 to 15.24cm of growing medium. To assess the effects of planting depth on plant performance, three green roof boxes were filled with 10.16cm of growing medium, and three were filled with 15.24cm of growing medium. For each soil depth, there was an all native box, an all food crop box, and a larger box that contained both natives and food crops. Within each box, four plants of each species were planted together in a square. The plants were equally spaced from one another, the other plant species, and the plot edges (see Appendix A, Figure A4: plant spacing). There were also three ground plots of similar species composition (see Appendix A, Figure A3: plot layout).

A key limitation of this design is that there are no true replicates at the box level of given treatment combinations. Moreover, plant "mixture" was confounded with box size (though not depth). It is not atypical in green roof research to be limited in the ability to replicate in this way, and external constraints prevented true replication of treatments. In order to complete any statistical analysis, the assumption has been made that the responses of individual plants within boxes can be used as independent observations – in other words, individual plants are used as the unit of replication with the clear understanding that future work should test the robustness of conclusions reached here with appropriate levels of replication.

Construction

All of the materials, as outlined in the green roof module instructions in Appendix B, were purchased to construct two 2.44m by 1.22m boxes. A few minor changes were made to the materials, such as purchasing treated wood, rather than non-treated cedar, for the outside edges of the 2.44m boxes and for the posts that held those boxes up (these pieces were not touching the plants or within one layer of them). This was done for affordability reasons. Also, angles on the boxes were not mitered due to lack of carpentry equipment. Also, the instructions were altered for a box of 10.16cm depth instead of 15.24cm as was outlined in the instructions. These changes should not have affected the function of the boxes. There were four 1.22m by 1.22m boxes that a colleague had already constructed that were available for this research project.

The boxes were all moved into place at the University of Michigan's Matthaei Botanical Gardens. The placement considered various aspects of the site. First, the boxes were situated so that sunlight was approximately equal for all of the plots. This design took into consideration that many actual roofs have a good deal of exposure to sunlight. Also, the boxes were slightly raised on one end, so that there was a slope that encouraged water to exit at the drip edge of the box, as would be desirable on weight-restricted roofs. A level was used to assure that the slope was similar for each box (about 2%). Finally, aesthetic appearance was considered. These boxes were available for visitors to observe, so situating them in a visually appealing way was relatively important.

Once all of the boxes were constructed they were filled with lightweight green roof soil from Midwest Trading Horticultural Supplies, based in Virgil, Illinois. The four boxes that were provided by a colleague for this research project already had soil in them from this company. To provide a cost effective lightweight-planting medium, the soil could be mixed with local media, like pottery shards. The mixture that was used in this experiment was composed of shale, baked clay (pottery shards), sand, and organic matter (Grese 2008). Mixtures composed of high contents of organic matter are not recommended because they might leach nitrogen or phosphorous out into the environment and they will compress with decomposition (Rowe et al. 2006). Mixing a substrate that is lightweight, nutritious enough to maintain the health of the plants, and not saturated with organic matter is the delicate balance to strive toward. This balance will be different for different roof weight requirements, climates, and plant compositions.

Ground Plot Preparation

To assess the combined effects of box structure and soil mixture on plant performance, food crop only, native only, and mixed plots were also constructed as ground plots in the research area (see Appendix A, Figure A3: plot layout). The ground plots had the same dimensions as the box plots, but did not restrict the depth to which plants could grow.

The areas for the ground plots were marked out with string and stakes. The placement of the ground plots also considered sunlight availability and aesthetic appeal.

The ground plot areas were rototilled in order to loosen up the hard ground and emulate the soil texture in the boxes. At this time, large rocks were removed from the soil. The soil used for the simulation boxes was not used on the ground plots due to cost. Therefore, the comparison is really one between a "garden-like" planting regime and a "green roof-like" planting regime that differ in several variables simultaneously (depth, soil type, height above ground).

Planting Preparation

All eight varieties of perennial plants were acquired (sources below) within a couple of days of when the planting was to take place (June, 2007). Plugs were transplanted into the simulation boxes and ground plots, rather than growing seeds in the boxes. Plugs were used because transplanting a plant with an established root structure for acquiring nutrients provides the plant with a better chance of survival when the soil provided to them is not extremely nutritious. All of the food crops – *Thymus vulgaris* (French thyme), *Origanum vulgare hirtum* (Greek oregano), *Fragaria vesca* (Alpine Strawberry), and *Artemisia dracunculus sativa* (French tarragon) – were purchased from a single vendor, Renaissance Acres Organic Herb Farm (Whitmore Lake, MI). Three of the varieties of native plants -- *Eragrostis spectabilis* (Purple lovegrass), *Aster oolentangiensis* (Sky blue aster), and *Pycnanthemum virginianum* (Mountain mint) – were purchased from the vendor, Wildtype (Mason, MI). The last native plant, *Carex pensylvanica* (Pennsylvania sedge), was not available through Wildtype, so was acquired from the University of Michigan's Matthaei Botanical Gardens.

All of the plants were checked visibly for general health so that plants were not planted that had observable pre-existing health problems. For example, plants that looked like they were senescing were removed from the pool of plants to put in the plots. The plants were also checked for any visible insects. The plants were also watered daily while they were still in the flats (on average five days of watering). Plants of equivalent size were distributed evenly among plots rather than at random. With so few plots, a random allocation of plants runs the risk of generating “small-plant” or “large-plant” pre-treatment effects. The even distribution assured that initial plant size was not confounded with treatment.

Planting

All of the plants, except for *Carex pensylvanica*, were planted during one night (June 26) in order to avoid growth variation due to timing of planting. The *Carex pensylvanica* were planted four days later when they became available. The plants were put in the ground and in the boxes at night because that is when there was as little difference in conditions between the flats and the ground and simulation boxes. If the plants were planted in the middle of an extremely hot and sunny day, there is a larger chance that they would not have survived the transfer. Planting was done in the order of species, not the order of various plots. This way, all of the *Origanum vulgare hirtum*, for example, were planted as close to the same time as possible.

All of the plants were planted with the same technique. First, the center location of where each plant was to be placed was measured and marked. The plants were an equally spaced distance from the wall boundary and other plants in an attempt to equilibrate competition among individuals. A 10.16cm deep hole was dug each time, some of the roots of the plants were spread out so that they could branch out, the plant was placed in the hole, and the edges of the hole were filled in with green roof soil.

Plants were watered to saturation after planting. This watering process was repeated one more time when the *Carex pensylvanica* were transplanted four days later. From that point on, the only water that the plants received was rainwater.

Measurements: Diameter and Height

The day after transplanting, the height and diameter (radial spread) of each plant was measured and recorded using a tape measure. The height was taken from where the plant's base intersected with the soil to the topmost height of the plant (see Appendix A, Figure A5: measuring technique). If the plant was bending over, as was common in *Aster oolentangiensis* it was straightened temporarily for the measurement. This was done because the height and diameter were meant to be general measurements of size, not of how much or little the plant bent over with weight. Next, what appeared to be the average diameter at the base of the plant was calculated. It was difficult to be extremely precise since plants do not grow in perfect cylinders.

A second set of height and diameter measurements were made just before the first freeze (October 10), when plant size should have been at its maximum.

Weekly qualitative observations were taken from each plant, including notes on appearance of the plants, apparent effects of wildlife, and weed abundance. Some quantifiable measurements were also made. These included tracking the weather and counting ripe strawberry fruits.

When weeds started to appear, time was spent each week pulling them. When there were too many weeds to entirely eliminate them, an equal amount of time was spent weeding each of those boxes or ground plots (see Appendix A, Figure A6). This was done because some of the beds grew a disproportionate number of weeds compared to others. As many weeds as possible were pulled in this experiment in an attempt to reduce the affect on study plants.

Measurement: Biomass

Estimates of aboveground biomass were made at the end of the experiment, before the first freeze (October 10). Root biomass was not included in this final measurement because no initial root biomass estimate was used to equally distribute plants of equal root biomass, so a biomass that included root weight could have skewed significantly the results. A quart sized Ziploc bag was labeled for each plant on each plot. Each plant was cut at its base and closed in its Ziploc bag (see Appendix A, Figure A7). Weeds were also collected from plots in a similar fashion, but pooled into a single bag per plot. For the plots that had a great abundance of weeds, only a representative quarter of the plot was pulled and then that number was multiplied by four. Garden scissors were used to cut each plant as close to the soil as possible while at the same time not picking up any dirt. It was necessary to do all of the cutting in one day in order to prevent the timing of the cut being a confounding variable. It was also imperative that the Ziploc bags were properly closed, to minimize loss of moisture from the plants.

Bags with plants were weighed within five days of harvest so that the plants did not mold. Ten empty Ziploc bags were weighed to find the average Ziploc bag weight. This weight was subtracted from the bag and plant weight to get the plant's wet weight.

When this process of weighing was complete, the plants were transferred from Ziploc bags to labeled paper bags for drying. It was important to get all of the tiny pieces of plant from the Ziploc to the paper bag. The plant filled paper bags, along with ten empty paper bags, were placed in a large drying oven for 48 hours. At this time, a couple of bags were removed from the oven and weighed, then put back in the oven. After a few hours, those same bags were weighed again. The weights had not changed from measurement one to two, so the drying process was complete. Immediately after removing the plants from the drying oven, the plants were weighed. The empty bags were weighed at this time as well and used to calculate the average bag weight. This weight was, like above, subtracted from the paper bag and plant weight to get the dry weight of each plant. Due to inconsistency in paper bag weight, some of the bags with a small quantity of vegetation had dry weights below zero. These measurements were removed for analysis.

RESULTS

Integration of Food Crops and Native Species

Growth Rate: Treatment by Species

The overall average growth rates (change in diameter and change in height) of food crops were uniformly higher in the presence of native plants than in their absence

($F_{1,88}$=14.42, P=0.0003, Appendix C, Figure C1, and $F_{1,88}$=4.67, P=0.0334, Appendix C, Figure C2). In contrast, average native plant growth rates (change in diameter and change in height) were not different in the presence of food crops compared to in their absence ($F_{1,88}$=0.16, P=0.6910, Appendix C, Figure C3, and $F_{1,88}$=0.71, P=0.4017, Appendix C, Figure C4).

Although the above highlights overall growth trends, the native plant species varied in their responses to growing in mixture or alone ($F_{3,88}$=6.38, P=0.0006, Appendix C, Figure C3). The growth rate (change in diameter) of sedge was lower in the presence of food crops than in their absence ($F_{1,22}$=19.79, P=0.0002, Appendix C, Figure C3) and the growth rate (change in diameter) of lovegrass was higher in the presence of food crops than in their absence ($F_{1,22}$=15.57, P=0.0007, Appendix C, Figure C3). There was so much variation in the change in height of oregano and the growth (change in height and change in diameter) of aster that a trend based on whether or not they were grown in mixture cannot be identified (Appendix C, Figure C2, C3, C4 respectively). Note: negative diameter or height growth represents tissue loss to herbivores and potential resprouting of smaller shoots.

Water Content by Species

The overall water content of food crops was unaffected by the presence of native plants ($F_{1,88}$=0.18, P=0.6710, Appendix C, Figure C5). Likewise, water contents of native plants were unaffected by the presence of food crops ($F_{1,87}$=0.02, P=0.8786, Appendix C, Figure C6). Based on these results, both native species and food crops did not gain or retain moisture based on whether or not they were grown in mixture or alone.

Dry Weight by Species

Food crops uniformly had a higher dry weight in the presence of native plants than in their absence ($F_{1,88}$=24.03, P<0.0001, Appendix C, Figure C7) and native plants had a higher dry weight in the presence of food crops than in their absence ($F_{1,87}$=9.30, P=0.0030, Appendix C, Figure C8). Based on these results, both native species and food crops perform better in mixture than alone.

Green Roof Soil Depth

Growth Rate: Depth by Species

The average growth rates (change in diameter and change in height) of food crops were higher in deep boxes than in either shallow boxes or ground plots ($F_{2,84}$=10.97, P<0.0001, Appendix C, Figure C9, and $F_{2,84}$=9.26, P=0.0002, Appendix C, Figure C10). Likewise, the growth rates (change in diameter and change in height) of native species were higher in deep boxes than in either shallow boxes or ground plots ($F_{2,84}$=16.21, P<0.0001, Appendix C, Figure C11, and $F_{2,84}$=15.97, P<0.0001, Appendix C, Figure C12). Based on these results, all plants grew better in deep boxes.

