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EVALUATION OF GROWING MEDIA FOR ANNUAL HERB PRODUCTION IN GREEN ROOF MODULAR TRAYS

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EVALUATION OF GROWING MEDIA FOR ANNUAL HERB PRODUCTION IN GREEN ROOF MODULAR TRAYS

by

Mary Margaret Fischer

B.S., Southern Illinois University, 2007

A Thesis
Submitted in Partial Fulfillment of the Requirements for the
Masters of Science

Department of Plant, Soil and Agricultural Systems
Southern Illinois University Carbondale
August 2012

THESIS APPROVAL

EVALUATION OF GROWING MEDIA FOR ANNUAL HERB PRODUCTION IN GREEN ROOF MODULAR TRAYS

By

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A Thesis Submitted in Partial

Fulfillment of the Requirements

for the Degree of

Masters of Science

in the field of Plant, Soil and Agricultural Systems

Approved by:

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AN ABSTRACT OF THE THESIS OF

Mary Margaret Fischer, for the Master of Science degree in Plant, Soil and Agricultural Systems.

TITLE: EVALUATION OF GROWING MEDIA FOR ANNUAL HERB PRODUCTION IN GREEN ROOF MODULAR TRAYS

MAJOR PROFESSOR: Karen Stoelzle Midden

Extensive urban development has led to the resurgence of green roofs. These vegetated roofs provide significant ecological and economic benefits including mitigation of the urban heat island effect, reduced storm-water runoff, lower energy costs, increased biodiversity, and improved aesthetics, as well as food production and security.

Urban agriculture and food security are becoming increasingly important factors of the green roof renaissance. Due to weight load limitations of potential buildings, the ability to produce quality food in shallow media, less than 6.75 cm, could encourage green roof food production. The effectiveness of a commercially available green roof media and a vermicompost custom blended green roof media was evaluated in two experiments on the roof of the Agriculture building at Southern Illinois University Carbondale. In a randomized complete block design, twelve green roof modular trays (six 61 cm x 61 cm and six 46 cm x 56 cm) were filled to the depth of 5.72 cm with each media type. Each block consisted of four treatments with three replications in two locations on the roof. One location received full sun and the other only partial shade. Two commercially-grown annual herbs, sweet basil (*Ocimum basilicum)* and Thai basil (*Albahaca tailandesa*) and parsley (*Petroselinum crispum var. neapolitanum*; *Petroselinum crispum ‘Krausa’*; and *Petroselinum crispum crispum*) were evaluated during the two experiments. The first experiment ran from mid-May to mid-July, 2011, and the second experiment ran from mid-August to late September, 2011. Media content, mineral analysis, and biomass were recorded for each treatment. Hand irrigation was utilized as needed.

In the first experiment, media, and an interaction of sunlight and media produced significant ($P \leq 0.05$) results for parameters of shoot height, shoot width and shoot weight. Sunlight, specifically partial shade, produced significant ($P \leq 0.05$) for shoot to root ratio. The commercially available green roof media produced more significant results for the parameters measured than the vermicompost-blend.

In the second experiment, an interaction was detected for basil shoot width; otherwise all other variables evaluated for basil were insignificant. Media, specifically the commercial green roof media, was significant ($p \leq 0.05$) for parsley shoot height, with an interaction of sunlight and media; shoot weight and dry shoot weight, and with an interaction of sunlight and media for shoot width. No significant results were observed with the other parameters measured.

The experiments indicated that the production of annual herbs on a green roof environment is possible. Further, the experiments found that the commercially available green roof media performed better than the custom vermicompost blend. Modular tray type had limited effect on results, but the advantage of pre-planting the trays before placement onto a green roof environment is an incentive for its use.

DEDICATION

I dedicate this work in loving memory to three people who departed my life too soon: my father, Dr. Christian Fischer, Jr., who taught Reproductive Physiology in the Animal Science Department of Southeastern Louisiana University for 40 years; my oldest twin son, Daniel Martin, my “Dan, the Man”; and my only daughter, Bonnie Anne, who had the most beautiful long red hair. I miss you all, but love never dies. I’ll see you on the flip side.

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CHAPTER 1

LITERATURE REVIEW.

Brief History of Green Roofs

Green roofs, or vegetated roofs, are not recent innovative discoveries. Known also as sod houses and “roof gardens” (Osmundson 1999), green roofs have existed in some form for thousands of years. Green roofs were purposefully designed spaces for religious purposes, protection from the elements, relaxation, entertainment, and food production. Following World War II, development and installation of new green roofs and roof gardens severely declined. It was not until the late 1950s and early 1960s before large-scale public and private roof gardens were designed and built (Osmundson 1999), a trend that continues today.