Significant species-by-depth interaction terms (Appendix C, Figures C10, C11, C12) highlight that species varied in their responses to box depth. The growth rate (in height) of oregano and strawberry varied around the mean by so much that a difference between the various average depths was not apparent (oregano: $F_{2,21}$=2.18, P=0.1379, Appendix C, Figure C10, strawberry: $F_{2,21}$=2.83, P=0.0817, Appendix C, Figure C10). The growth rate (change in diameter) of mint was higher in deep boxes than in shallow boxes ($F_{2,21}$=3.67, P=0.043, Appendix C, Figure C11). The growth rate (change in diameter) of aster was higher in deep boxes than in shallow boxes, which were higher than ground plots ($F_{2,21}$=18.34, P<0.0001, Appendix C, Figure C11). Sedge and lovegrass growth rate values (change in diameter) varied around the mean by so much that differences in averages are insignificant (sedge: $F_{2,21}$=1.33, P=0.2863, Appendix C, Figure C11, lovegrass: $F_{2,21}$=1.57, P=0.2312, Appendix C, Figure C11). The growth rate (change in height) of mint was higher in ground plots than in shallow boxes ($F_{2,21}$=4.79, P=0.0194, Appendix C, Figure C12). In contrast, the growth rate (change in height) of lovegrass, was higher in deep boxes than shallow boxes ($F_{2,21}$=4.82, P=0.0189, Appendix C, Figure C12). Also, the growth rate (change in height) of aster was higher in deep boxes than ground plots ($F_{2,21}$=31.37, P<0.0001, Appendix C, Figure C12). For sedge, the growth rate values (change in height) varied around the averages for each depth by so much that differences are not significant (Appendix C, Figure 12).

Water Content by Depth

The water content of food crops was generally higher in shallow boxes than in either deep boxes or ground plots ($F_{2,84}$=4.09, P=0.0202, Appendix C, Figure C13). However, the effect of depth is weak in comparison to significant variation in water content among crop species (Appendix C, Figure C13). The water content of native species was generally unaffected by the depth of the plots ($F_{2,71}$=2.19, P=0.1195, Appendix C, Figure C14). More specifically, lovegrass had a higher water content in ground plots than in deep or shallow boxes ($F_{2,21}$=4.38, P=0.0258, Appendix C, Figure C14), mint had a higher water content in shallow boxes than in the ground plots ($F_{2,21}$=6.84, P=0.0051, Appendix C, Figure C14), and aster and sedge water content did not vary significantly based on depth (aster: $F_{1,14}$=0.01, P=0.9370, Appendix C, Figure C14, sedge: $F_{2,15}$=0.69, P=0.5188, Appendix C, Figure C14). As with food crops, variation in water content among native species was much more important than variation in water content by depth (Appendix C, Figure C14).

Dry Weight by Depth

The dry weight of food crops was uniformly larger in deep boxes than in either shallow boxes or ground plots ($F_{2,84}$=14.34, P<0.0001, Appendix C, Figure C15). Likewise, the dry weight of native species was uniformly larger in deep boxes than in either shallow boxes or ground plots ($F_{2,71}$=38.33, P<0.0001, Appendix C, Figure C16), with some variation among native species in the magnitude of depth effect ($F_{5,71}$=3.74, P=0.0046, Appendix C, Figure C16).

Integration of Food Crops and Native Species in Various Green Roof Depths

Food crops grew better (change in diameter) in mixture with native plants than alone in both shallow ($F_{1,30}$=24.27, P<0.0001, Appendix C, Figure C17) and deep ($F_{1,30}$=26.23, P<0.0001, Appendix C, Figure C17) boxes. In contrast, the growth rate of food crops was actually lower in the presence of natives in ground plots ($F_{1,30}$=12.72, P=0.0012, Appendix C, Figure C17). Exactly the same depth by mixture interactions held for plant dry mass (Appendix C, Figure C18). Based on depth, fruit production by strawberry plants did not differ in the presence of native species compared to in their absence ($F_{1,18}$=0.02, P=0.8979, Appendix C, Figure C19).

Comparison Among Species

Growth Rates for Individual Species

As measured by change in diameter, crop species growth rates were highest for tarragon and lowest for strawberry plants ($F_{3,88}$=5.25, P=0.0022, Figure 2, and $F_{3,84}$=5.43, P=0.0018, Appendix C, Figure C9). In comparison to gains in diameter, oregano did not gain in height ($F_{3,88}$=15.20, P<0.0001, Appendix C, Figure C2, and $F_{3,84}$=19.55, P<0.0001, Appendix C, Figure C10). Among the native plants, mint gained mass by increases in diameter and height, aster gained mass by increases in diameter, and lovegrass gained mass by increases in height. Sedge performed relatively poorly throughout ($F_{3,88}$=9.08, P<0.0001, Appendix C, Figure C3, and $F_{3,88}$=6.02, P=0.0009, Appendix C, Figure C4, and $F_{3,84}$=19.37, P<0.0001, Appendix C, Figure C12, and $F_{3,84}$=12.83, P<0.0001, Appendix C, Figure C12).

Water content for Individual Species

For food crops, when analyzed by mixture or depth, tarragon had a higher water content than oregano, thyme, and strawberry ($F_{3,88}$=12.51, P<0.0001, Appendix C, Figure C5, and $F_{3,84}$=4.87, P<0.0001, Appendix C, Figure C13). Among native species lovegrass had a much lower water content than the other species ($F_{3,87}$=11.15, P<0.0001, Appendix C, Figure C6, and $F_{3,71}$=195.18, P<0.0001, Appendix C, Figure C14).

Dry weight for Individual Species

Difference among crop species in dry mass were minor in comparison to the effects of mixture and depth described previously ($F_{3,88}$=3.01, P=0.0344, Appendix C,

Figure C7, and $F_{3,84}$=3.13, P=0.0300, Appendix C, Figure C16). Among native species, sedge performed poorly throughout and aster performed poorly when grown with native plants only ($F_{3, 87}$=13.82, P<0.0001, Appendix C, Figure C8, and $F_{3,71}$=38.33, P<0.0001, Appendix C, Figure C16).

DISCUSSION

Food crops grew more (change in diameter, change in height, and dry weight) in mixture with native plants than alone and both food crops and native plants grew more (change in diameter, change in height, and dry weight) in deeper plots than in shallow boxes or the ground. For food crops, there was a higher water content in shallow plots than in deep plots. More strawberry fruits were produced in the deep boxes. These patterns are considered in detail below.

Food Crops in Mixture

Overall, food crops grew more (change in diameter, change in height, and dry weight) in mixture than when grown alone. Potential explanations for why food crops performed better when planted in mixture in this experiment are pest resistance, competition/facilitation, box size, and weed prevalence in certain boxes.

Growing plants in polyculture can increase yields by decreasing pests. For example, in the case of maize and cowpeas, an experiment showed that an intercropping system produced higher yields than that of a mono-crop system (Skovgard and Päts 1997). These results are not consistent in all situations, but might aid in explaining the food crops' growth in mixture compared to alone in this instance. The resource concentration hypothesis and natural enemies hypothesis explain mechanisms for this phenomenon (Harmon et al. 2003). The resource concentration hypothesis states that specialist herbivore species should be found at higher density in larger patches than smaller patches because pests will migrate to the areas with a higher abundance of hosts and it is easier for pests to locate large patches (Hambäck and Englund 2005). The natural enemies hypothesis states that a diversity of plants facilitates a diversity of prey, which then encourage natural enemies or other pest species (Letourneau 1987). Therefore, it is possible that some of the pests on the food crops could not locate hosts when they were grown with native plants. Further, diversity might be particularly important for perennial crops because traditional disease resistance methods, like crop rotation, tillage, and delayed seeding cannot be implemented (Cox et al. 2005). Additional long-term research on pests of the specific plants used in the experiment would be required to analyze the potential of this interaction. Plant interactions would be an aspect to consider before planting (Vandermeer et al. 1984).

Facilitation and complementarity are both phenomena that could lead to overproduction or higher yields (Hooper et al. 2005) and competition could lead to lower yields (Hauggaard-Nielsen et al. 2007). In this case, the intraspecific competition between various food crops may have been stronger than the competition between native species and food crops. The food crops may have occupied more similar nutrient, light, or water niches in relationship to each other than in comparison to native species. This is unlikely because, both in the mixture and food crop only plots, each species was planted in a cluster of its own species (Figure A3). The aspect that changed from one plot to the next was proximity of various clusters. Thus, in each type of plot the majority of the competition would come from other individuals of the same species. A comparison of each plot's growth based on individual plant location would aid in coming to a conclusion on this hypothesis. Barring the above factors, light competition could only have had a minimal effect if at all, considering the relatively similar growth in height and leaf distribution of many of the plants, which are indicators of being able to coexist (Nevai and Vance 2008).

The boxes in mixture were twice as large as the "only native" and "only food crop" boxes. Each raised box was constructed and oriented in the same way in that they were set on a slight slope with a drainage drip edge on the north end of each box. This means that when there was significant precipitation the plants at the northern end of each box had more opportunity to retain the water as it all had to run under those plants to exit the box. Further, potentially, in the larger boxes, more water passed underneath the plants on the northern end, which may have affected their growth. Although it is known that water is especially important for horticultural crops (Petropoulos et al. 2008), hypotheses on specific effects of water running through the box to drain are speculative because no research has specifically addressed this issue.

In Gibson et al.'s (2008) research on weed communities and the production of soy, the presence of weeds affected food crop yield in terms of quantity and quality. Therefore, although lacking replicates to do statistical analysis, it is worth consideration that the 10.16cm depth plots that included food crops had largely different amounts of weeds based on if they were planted alone or in mixture. The box of food crops only, which was half the size of the box in mixture, had 44.72 grams of weeds, while the box that was in mixture, virtually had no weeds. This could mean a number of different things. It could mean that native species are more capable than food crops of out competing the weeds that were present, as seen in the Gause's (1934) competitive exclusion principle (Vandermeer et al. 1984). This is likely because weeds and native species are more adapted to the environment than a non-native food crop, for example (Cluberkis et al. 2007). Or, the interaction that the native species have with the food crops might have made the food crops more able to out compete the weeds. Or, the difference in the origin of the soil in the mixture boxes compared to the food crop only boxes may have had an effect on growth (the importance of substrate for growth as discussed previously (Rowe et al. 2006)). Because the food crop only boxes had some soil that had been outside for two seasons, weed seeds may have had an initial competitive advantage over the transplanted food crops that the food crops, in the 10.16cm boxes, could not overcome. However, the weeds did not vary much between food crops in mixture and food crops alone for the 15.24cm boxes or ground plots when weed quantity was observed in proportion to plot size.

Native Species and Food Crops in Deep Boxes

Overall, both food crops and native species grew more (change in diameter, change in height, and dry weight) in deep boxes than shallow boxes or ground plots. Hypotheses for this result include root requirements, nutrient availability, water availability, and weed prevalence.

Roots provide plants with essential nutrients for growth. When the plants for the 10.16cm plots were transplanted the roots were touching the bottom of the box. Therefore, there was no more room for the roots to grow down. When a plant is not receiving enough of the nutrients that it needs to survive it will put more energy into extending roots and less into above ground growth (Snyder and Williams 2007). An experiment on cottonwood trees has reflected this pattern with rises and decreases in the water table (Snyder and Williams 2007). Perhaps plants in the deep boxes were using less energy to extend their roots because they had access to nutrients below them and to their sides. However, if the roots' need to expand was the only factor affecting growth then the ground plot would have flourished even more than the deep box. To respond to this result some other soil conditions and weeds must be considered.

The quantity of soil medium as well as the restricting walls of the boxes might have influenced the presence of water, which plants need for growth, in each box or plot. Whenever there is a significant amount of precipitation a larger quantity of soil medium is going to retain more of that water. The 10.16cm depth box would be the least favorable in this regard. However, another aspect that might be favorable for plants in terms of the uptake of water is the presence of a restricting bottom of the box on which water might collect for longer periods of time than if it were simply percolating down through the soil. In this instance the ground plot might be least favorable since there is no table for the water to sit on. Perhaps, the deep box (15.24cm) was the most favorable combination in that there was a fair bit of soil in these boxes and there was also a restricted bottom for water to sit.

The quantity of weeds in the 15.24cm depth boxes was close to zero in almost every box, which could have affected positively the growth of those plants. The weeds could have been so minimal because of plant competition or weed seeds previously in the soil. These deeper boxes might have had enough resources to create a competitive advantage to plants over the weeds. Or, as discussed earlier, the deep boxes might have had fewer or no weed seeds in the soil prior to planting while for other boxes and plots this was not the case. However, this is unlikely since, of the four boxes that were provided, two were deep and two were shallow depths, so if weed seeds were the sole explanation for weed prevalence all four boxes would have had more weeds than the newly constructed boxes. This was not the case. It is also important to realize that the weed distribution might not have been a reflection of competition or affected growth in any way.