Contemporary Green Roofs

A green roof is significantly different from a roof garden, though the two terms are often and incorrectly used interchangeably. A green roof is a green space usually designed and installed to cover a large area of a building’s roof in the most economical and efficient means with an emphasis toward financial and ecological benefits. A roof garden is an area usually designed for aesthetic or recreational purposes such as entertaining or as an additional outdoor living space for a building's residents. Planting is often done in free-standing isolated containers and planters located on an accessible roof terrace or deck (Peck and Kuhn 2000). Both green roofs and roof gardens reestablish the relationship between humans and nature that can be lost in urban environments (Ong 2003). The challenge in designing green roofs and roof gardens is to replicate the benefits of green open space while keeping them light and affordable.

Green Roof Guidelines or Directives

The modern understanding, definitions, standards, and application of green roof technology was first developed in Germany following a renewed of interest in green roofs for environmental benefits beginning in the 1960s. By the 1970s, guidelines were needed for the emerging industry. The *Forschungsgesellschaft Landschaftsent-wicklung Landschaftsbau e.v.* or FLL (*Guidelines for the Planning, Execution and Upkeep of Green-Roof Sites*) was developed, published and translated into English for the first time in 1992, updated in 1995, and a new 2002 translation was recently released (Cantor 2008). The FLL Guidelines were recently updated in March, 2008, but are not yet available in English. The 2008 version reportedly has updated values for design loads and water retention of building materials. This includes important changes to the media layer, notably, a single layer intensive application introduced as a result of market trends (Waldbaum 2011). Distinction is now made between single layer (simple) and multiple layer intensive or extensive green roofs. The FLL are currently the most comprehensive guidelines and have formed the basis for development of other regional guidelines.

The Swiss Directives, '*Gründachrichtlinie für Extensivdachbegrüningen',* consists of two different booklets (Waldbaum 2011). The first booklet, developed in 1999 and revised in January 2007, deals with water management and vegetation, ('*Wasserhaushalt und Vegetation').* The second booklet, developed in 2002, deals with the certification for quality assurance and ecological performance (*'Labelvergabe und Ökobilanz')*. Both booklets deal exclusively with extensive green roofs. Therefore, the Swiss refer to the FLL Guidelines for intensive green roofs applications. The Swiss (SFG) award labels on the basis of ecological criteria using Eco-indicator points. The Swiss Directives concentrate on water management and vegetation in relation to local conditions such as climate and plant species.

The Austrian Directive or Austrian Normative Rule (ONR 121131), *(‘Qualitätssicherung im Grünraum – Gründach – Richtlinien für die Planung, Ausführung und Erhaltung’*), ‘Quality Assurance for Green Spaces-Green Roofs-Guidelines for their Planning, Implementation and Maintenance’, were issued in 2002 (Waldbaum 2011). The Austrian Directive also points to the FLL Guidelines and the Swiss Directives as well as the directives from the International Federation of Roofers. The Austrian Directive describes four types of green roofs that are in use in Austria, intensive, reduced intensive, extensive and reduced intensive, with lists of appropriate plants for each. The Austrian Directives main emphasis is on soil quality: chemical components in the soil, soil testing, and inorganic substances in the soil. The Austrians also developed a point system to assess the adequacy of a green roof. The marked difference between the FLL Guidelines and the Austrian Directives is the maximum permitted amounts of nutrients in the media, specifically nitrogen, phosphorus, potassium and magnesium for intensive and extensive green roof applications. Austria has more stringent rules. There is also a difference in the recommended pH value between the three countries. The Swiss Directives recommend pH values between 6.5 and 8.5. The FLL suggests pH values between 6.0 and 8.5 for multi-layer intensive applications and between 6.5 and 8.5 for single-layer intensive and extensive green roof applications. The Austrian Directive recommends pH values between 5.5 and 6.5 (maximum 7.0) for intensive applications and 6.5 to 8.0 for extensive applications (Waldbaum 2011).

The United Kingdom’s (UK) Green Roof Organization (GRO) worked closely with the National Federation of Roofing Contractors (NFRC) in the development of their guidelines. The GRO Green Roof Code: Green Roof Code of Best Practice for the UK 2011 is a basic primer relating to green roof design, specification, installation, and maintenance. The United States (US) has also developed their own guidelines through the American Society for Testing and Materials (ASTM). However, the FLL Guidelines are still considered to be the only time-tested guidelines for green roof construction.