Plant Water Content in Shallow Boxes

Although of weak significance, the food crops had a higher water content in the shallow boxes than in the deep boxes or ground plots. Explanations for this include the potential of re-sprouting and the bottom of the box's proximity to plant roots.

Based on when the water content calculations were made, the shallow box plants might have had some re-sprouting occurring. New plant tissue is generally higher in water content than old plant tissue (Saura-Mas and Lloret 2007)**.** The re-sprouting timing might have been different than in the other depth boxes or the ground plots because of nutrient availability. In this case the water content in the various boxes is not necessarily different, only the amount of water each plant retains. Or, there might be a difference in the water available to the plants in each box. A shallow box might provide water to the roots from the bottom of the box as explained earlier.

Fruit Production

Strawberry plants produced more fruits in deep boxes than in shallow boxes or ground plots. The plants did not, however, produce more, in terms of fruits, when grown in mixture versus grown alone. Explanations for these results include the potential deep box benefits as discussed above as well as potential growth and reproduction tradeoffs.

Although the strawberry plants produced about the same number of fruits regardless of whether the plants were in mixture or with other food crops, the growth of the strawberry plants (change in diameter, change in height, dry weight) did differ based on this variable. This might mean that strawberry plants compromise above ground leafy biomass in order to produce a minimum number of fruits. A pattern of this nature is seen in *Salix planifolia spp* in which females allocate many resources to fruit production (Turcotte and Houle 2001). This means that regardless of each plant's mass, the fruit production would remain fairly similar. However, when all of the individual masses are lined up with individual fruit production there appears to be a trend where the higher the leaf mass the higher the fruit production (see Appendix C, Figure C20). This trend is also seen when only the deep box plants are charted. When the shallow box plants are charted and the ground plot plants are charted there seems to be no relationship between fruit quantity and leaf mass. Overall, I found no evidence of a tradeoff between fruit and foliage production in strawberries.

PITFALLS, CAVEATS, AND FUTURE DIRECTIONS

If I had the opportunity to repeat or expand on the work described here, I would take the following into account.

Replication

Excitement and ambition to answer as many questions as possible in order to fully understand the potential for agriculture on green roofs and restrictions on space and building resources led to a lack of replicates for many of those questions. The boxes that were in mixture were also larger than the boxes that were not. Optimally there would have been a number of mixture box replications as well as large box replications of native species only and food crops only. This way box size would not have added another variable and boxes could have been used as replicates rather than individual plants.

Time

Inherently, the nature of evaluating the success of perennials cannot sufficiently be completed in one summer. Many perennials take a season to establish themselves and therefore growth patterns might be entirely different from the first to second season (Grese 2007). It would have been optimal to compile results from at least a few years. Also, it would be preferable to have more time prior to the growing season to make plant vendor contacts, design the experiment, and construct the boxes. It is fairly difficult to acquire large quantities of uncommon species without contacting vendors a season early. This experiment had to make some species changes at the last minute for this reason.

Species Variation

Although the eight species that were used were selected deliberately and have been informative, it would be beneficial to test many more native species and food crops in order to answer the broad questions of: is there potential for agriculture on extensive green roofs and can native species and food crops be incorporated into the same extensive green roof system. Many food crops that would optimally be grown on green roofs are much more nutrient and water dependent than the ones used in this experiment. Potential for production of a more diverse group of food crops would probably be more appealing to consumers than herbs and strawberries. Perhaps a drip irrigation system (low quantity of water) could aid in making this diversity possible. Also, green roofs could be analyzed for their potential to make money on the food that they produce. Due to the size of any given roof, it might be more economical to grow herbs rather than wheat, for example. With the potential for food production, economic analyses of value should include more than the cost of construction to install green roofs.

Box Construction

Having the boxes on a slight slope for drainage purposes added a variable that was not properly accounted for. Due to the water slowly running down the gradient of the slope the plants at the north end, downhill side, of each box were subjected to a higher volume of water. In the future having more replicates and mixing up the order of which plants were on the north side would eliminate this confounding variable.

Measurements

It could have been useful to do a series of size measurements beyond initial and final. This might show different rates of establishment, phases of dying back, and phases of re-sprouting by species or any of the other variables tested. There also may have been a more precise method of measurement. Most plants do not grow out from the base of the plant in a perfect circle, which makes an average diameter measurement difficult. Plants also do not always grow straight up in the air, which makes a height measurement difficult.

It also would have been useful to have initial and final biomasses, rather than just final. Although like sized plants were equally distributed throughout each box and plot so that each box or plot had an equal combination of sizes, this distribution was performed visually rather than by weight, which would have been more precise. Further, a root biomass would have been informative if it had been possible to do an initial biomass.

Finally, it would have been useful to analyze plant growth rate in comparison to rainfall in order to determine whether or not growth rate was a function of rainfall. This is important in determining the feasibility of growing food crops on extensive green roofs. The summer in which this research was performed, 2007, was dryer than average for southeast Michigan, so it was implied that if food crops could survive under these conditions without irrigation then they would likely survive most other summers. However, looking into the specific details of rainfall and plant growth interaction could provide additional insight.

Soil

All of the soil needed to have come from the same source at the same time or each source needed to have been mixed together thoroughly. In this research, the small boxes that were provided came with dirt in them that had been sitting out (some inside, some outside) for at least one growing season. This inconsistency, potentially, created an unnecessary confounding variable. If each box would have had the same mixture of soil, analyses of soil respiration would have been performed, as soil samples were collected for these purposes. Consistency in soil conditions is important because over time pore space within the soil might change due to settling, changes in organic matter, decaying roots, and burrowing animals, which have the potential to change growth rates, water content, and dry weights (Getter et al. 2007).

Feasibility in Practice

The simple fact that food crops can be grown on extensive green roofs does not mean that this practice will be implemented or that there is one best or prescribed method for what to plant or how to plant it. Complexity in ecosystem dynamics that is yet to be fully understood makes prescribing one solution across a broad spectrum dangerous (Lindenmayer et al. 2007). Questions of extensive roof access, labor for harvesting, and consumer values are critical to implementation, but have not been addressed here. This research has attempted to contribute to an understanding of the vegetation potential in which other research needs to build upon. In order to facilitate implementation and to make change, dialogue between ecologists, social scientists, consumers, and engineers is the critical next step in our interconnected world.

CONCLUSION

After conducting this research, it can be concluded that there is potential to integrate food crops and Michigan native plants into the same extensive green roof system. Results indicated that food crops grew more (change in diameter, change in height, and dry weight) in mixture with native plants than alone and both food crops and native plants grew more (change in diameter, change in height, and dry weight) in deeper plots than in shallow boxes or the ground. For food crops, there was a higher water content in shallow plots than in deep plots. More strawberry fruits were produced in the deep plots.

In planning the construction of a green roof to incorporate food, one might consider using a 15.24cm substrate depth and planting native plants along with food crops, if at all possible.

As green roofs have become almost standard in nations like Germany, there is no reason that the United States cannot follow this initiative. The general public needs to become informed on the value of green roofs for the environment and their own health, an easy-to-manage building construction template must be created, the government should consider some form of tax break for implementation, and more quantifiable research on the value of green roofs must be performed and published.

ACKNOWLEDGEMENTS

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Katherine Superfisky, a fellow student who provided a necessary second set of hands throughout the process.

APPENDIX A

Figure A1: A picture of the boxes and ground plots prior to planting.

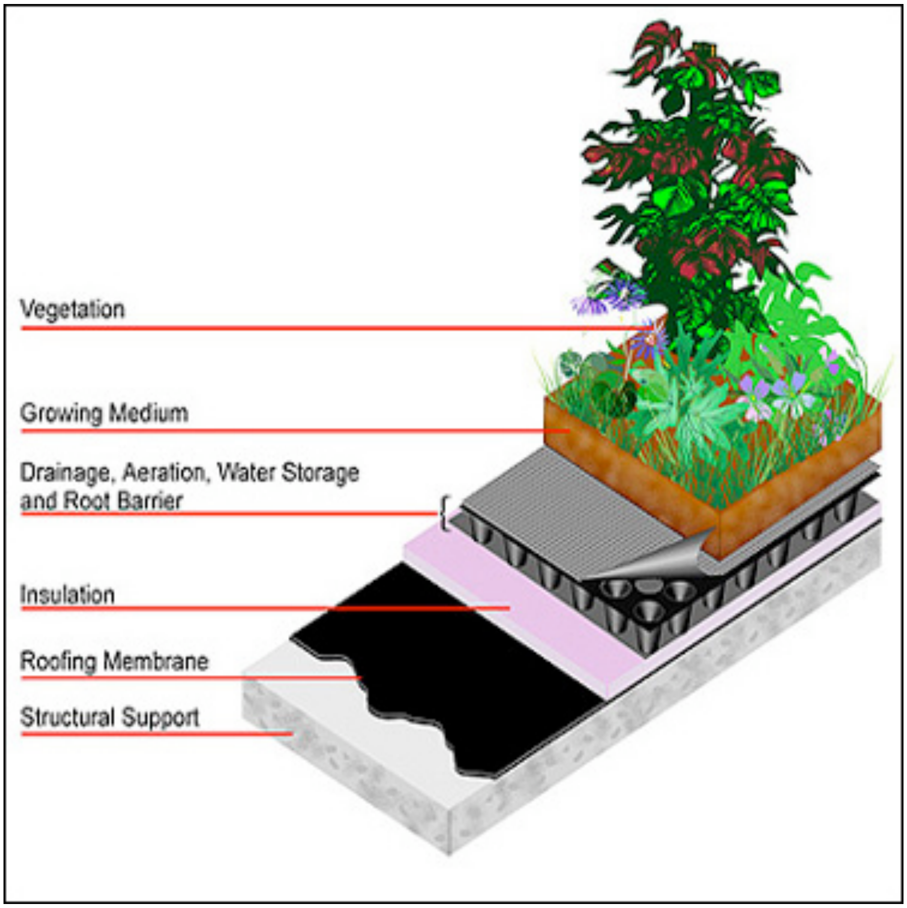


Figure A2: Diagram of typical green roof layers (Scott 2006).

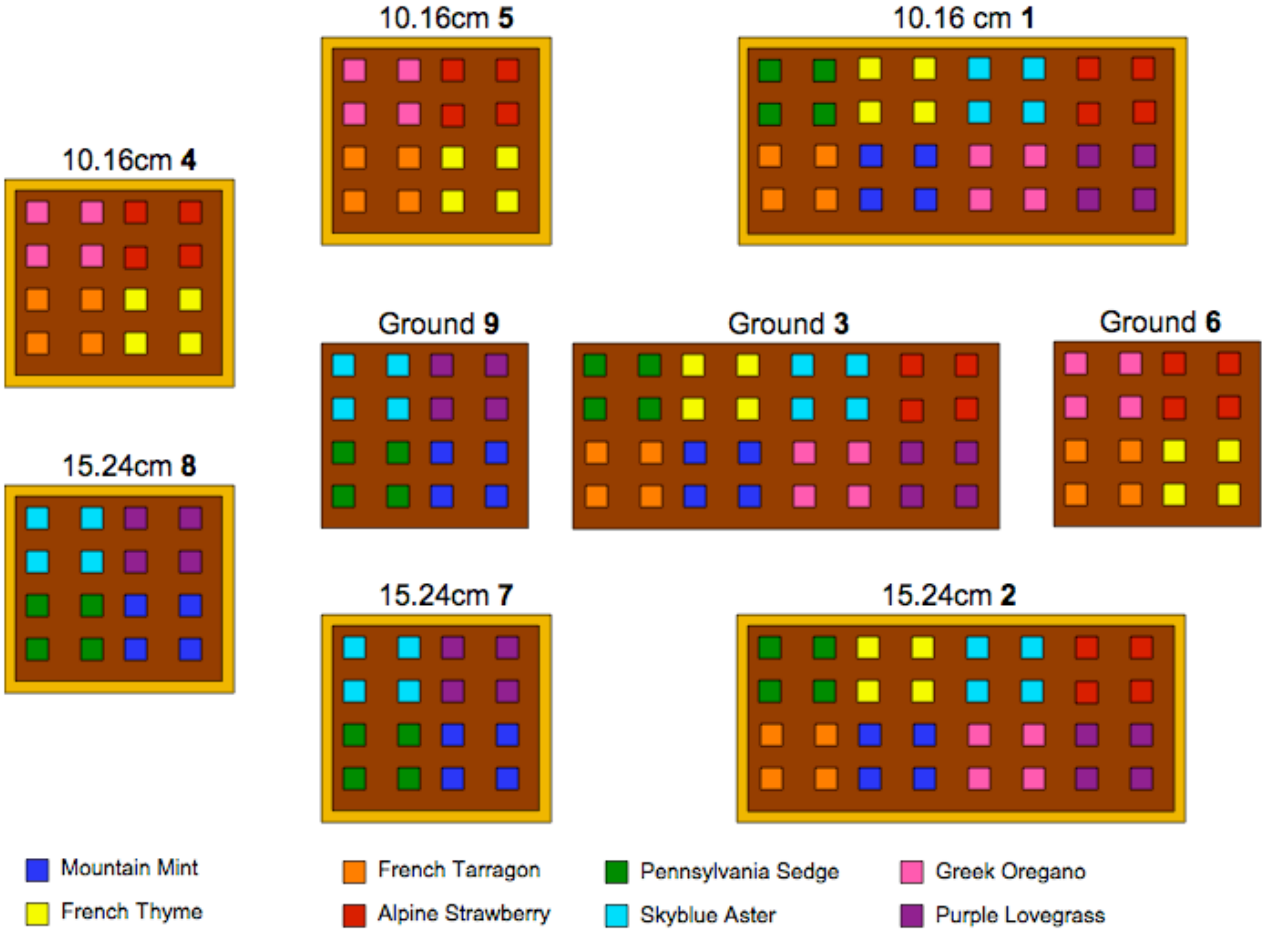


Figure A3: Diagram of plot layout.

Figure A4: Plants were planted an equal distance from the box edges and other plants.

Figure A5: Measuring technique. A tape measure was used to measure the average diameter and height (when plant was held up straight) of each plant at the beginning and end of the growing period.

Figure A6: Weeds (Common purslane) in plot 7, mid summer.

Figure A7: Plants were cut and stored in Ziploc bags.

APPENDIX B

HOW TO BUILD GREEN ROOF RESEARCH MODULES:

STEP – BY – STEP INSTRUCTIONS

BY JOEL PERKOVICH

CONTENTS

LUMBER MATERIALS AND COSTS FOR 16 GREEN ROOF MODULES

QUANTITY	MATERIAL	ESTIMATED COST ($)
17	3/4"x4'x8' CDX PLYWOOD, UNTREATED	459
9	2x6x10' CEDAR, ROUGH, #2 OR BETTER (TYP)	143
46	23 2x4Xx6' CEDAR	255
12	2x8x14 CEDAR	410
12	2x10x14' CEDAR	465
39	2x6x14' SPF, # 2 OR BETTER	546
17	4x4x12' CEDAR	552
HARDWARE	CAN VARY DEPENDING ON FASTENERS USED (3" DECK SCREWS OR FINISH NAILS, 2" DECK SCREWS, ROOFING NAILS, 130, ¼" DIAMETER, CARRIAGE BOLTS)	100
	TOTAL	**$2,930**

?

add spaces after "x" and foot + inch marks for actual dimensions

NOTES

- FASTENERS USED ON CEDAR TO BE STAINLESS STEEL, ALL OTHERS TO BE GALVANIZED
- ALL LUMBER #2 OR BETTER
- GREEN ROOF COMPONENTS (DRAINAGE LAYER, WATERPROOF MEMBRANE, ROOT BARRIER) WILL VARY IN COSTS DEPENDING ON BRAND NAME AND SUPPLIER)
- POST-SLEEVE DESIGN ALLOWS MODULES TO BE EASILY DISASSEMBLED AND RELOCATED WHILE LEAVING MODULE STRUCTURE IN TACT
- MATERIALS QUANTITIES CALCULATE FOR APPROXIMATELY 10% EXTRA

HAPPY BUILDING!...

I.

HOW TO BUILD GREEN ROOF RESEARCH MODULES: STEP BY STEP INSTRUCTIONS

1. CONSTRUCT 46" X 48" ROOF DECK FRAME USING 2X6 SPF LUMBER. ASSEMBLE WITH FRAMING NAILER OR 3" DECK SCREWS. THE ONE CENTRAL JOIST MUST RUN PARALLEL WITH THE 46" SIDES AND IS 24" OC.

2. ATTACH 48" X 48" EXTERIOR GRADE, *UNTREATED* PLYWOOD TO FRAME. (TREATED PLYWOOD MAY AFFECT BONDING STRENGTH OF WATERPROOF MEMBRANE.) ALLOW 2" OVERHANG ON ONE OF THE SHORT 46" ENDS. ASSURE ALL OTHER EDGES ARE FLUSH WITH FRAME. ATTACH WITH FRAMING NAILER OR 3" DECK SCREWS, 8" OC. <u>SEE DETAIL 1A</u>.

3. CONSTRUCT POST SLEEVES USING 2X6 SPF FOR SIDES AND 2X4 SPF FOR TOP. CUT 2X4 TOP INTO 3 ½" SQUARE TO ALLOW SNUG FIT OF A 4 X 4 POST –USE A 4 X 4 SCRAP FOR A TEMPLATE WHEN CONSTRUCTING SLEEVE TO ASSURE POSTS WILL FIT PROPERLY WHEN INSTALLED IN STEP 12. ATTACH POST SLEEVES TO DECK FRAME CORNERS WITH FOUR 2 ½" DECK SCREWS GOING THROUGH THE EXTERIOR OF THE 2X6 FRAME AND INTO THE SLEEVE EDGES. ALSO, SECURE SLEEVES TO DECK WITH FOUR 2" DECK SCREWS GOING THROUGH DECK INTO TOP OF SLEEVE. <u>SEE DETAIL 2A.</u>

4. ATTACH 2X4 CEDAR TRIM AROUND BASE OF FRAME, EXCEPT TO SIDE WITH 2" OVERHANG. ATTACH 2X6 CEDAR TRIM TO SIDE WITH 2" OVERHANG, SO THAT THE OVERHANG IS NOW ONLY ½". MITER ALL ANGLES. ASSURE BOTTOMS OF TRIM ARE FLUSH WITH BOTTOM OF FRAME. SECURE WITH PAIRS OF 2 ½" DECK SCREWS ABOUT 12" OC. *BE SURE ALL FASTENERS USED FOR CEDAR ARE STAINLESS STEEL TO PREVENT STAINING OF WOOD.*

5. ATTACH MEDIA CONTAINING CEDAR EDGING TO FRAME, DIRECTLY ABOVE THE 2X4 TRIM. FOR MODULES DESIGNED FOR 4" MEDIA DEPTH, USE 2X8S. FOR MODULES DESIGNED FOR 6" MEDIA DEPTH, USE 2X10S. MITER ALL ANGLES. *DO NOT ATTACH ANY EDGING TO SIDE WITH ½" OVERHANG, THIS MUST BE DONE IN STEP 11.* SECURE WITH THREE ¼" DIAMETER CARRIAGE BOLTS. BOLTS SHOULD NOT BE MORE THAN 1 ½" UP FROM BASE OF EDGING TO AVOID PLYWOOD DECK, AND 10" IN FROM EACH EDGE TO AVOID HITTING THE POST SLEEVES. EVENLY SPACE BOLTS ABOUT 12" OC. FOR ADDED STRENGTH AT THE EDGES, CAREFULLY

FASTEN ALL MITERED ANGLES TO ONE ANOTHER WITH THREE 2" DECK SCREWS, THROUGH THE EDGING ON THE 46" SIDE. <u>SEE DETAIL 3A.</u>

6. GENEROUSLY CAULK AND FILL ALL INTERIOR SEAMS WITH VULCAN HEAVY DUTY CAULK, OR OTHER CONSTRUCTION/EXTERIOR GRADE, SILICONE-BASED CAULKING. ALLOW PROPER CURING TIME AS INDICATED ON LABEL.

7. SECURE DRIP EDGE TO OVERHANG WITH ROOFING NAILS.

8. GENEROUSLY AND EVENLY BRUSH TREMCO® WATERPROOF MEMBRANE ONTO DECK AND ON INTERIOR EDGING WALLS. SEAL OVER SEAMS WELL. BE SURE TO EXTEND MEMBRANE COVERAGE JUST BEYOND ALL FASTNER HEADS FOR DRIP EDGE. ALLOW 24 HOURS TO CURE. IF USING AN EPDM WATERPROOF MEMBRANE, FOLLOW INSTALLATION INSTRUCTIONS.

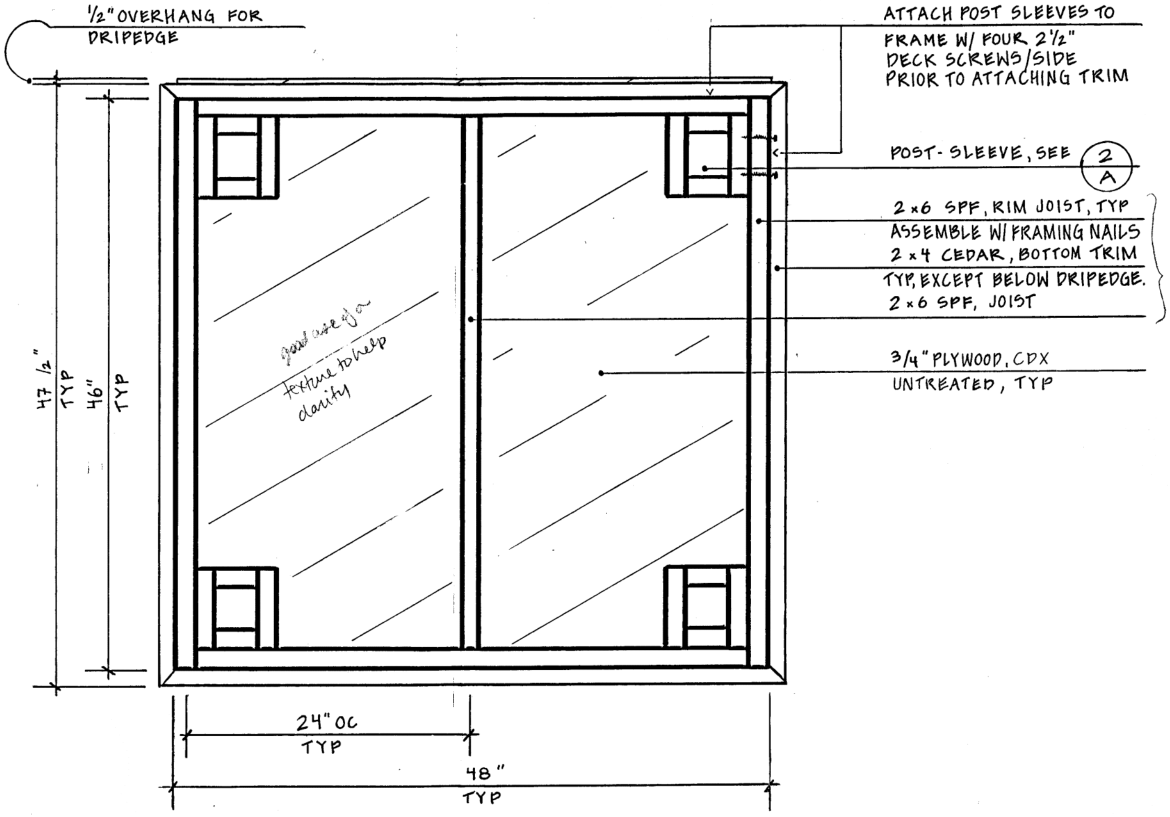
9. INSTALL PVC ROOT BARRIER OVER WATERPROOF MEMBRANE. RUN ROOT BARRIER UP EDGING WALLS, WITHIN 1" OF TOP –MAY USE HEAVY DUTY STAPLER TO SECURE ROOT BARRIER TO WALLS. DO NOT STAPLE INTO DECK.

10. LAY DRAINAGE LAYER TIGHT TO EDGES OF DECK AND WITHIN 1" OF END OF DRIP EDGE.

11. ATTACH FINAL MEDIA EDGING. BOTTOM OF EDGING MUST SIT ON TOP OF DRAINAGE LAYER, SO BOARD MUST BE RIPPED DOWN TO ABOUT 5 7/8" –MAY VARY SLIGHTLY, DOUBLE CHECK. MITER ANGLES. SECURE TO OTHER MITERED EDGE PIECES WITH 2" DECK SCREWS, STARTED THROUGH THE 46" EDGING SIDE. CAULK REMAINING SEAMS AND APPLY WATERPROOF MEMBRANE, ALWAYS ALLOWING FOR PROPER CURING TIME.