Categories of Green Roofs

Extensive

An extensive green roof is usually an inaccessible installation with a thin growing media (2-2.5cm to 15-15.2 cm) composed of inorganic material. These roofs, typically installed for environmental benefits, may not be intended to be seen (Dunnett and Kingsbury 2008). According to the Greenroofs (Greenroofs 2011), “extensive green roofs can be constructed on roofs with slopes up to 33%, and can be retrofitted onto existing structures with little, or most often, no additional structural support”. Plant materials are usually perennials selected for their limited height, hardiness, adaptability to climatic conditions, and other requirements of the specific roof’s environment or microclimate, and treated en masse, like a grass lawn (Fig. 1.1). These roofs require minimal maintenance (e.g. removal of problem species, etc.). Extensive roofs are generally less expensive than intensive roofs, both in construction and maintenance requirements. Extensive green roof systems can range in weight from 97.6-165.92 kg/m^2. (A Guide to Rooftop Gardens 2000), while Cantor (2008) states the weight range is 48.8-170.9kg/m^2. The average weight of a fully saturated minimum extensive green roof is 82.96 kg/m^2 (Greenroofs 2011) , comparable to the weight of gravel ballast placed on many conventional roofs.

Functional Layers of a Typical Extensive Green Roof

1. Roof deck, Insulation, Waterproofing
2. Protection and Storage Layer
3. Drainage and Capillary Layer
4. Root Permeable Filter Layer
5. Extensive Growing Media
6. Plants and Vegetation

(a)

a. Source: Green Roof Service LLC

(b)

b. Courtesy of Green Roofs for Healthy Cities (www.greenroofs.org)

Figure 1.1. Extensive green roof layer system (a) and extensive residential green roof (b)

Intensive

An intensive green roof has a growing media deeper than 15.2 cm. This greater depth requires a stronger structure to support the additional weight of the growing medium, plant material, and possibly, people. These roofs are intended to be seen (Dunnett and Kingsbury 2008), and often, used for relaxation, entertaining, gardening, etc. (Fig. 1.2). Intensive green roofs can be distinguished from the typical roof garden of container-filled plants by the continuous underlying green roofing layer system. Ideally, these green roofs should have relatively flat roof surfaces (1 - 1.5%) or mild roof slope percentages of up to 3% (Greenroofs 2011). The ecological benefits can be greater due to the natural processes utilized by larger and more diverse plant species (Greenroofs 2011). Other elements which can be found on an intensive green roof may include planters, water features, pergolas or sculptures. These roofs require a higher level of maintenance (Cantor 2008). An intensive green roof system weighs about 244.1 - 1,464.7kg/m^2 (Cantor 2008).

Semi-Extensive, Semi-Intensive or Hybrid

Another type of green roof combines features of both extensive and intensive green roofs. Known as semi-extensive, semi-intensive or hybrid, depending on one’s country of origin, these green roofs have a slightly deeper layer of growing media than extensive green roofs, usually 10-20 cm (± 25%), and can support a wider and more diverse range of plants (Fig. 1.3). These roofs are typically visible and intended for human use (Dunnett and Kingsbury 2008). These roofs have similar low or no-input maintenance requirements as the extensive green roofs. Weight is dependent on depth and type of the media, plants used, and any additional components, such as pavers, benches, etc. (Table 1.1 and Table 1.2).

(a)
Brooklyn Grange, Queens, NY
Courtesy of Green Roofs for Healthy Cities (www.greenroofs.org)

(b)
Gary Comer Youth Center
Courtesy of Green Roofs for Healthy Cities (www.greenroofs.org) and John Ronan

Figure 1.2. Intensive industrial green roof (a) and (b)

(a)
Mountain Equipment Co-op, Toronto, CA
Courtesy of Green Roofs for Healthy Cities (www.greenroofs.org)

(b)
Modular green roof system with low lying shrubs
Courtesy of Green Roofs for Healthy Cities (www.greenroofs.org

Figure 1.3. Semi-extensive, semi-intensive, or hybrid green roof (a) and (b)