12. LAY MODULE TOP DOWN SO UNDERSIDE IS FACING UP. CUT FRONT AND BACK POSTS TO PROPER HEIGHT TO ACHIEVE YOUR DESIRED SLOPE. INSERT 4X4 POSTS INTO SLEEVES. USING ONE ¼" LAG BOLT AND WASHER FOR EACH EXPOSED SLEEVE SIDE, SECURE SLEEVE TO POSTS.

13. FILL MODULE WITH GROWING MEDIA. PLANT!

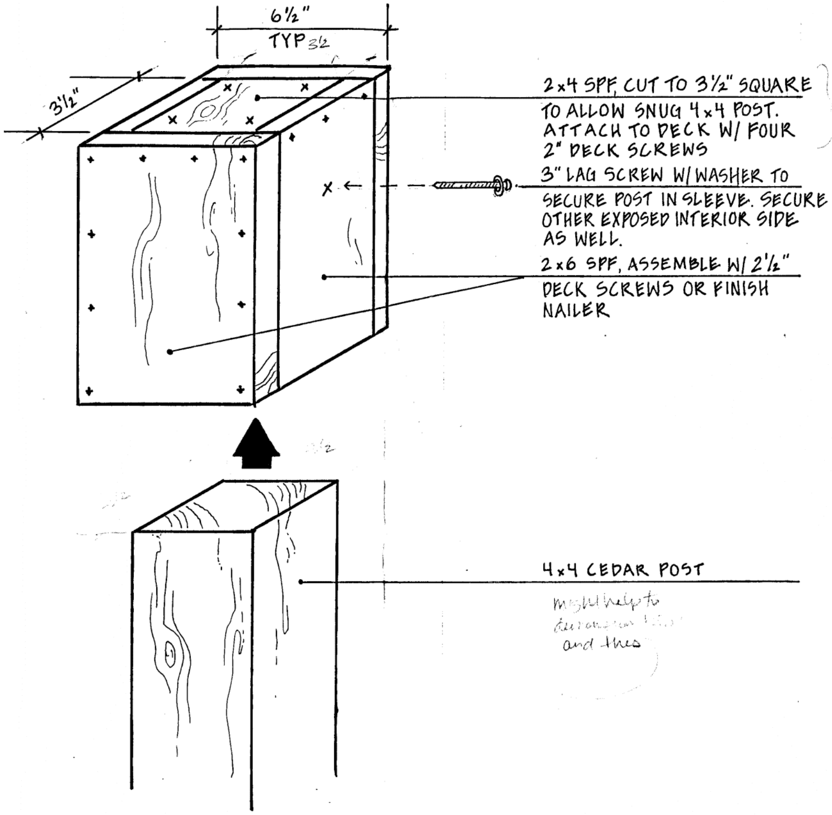


good use of texture to help clarity

SPREAD
SO IT'S C
WHAT NO
GOES W/

1/A GREEN ROOF MODULE FRAMING PLAN

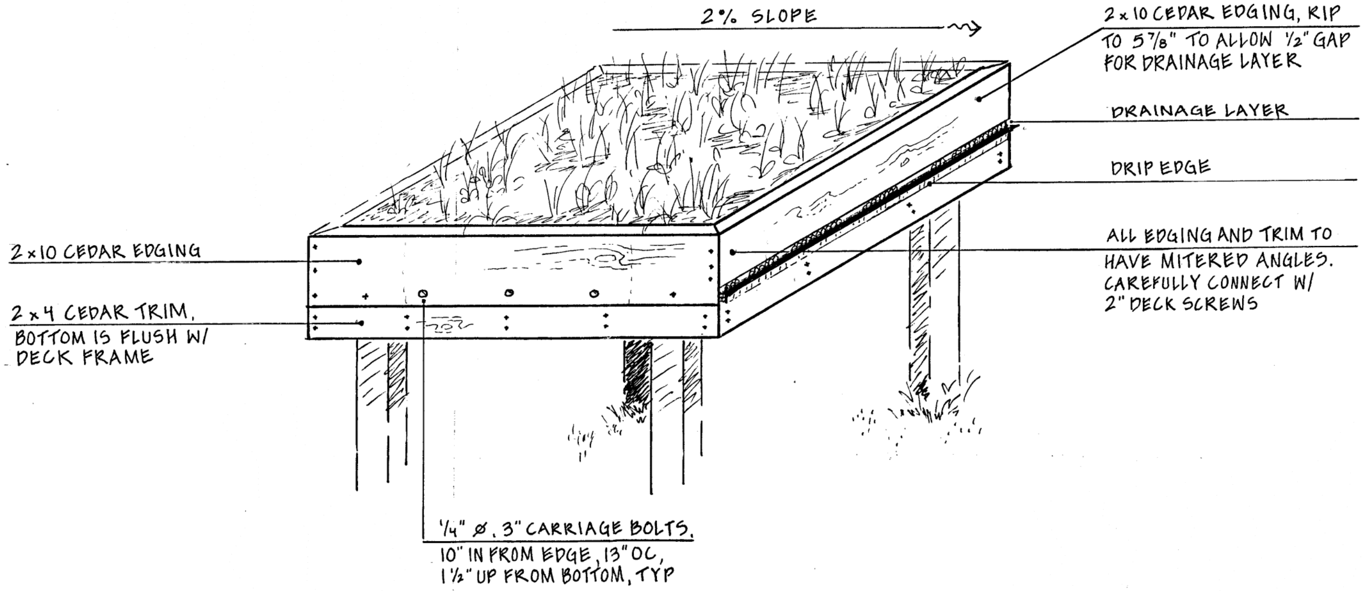
SCALE: 1" = 0'-8"



a lot of stability rests on these fasteners

might help to dimension this and this

2 A POST· SLEEVE SCHEMATIC



3/A GREEN ROOF MODULE, 6" MEDIA DEPTH

3.

APPENDIX C

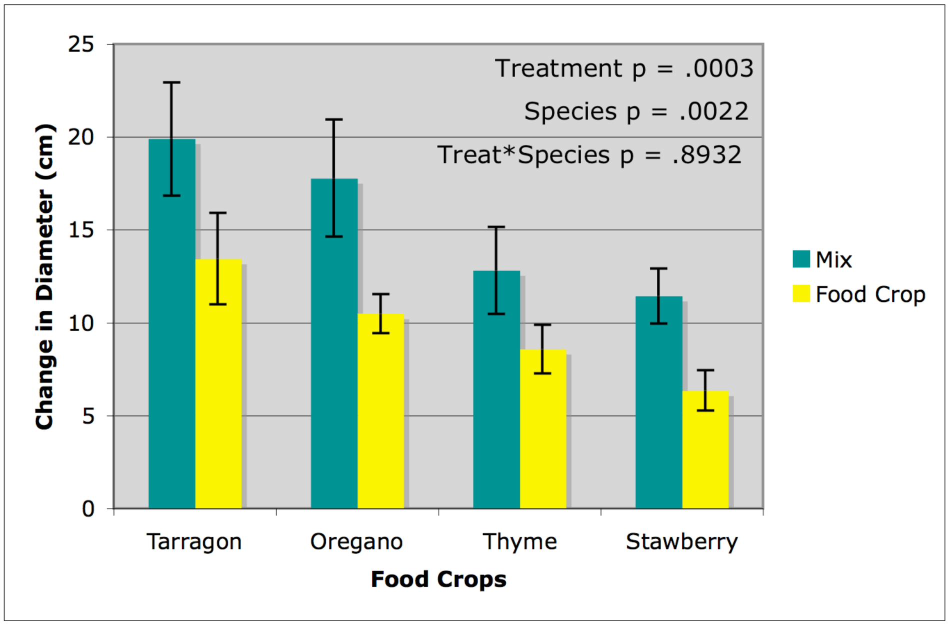


Figure C1: A comparison of plant growth rate (change in diameter) of four food crop species grown in mixture with native plants (green columns) and alone (yellow columns). Columns are the means of 12 samples and bars represent standard errors.

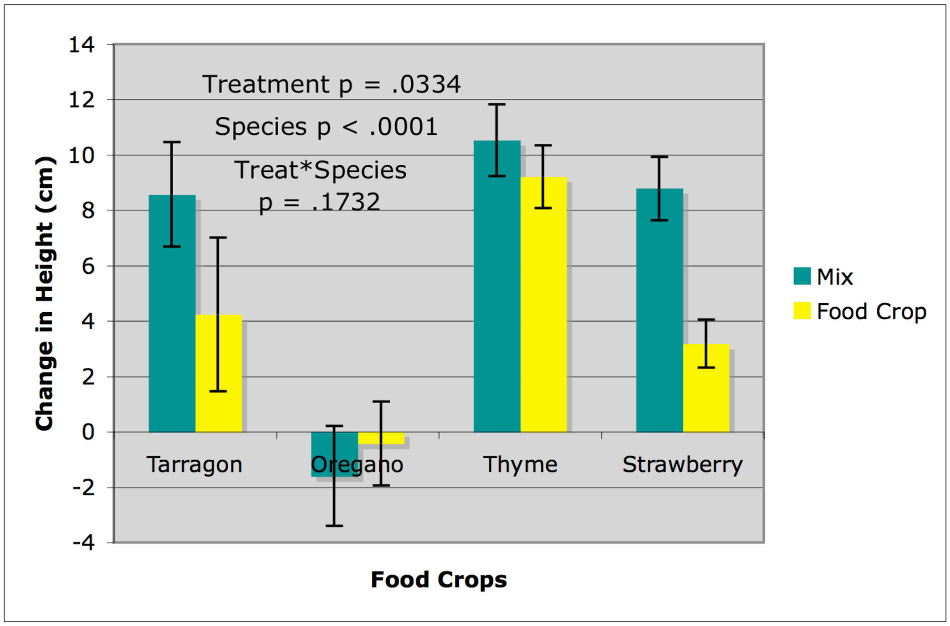


Figure C2: A comparison of plant growth rate (change in height) of four food crop species grown in mixture with native plants (green columns) and alone (yellow columns). Columns are the means of 12 samples and bars represent standard errors.

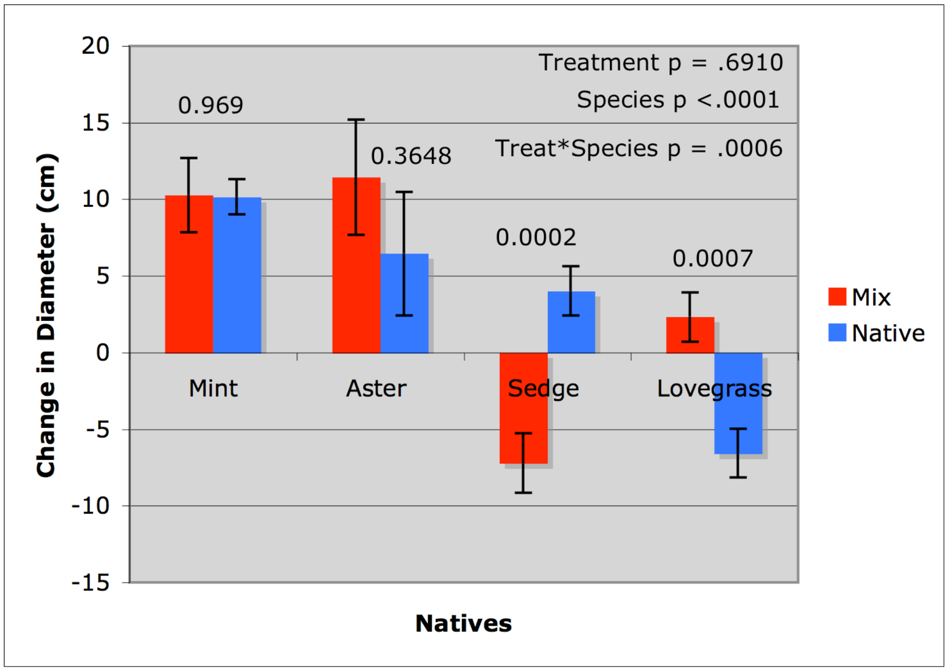


Figure C3: A comparison of plant growth rate (change in diameter) of four native species grown in mixture with food crop species (red columns) and alone (blue columns). Columns are the means of 12 samples and bars represent standard errors.