Table 1.1: Green Roof Types and Plant Recommendations for Specific Media Depth

Depth of media in cm			4	6	8	10	12	15	20	25	30	35	40	45	50	60	70	80	90	100	125	150	200
Type of green roof and vegetation	Extensive	Moss, sedum	🟩	🟩	🟩																		
		Sedum, moss, herbaceous plants		🟩	🟩	🟩																	
		Sedum, moss, grass plants				🟩	🟩	🟩															
		Grass, herbaceous plants						🟩	🟩	🟩													
	Hybrid	Grass, herbaceous plants					🟩	🟩	🟩	🟩	🟩	🟩											
		Shrubs, bushes					🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩								
		Shrubs, bushes						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩								
		Small trees, shrubs, bushes							🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			
	Intensive	Lawn						🟩	🟩	🟩	🟩	🟩											
		Low-lying shrubs						🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩								
		Medium height shrubs							🟩	🟩	🟩	🟩	🟩	🟩	🟩								
		Tall shrubs, medium shrubs										🟩	🟩	🟩	🟩	🟩	🟩						
		Large bushes, small trees														🟩	🟩	🟩	🟩	🟩	🟩		
		Medium size trees																		🟩	🟩	🟩	🟩
		Large trees																				🟩	🟩

(adapted from the FLL Guidelines, 2002)

Table 1.2. Weight of green roof media materials.

Media Materials	Weight of a 1 cm-layer (kg/m$^{2)}$
Gravel	16-19
Pumice	6.5
Sand	18-22
Top Soil	17-20
Water	10
Lava	8
Perlite	5
Vermiculite	1
Lightweight expanded clay aggregate	3-4

Saturated weights are list, as appropriate.
Data Source: Osmundson (1999) and Johnston and Newton (1993).

Types of Green Roof System Installations

There are two types of green roof system installations: the layer system and the tray or modular system. Each has its benefits and drawbacks. The layer system involves installation of multiple components on top of the roof deck using an edge restraint to define the planting area. These components include a waterproof membrane, root protection barrier, drainage layer, filter mat, growing media and plants. Depending upon the design, some of these components may be omitted. One benefit of a layer system is that it can be adapted to any roof configuration whether rectangular, circular, or such and can effectively cover extremely large areas.

The tray or modular system is individual units which each contain the growing media, a drainage system, and plants (Dunnett and Kingsbury 2008). One advantage of the tray system is the modular size averaging 45.7 cm x 55.9 cm to 116.84 cm x 116.84 cm. Sizes start at a weight one person can handle to larger trays that require two strong workers to handle (Cantor 2008). Modular systems work well in areas that are flat and rectilinear as most trays are square or rectangular shaped. Phased installations are better suited for a tray system as each phase can fit snugly against the previous installation (Cantor 2008). One distinct advantage of the modular system is that the trays can be pre-planted before the installation.

Green Roof System Considerations

One limiting factor used in determining the type of green roof installation is the weight load limit of the building’s roof. The American Society for Testing and Materials (ASTM) under Standard Practice E-2397 has developed a “standardized procedure for predicting the system weight of a green roof system” (American Society for Testing and Materials 2011). Green roofs are designed to support both live and dead weight load limits. Live load weight is transitory in nature, including temporary installations and human traffic and the effects of wind shear

(Dunnett and Kingsbury 2008). Dead load weight accounts for the saturated weight of the roof itself, permanent fixtures like heating and cooling equipment, roofing layers, and rain, snow and ice loads. According to ASTM E-2397, a vegetated roof covering system is required to retain 2.5 cm of moisture at maximum water capacity with wet dead weight of this system not exceeding 97.6 kg/meter^2 (Snodgrass and McIntyre 2010). Live and dead weight load limits are calculated before the green roof weight is determined. Weight load limits determine, not only the type of green roof system installation, but also the types of plants and the depth of the media that can be used in a green roof system. Depth of media for most green roof systems can range from 2.0 cm to 20 cm or more (Dunnett and Kingsbury 2008). Saturated weight loads range from less than 49 kg/m^2 to approximately 98 kg/m^2 for most green roof installations (Wark and Wark 2003).

Friedrich (2005) indicates that green roof media should have these qualities: good drainage and aeration; water retaining capacity without becoming waterlogged or heavy; nutrient holding capacity or cation exchange capacity (CEC); permanent and resistant to decomposition; light weight, yet sturdy to resist wind displacement or shrinkage; and stable in order to support plants. Typical media utilized in a green roof system is soil-less, lighter in weight, and less fertile than ordinary garden or top soil (Dunnett and Kingsbury 2008). Green roof media may include crushed expanded shale, light weight expanded clay, terra cotta, pumice, lava (scoria), expanded slate or crushed brick (Cantor 2008; Dunnett and Kingsbury 2008). FLL guidelines recommend approximately 3-10 % organic materials (mass, based on dry weight) can be added to provide initial nutrients to a newly planted green roof (Cantor 2008). Dunnett and Kingsbury (2008) state that typical commercial green roof mixtures include organic matter between 10% and 20% by volume, and that unless the organic matter is completely decomposed it will rob the substrate of nitrogen as it completes its decomposition.

Leak detection systems, recommended for either system application, can help pinpoint. more precisely, the location of a faulty membrane leak for quick and timely repairs. The latest updated version of the FLL Guidelines, published in March 2008, was prompted by changes in the German waterproofing standards. It also took into account updated values for design loads and water retention of building materials (Waldbaum 2011). The FLL Guidelines have set higher standards testing for resistance to root penetration and resistance to rhizomes, both potential causes of green roof leaks. There are additional considerations in determining which green roof system is best (Martin 2005).

Advantages of Green Roofs

Technical

Storm water management is a major concern and expense to both the residents and local governmental entities of sprawling urban areas. The situation is compounded by the usage of impermeable materials such as concrete, asphalt, and roof tiles to name but a few. These materials form the basic composition of an urban area's streets, sidewalks, rooftops and buildings. Dunnett and Clayden (2007) reported that roofs comprise approximately 40-50% of the impermeable surfaces in urban areas. Nearly all rainfall hitting a non-living roof flows off the roof tops of buildings and houses into the local storm water drainage systems. Due to increased impermeable surfaces in expanding urban areas, these systems often overflow onto the streets and overload the municipal drainage systems. In contrast, a living green roof can absorb much of the rainfall, therefore reducing overflow and flooding (Dunnett and Kingsbury 2008). The International Green Roof Association (IGRA Green Roof Pocket Guide 2011) indicated that between 50 to 90 % of precipitation that falls on a green roof is retained and returned directly to the water cycle via evaporation depending on the type of construction. Media depth is the main determinant of how much water is retained (Dunnett and Kingsbury 2008). Retention differs according to the current roof moisture content. Less rainfall can be retained if there has been a recent rainfall because the media is likely near its water-retaining capacity (VanWoert et al. 2005; Rowe et al. 2003). Season is another determining factor in the amount of water that can be returned to the atmosphere through evapotranspiration. Retention rates in summer can range between 70 and 100%, but in winter only 40 to 50% (Peck 1999).

Major cities like Toronto, Chicago, Vancouver, Portland, London and Copenhagen, are encouraging, implementing, and even mandating the use of green roofs and permeable surfaces (A Guide to Rooftop Gardens 2000). Cities like Portland have created building codes that offer bonuses to developers in new buildings, so that for every 0.09 m^2 of green roof created, they are allowed an additional 0.27 $m^2$of floor space (Dunnett and Kingsbury 2008). Copenhagen recently became the first Scandinavian city to adopt a policy that requires green roofs, not only for all new buildings with roof slopes of less than 30°, but also for retrofits, both public and private (Green Design Will Save the World 2011). As these cities have found, policies must be written to establish a precedent for allowing for green roof usage as a key contributor to storm water management and reduction.

An important part of the early research into green roofs conducted in Germany was building insulation (Dunnett and Kingsbury 2008). Due to the thickness of the entire installation, from waterproofing to plant materials, green roofs have insulating properties. The cooler ambient temperatures that result from the installation of the green roof improve the efficiency of the air conditioning units and lower the energy costs. The insulating factor of the green roof also lowers heating requirements in the winter (Cantor 2008). Dunnett and Kingsbury (2008) state that the direct economic benefit in reducing the energy costs of an individual building is one of the strongest arguments for the wider installation of green roofs.

Photovoltaic panels (PV), another new technology, often installed on green roofs, provide dual benefits in terms of energy production and energy conservation. On a roof, the solar radiation is most intense assuring a high degree of efficiency in converting solar energy to electricity (Cantor 2008). Cantor further states that these panels work best within a certain range of ambient air temperatures, normally around 24°C as the PV can lose 0.5% efficiency per degree C above 25^{o}C. Evapotranspiration from the vegetation on the green roof can increase efficiency of PV. The vegetation fluctuation of temperatures at roof level maintains a more efficient microclimate around the panels to around 20 to 28°C (Green Roofs and Solar Energy 2011).