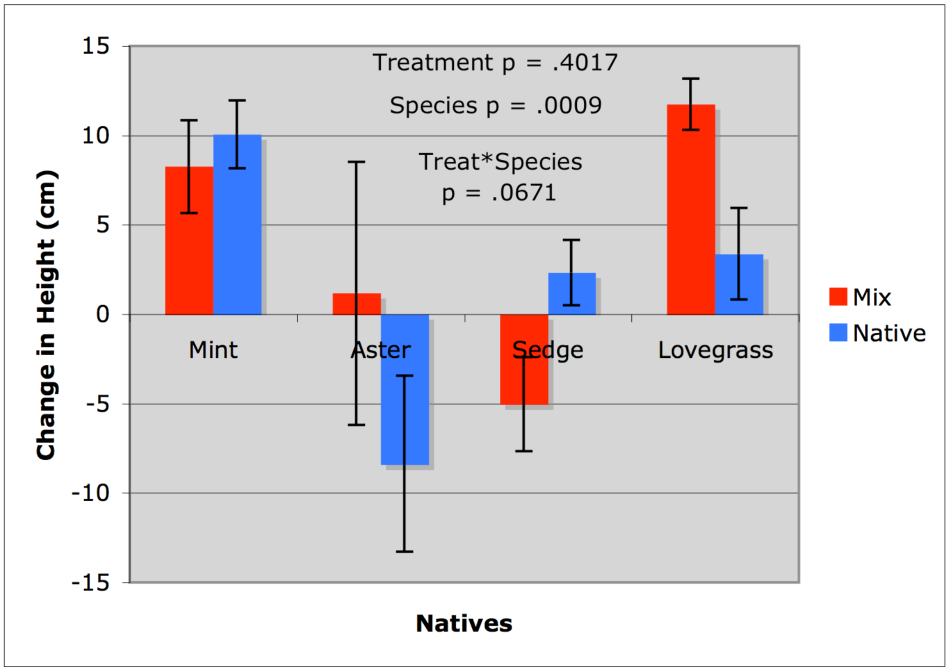


Figure C4: A comparison of plant growth rate (change in height) of four native species grown in mixture with food crop species (red columns) and alone (blue columns). Columns are the means of 12 samples and bars represent standard errors.

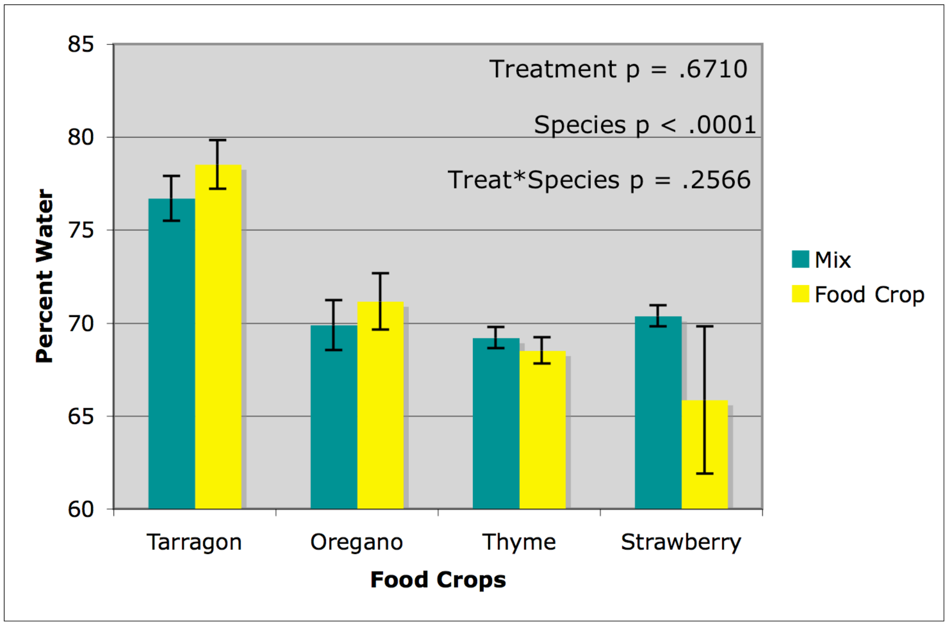


Figure C5: A comparison of plant water content (as a percent of the plant's weight) of four food crop species grown in mixture with natives (green columns) and alone (yellow columns). Columns are the means of 12 samples and bars represent standard errors.

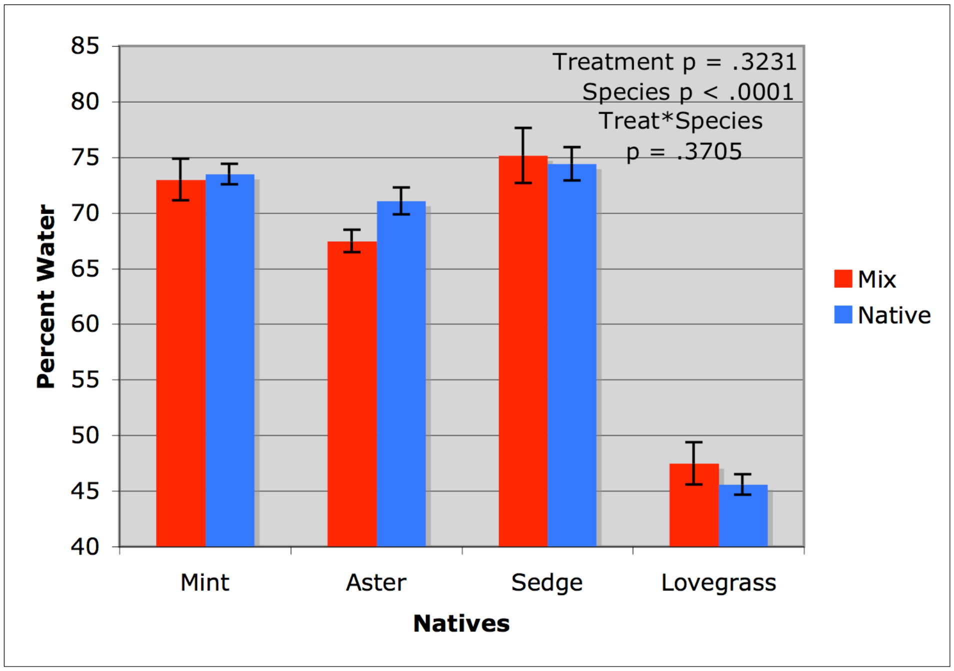


Figure C6: A comparison of plant water content (as a percent of the plant's weight) of four native species grown in mixture with food crops (red columns) and alone (blue columns). Columns are the means of 12 samples (Due to bag weight inconsistency 9 samples were used from Aster mixture, 7 from Aster in native only plots, 7 from Sedge in mixture, and 11 from Sedge in native only plots) and bars represent standard errors.

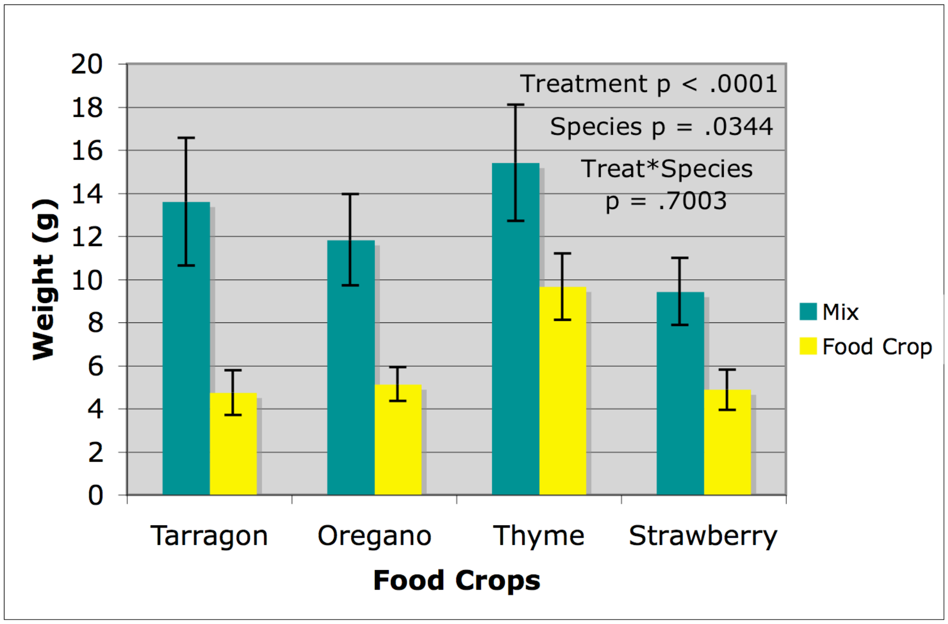


Figure C7: A comparison of plant dry weight (in grams) of four food crop species grown in mixture with natives (green columns) and alone (yellow columns). Columns are the means of 12 samples and bars represent standard errors.

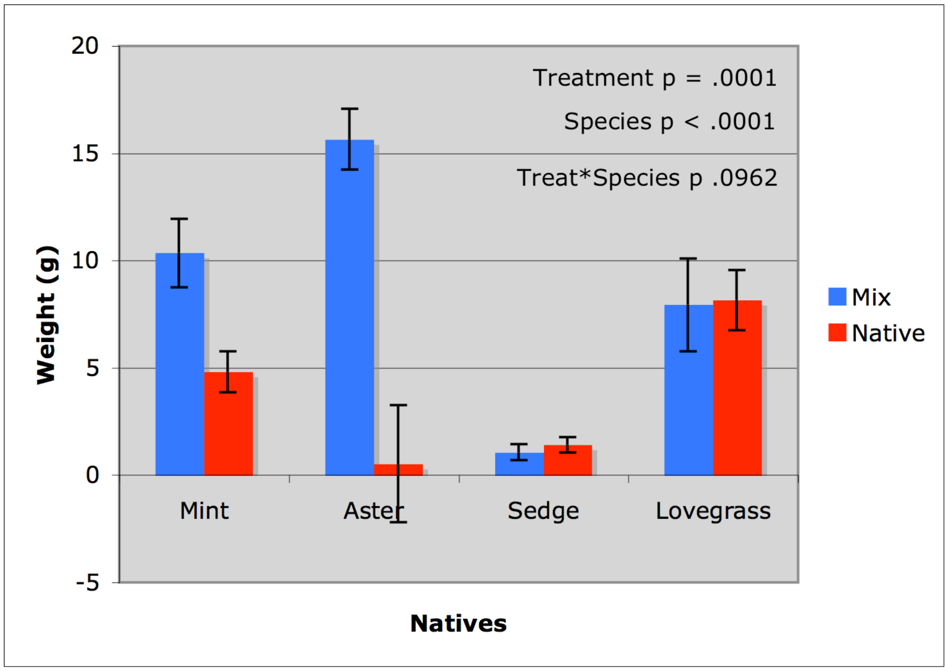


Figure C8: A comparison of plant dry weight (in grams) of four native species grown in mixture with food crops (blue columns) and alone (red columns). Columns are the means of 12 samples (Due to bag weight inconsistency, as detailed in methods, 9 samples were used for Aster in mixture, 8 from Aster in native only plots, 7 from Sedge in mixture, and 11 from Sedge in native only plots) and bars represent standard errors.

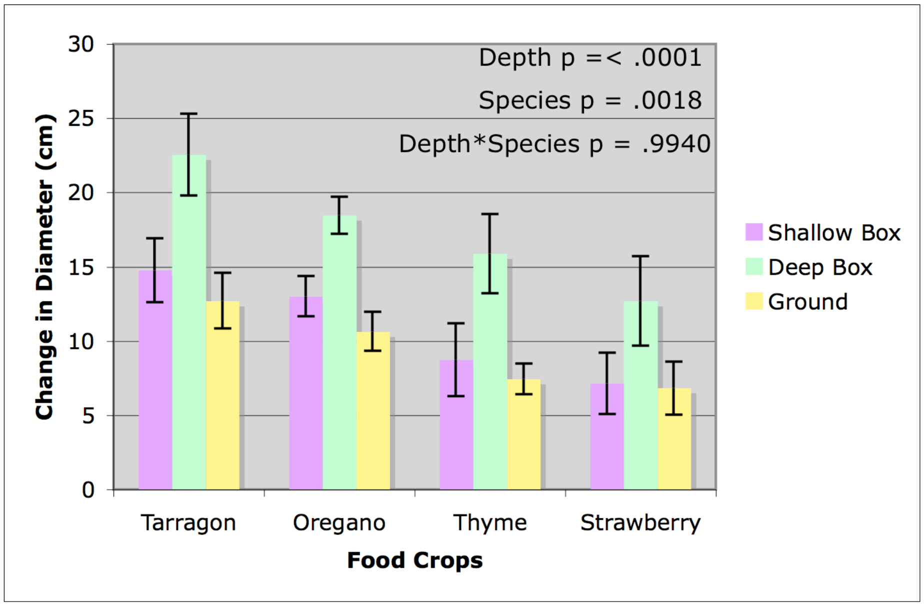


Figure C9: A comparison of plant growth rate (change in diameter) of four food crop species grown in depths of 10.16cm (purple columns), 15.24cm (green columns), and a depth unrestricted ground plot (yellow columns). Columns are the means of eight samples and bars represent standard errors.

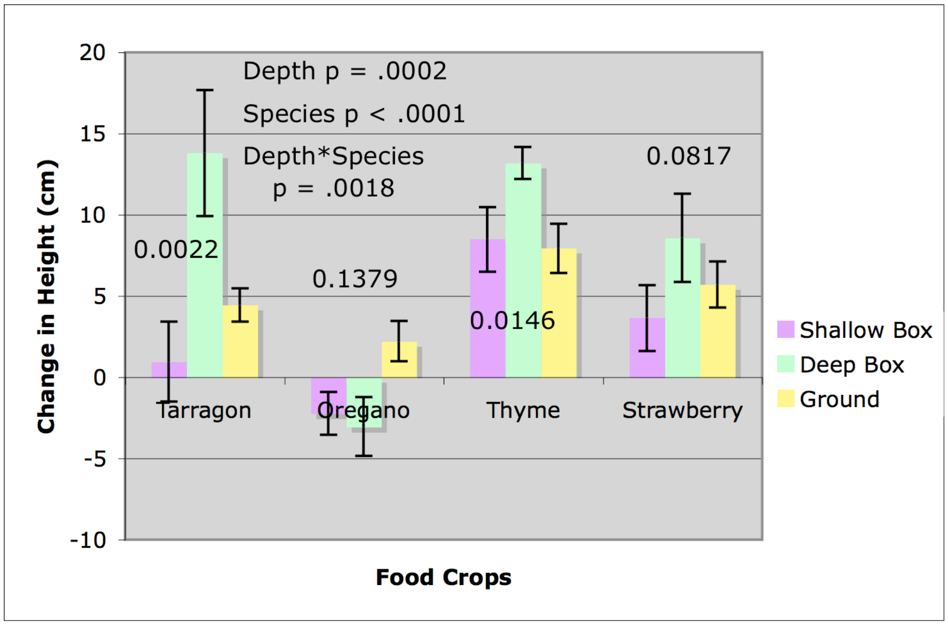


Figure C10: A comparison of plant growth rate (change in height) of four food crop species grown in depths of 10.16cm (purple columns), 15.24cm (green columns), and a depth unrestricted ground plot (yellow columns). Columns are the means of eight samples and bars represent standard errors.

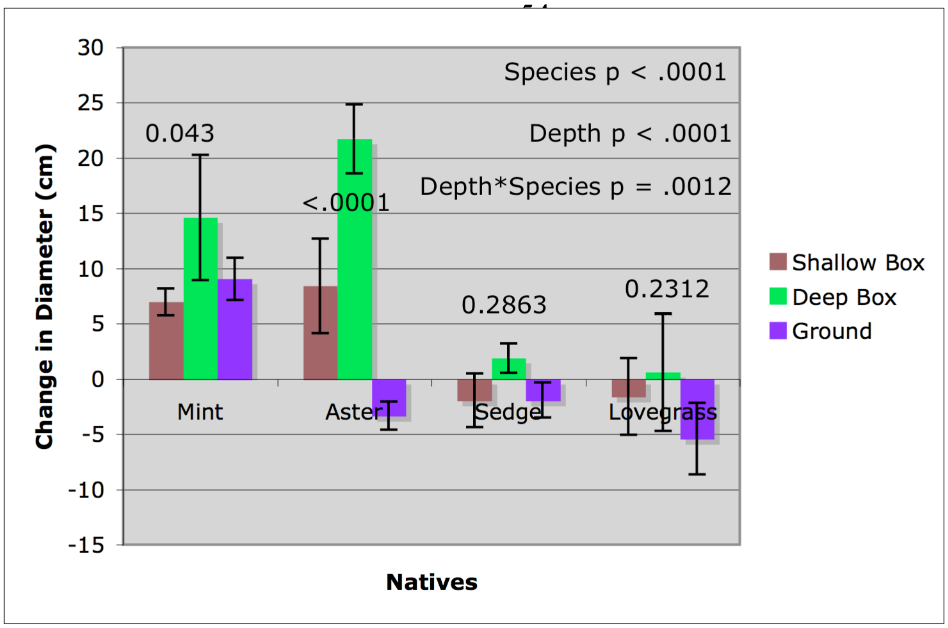


Figure C11: A comparison of plant growth (change in diameter) of native species grown in depths of 10.16cm (brown columns), 15.24cm (green columns), and a depth unrestricted ground plot (purple columns). Columns are the means of eight samples and bars represent standard errors.

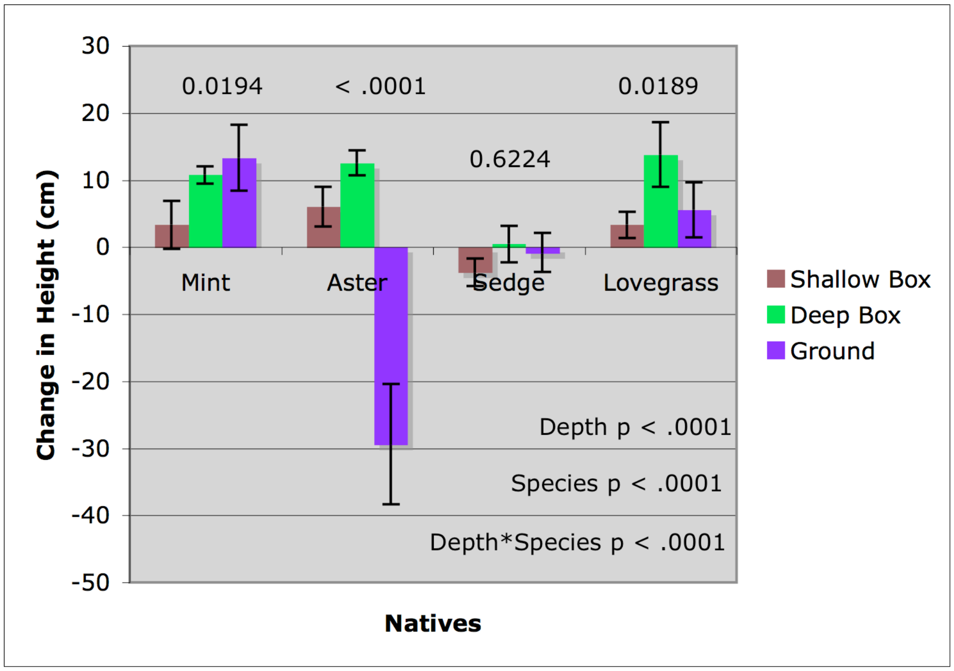


Figure C12: A comparison of plant growth (change in height) of four native species grown in depths of 10.16cm (brown columns), 15.24cm (green columns), and a depth unrestricted ground plot (purple columns). Columns are the means of eight samples and bars represent standard errors.

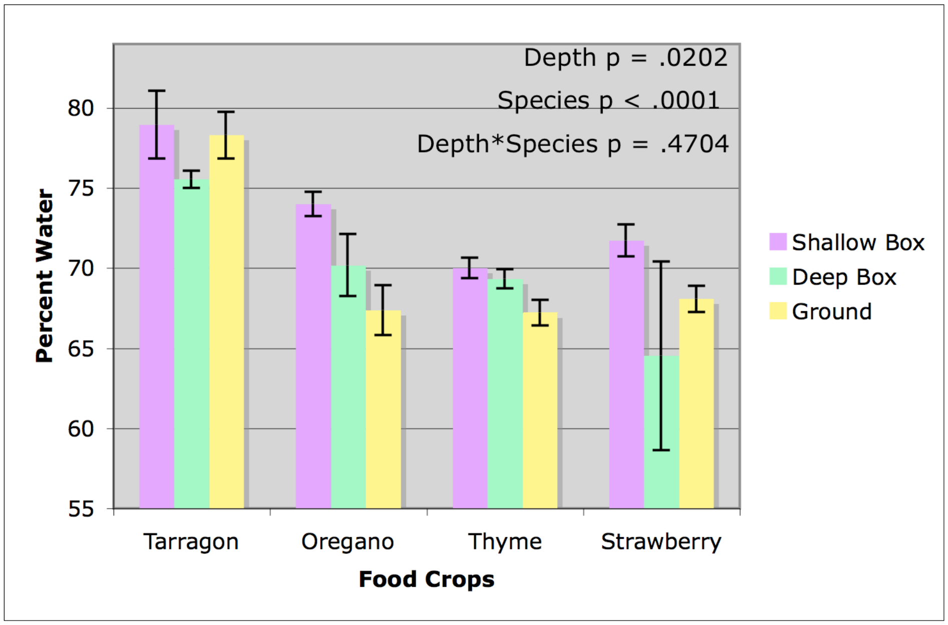


Figure C13: A comparison of plant water content (as a percent of the plant's weight) of four food crop species grown in depths of 10.16cm (purple columns), 15.24cm (green columns), and a depth unrestricted ground plot (yellow columns). Columns are the means of eight samples and bars represent standard errors.

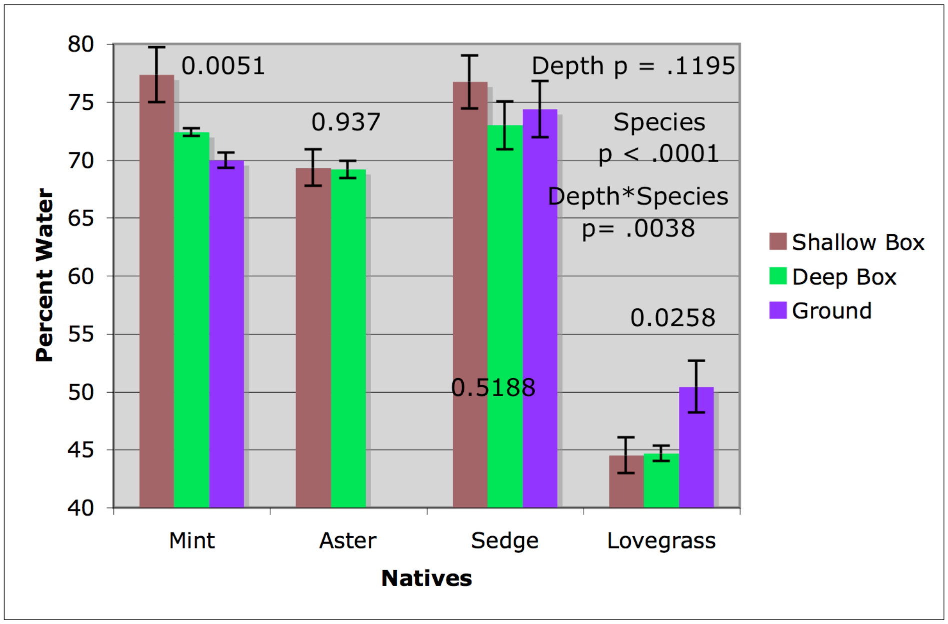


Figure C14: A comparison of plant water content (as a percent of the plant's weight) of four native species grown in depths of 10.16cm (brown columns), 15.24cm (green columns), and a depth unrestricted ground plot (purple columns). Columns are the means of eight samples (Due to bag weight inconsistency Aster ground plots were not used and only six samples were used for Sedge shallow boxes, deep boxes, and ground plots) and bars represent standard errors.

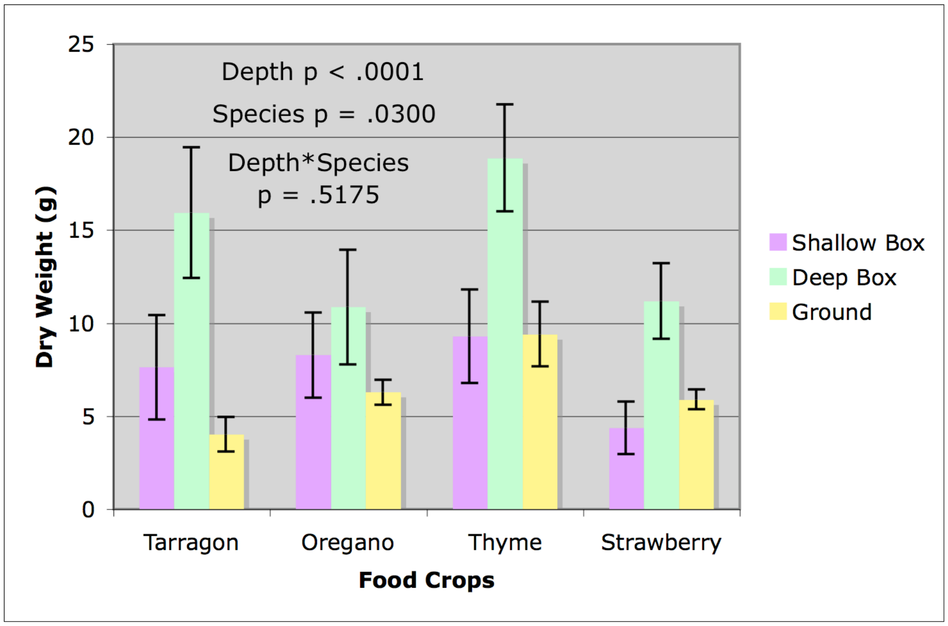


Figure C15: A comparison of plant dry weight (in grams) of four food crop species grown in depths of 10.16cm (purple columns), 15.24cm (green columns), and a depth unrestricted ground plot (yellow columns). Columns are the means of eight samples and bars represent standard errors.

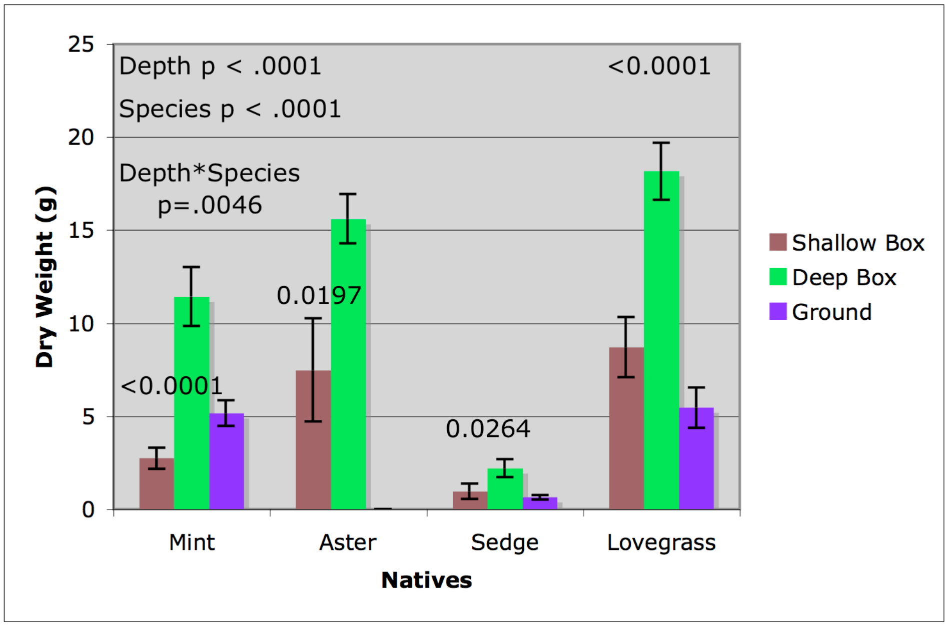


Figure C16: A comparison of plant dry weight (in grams) of four native species grown in depths of 10.16cm (brown columns), 15.24cm (green columns), and a depth unrestricted ground plot (purple columns). Columns are the means of eight samples (Due to bag weight inconsistency, as detailed in methods, samples from Aster in ground plots was not used and six samples were used for Sedge shallow boxes, deep boxes, and ground plots) and bars represent standard errors.

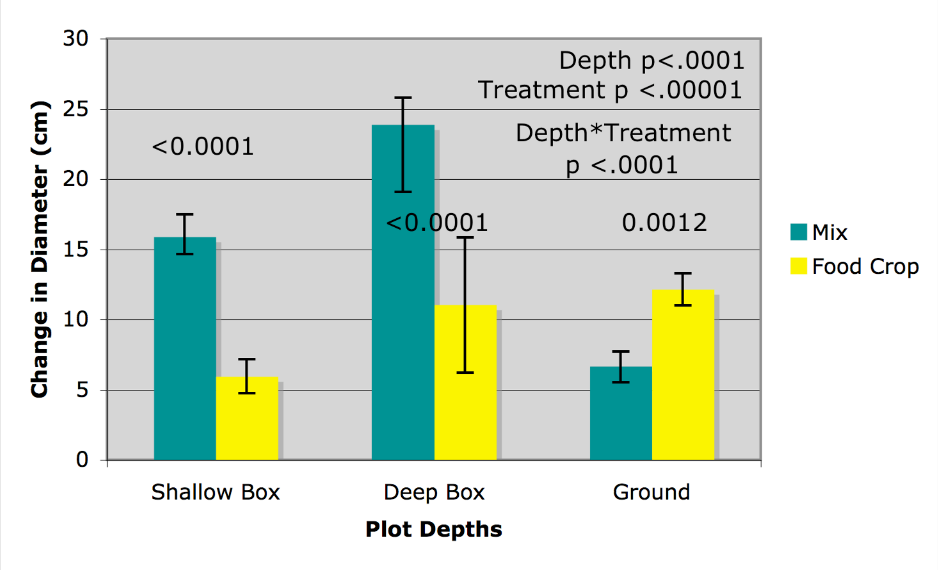


Figure C17: A comparison of plant growth rate (change in diameter) of plot depths of 10.16cm, 15.24cm, and a depth unrestricted ground plot for food crops in mixture (green columns) and alone (yellow columns). Columns are the means of 16 samples and bars represent standard errors.

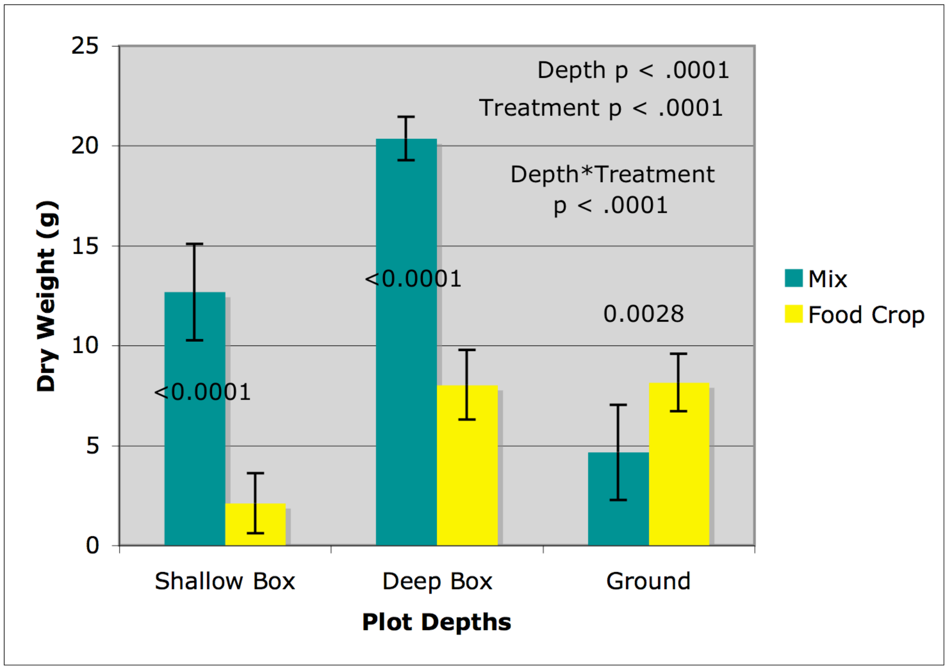


Figure C18: A comparison of plant dry weight (in grams) of plot depths of 10.16cm (“Shallow Box”), 15.24cm (“Deep Box”), and a depth unrestricted ground plot (“Ground”) for food crops in mixture (green columns) and alone (yellow columns). Columns are the means of 16 samples and bars represent standard errors.

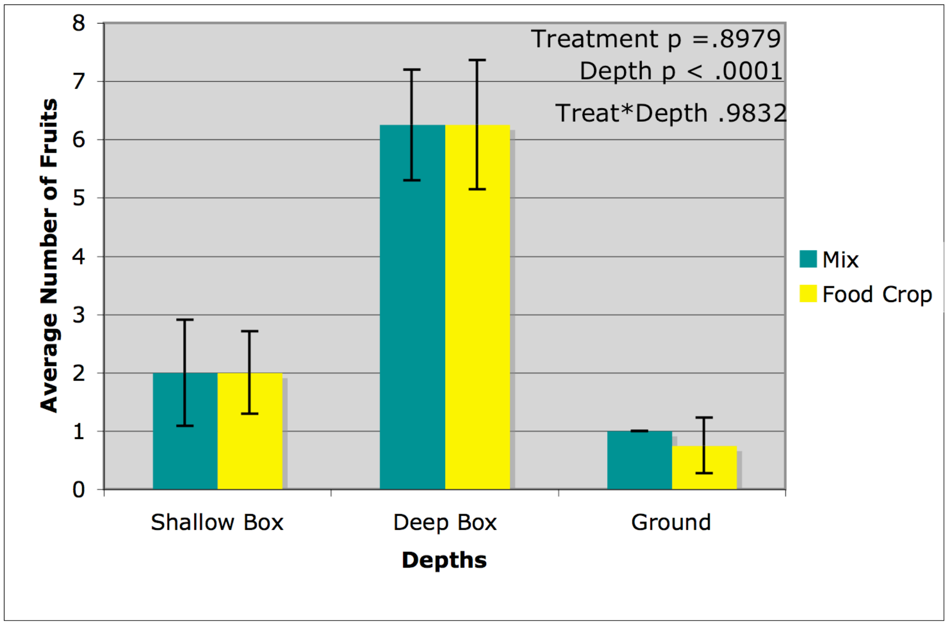


Figure C19: A comparison of the number of fruits on strawberry plants in mixture (green columns) and alone (yellow columns) in 10.16cm shallow plots, 15.24cm deep plots, and unrestricted ground plots. Columns are the means of 8 samples and bars represent standard errors.

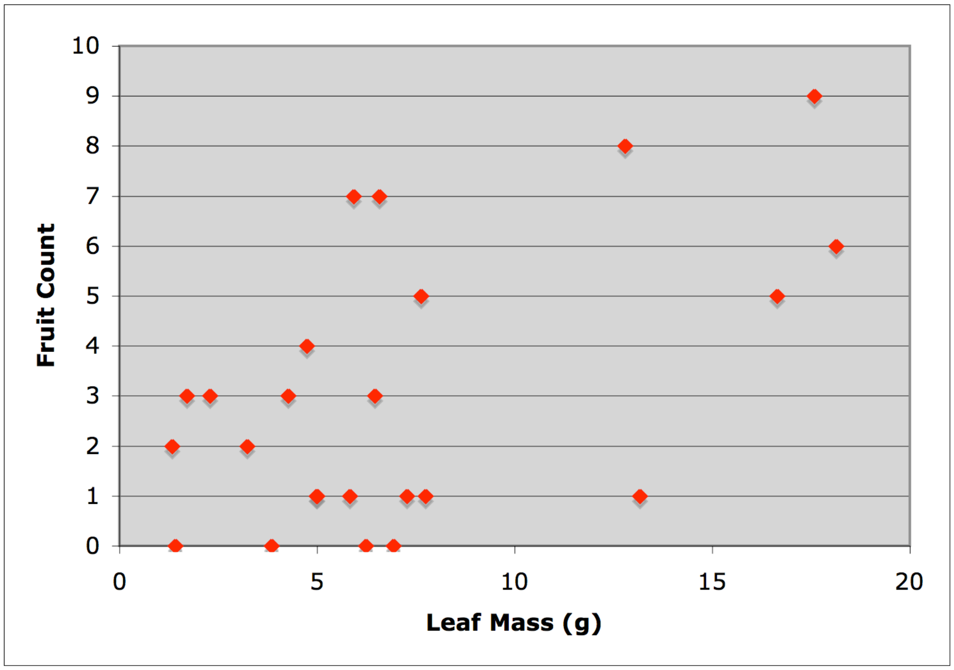


Figure C20: A comparison of fruit count in relationship to leaf mass. Red points represent each strawberry plant.

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