Noise levels in dense urban areas are harsh and unpleasant. Hard surfaces in these areas tend to reflect sound rather than absorb it. Dunnett and Kingsbury (2008) found that both substrate and plants make a contribution as acoustic insulation. Substrates block lower sound frequencies and plants block higher ones. The amount of sound reduction is dependent on the type of green roof system and the depth of the media. LivingRoofs (Noise and Sound Insulation 2011) found that a green roof system with a 12 cm media layer can reduce sound by 40 decibels (dB) and one 20 cm deep by 46-50 dB. German researchers reported that a 10 cm depth green roof reduced sound transmission into the buildings at the Frankfurt airport by 5 dB (Dunnett and Kingsbury 2008). However, additional scientific research is needed to substantiate claims.

Owner Incentives

Replacing a standard roof can be a costly, yet necessary expense for both the public and private sectors. Two factors contributing to the necessity of roof replacement are degradation of the roofing material and leaking. Liu (2002) indicated that solar radiation has a strong influence on the heat flow through the roof. Heat exposure can accelerate aging in bituminous material used in roofing, reducing its durability. Dunnett and Kingsbury (2008) note ultraviolet radiation can change the chemical composition and degrade the mechanical properties of bituminous products. The extent of surface temperature increase depends on the color of the roofing membrane. Darker colored membranes absorb more solar radiation than the lighter colored membranes, thus causing more rapid deterioration of the roofing membrane (Dunnett and Kingsbury 2008). The membrane, being exposed to the elements, absorbed solar radiation during the day and re-radiated the absorbed heat at night, creating high daily energy demand for space conditioning (Liu 2002). Furthermore, Liu (2002) indicates that on a green roof, the growing medium and the plants can enhance the thermal performance of the green roof by providing shading, insulation and evaporative cooling; and growing medium and plants, acts as a thermal mass, which effectively damp the thermal fluctuations going through the roofing system. The plant layer can shield off as much as 87% of solar radiation while a bare roof receives 100% direct exposure (Wong et al. 2003). Liu (2002) found that the growing medium and the plants modified the heat flow and reduced the average daily energy demand to less than 1.5 kWh (5,100 BTU (British Thermal Unit))—a reduction of more than 75 % compared to standard roofs.

A study of temperatures under the membranes of a conventional roof and a green roof was conducted at Nottingham Trent University in the UK. The researchers found winter/summer temperatures under the membrane of a conventional roof to be 0.2°C/ 32°C, respectively, and temperatures under the membrane of a green roof to be 4.7°C/ 17.1°C, respectively (Energy Conservation 2011). The National Research Council of Canada found temperature fluctuations during spring and summer on a conventional roof were 45°C, while under a green roof the fluctuations were 6°C (Energy Conservation 2011). The positive effect of the temperature on moderating heat flow through the membrane under a green roof protects the membrane from the effects of UV (ultraviolet) and sunlight while the building by shading, insulating and evapotranspiration.

Leaks are another factor often requiring roof replacement. An advantage of green roofs is that they must be installed by a higher standard than conventional roofs. FLL Guideline requirements (FLL-Guidelines for the Planning, Execution and Upkeep of Green-roof Sites 2002) for roofing membranes are strict with regards to the green roof systems for waterproofing, diffusion of moisture and drainage, root penetration, and compatibility of plant and environmental materials. These requirements provide for the implementation of damp-proof linings, root penetration barrier sheeting, and completely sealed joints and borders. This ensures that a green roof system is waterproof, thus reducing concerns of leakage and extending the life of the roof. The International Green Roof Association (IGRA Green Roof Pocket Guide 2011) concur that green roofs can double the life of the waterproofing.

While installing a green roof is more expensive than a conventional roof, the longevity of the roof offsets the initial cost. According to then Mayor Richard Daley of Chicago, Illinois, a green roof system costs about 50% more than a conventional roof (A Guide to Rooftop Gardens 2000). Dunnett and Kingsbury (2008) found a conventional roof in the United States at 2002 prices costs \$4.00 to \$8.50 per square foot with the lower figure for a system expected to last approximately 15-20 years. The higher figure would be for a system expected to last 50-100 years (Dunnett and Kingsbury 2008).

The US Green Building Council's Leadership in Energy and Environmental Design (LEED) program is a nationally accepted benchmark for the design, construction and operation of high performance green buildings. LEED certification is available for all building types including new construction and major renovation; existing buildings; commercial interiors; core and shell; schools and homes. The allocation of points is based on strategies that will have greater positive impacts on what matters most – energy efficiency and CO_2 reduction (LEED Green Building Certification System 2011). Gaining high scores under these schemes can make economic sense (Dunnett and Kingsbury 2008). Another benefit is the considerable public relations value in using a green roof to project an environmentally aware image for a building or organization. A visible green roof is the most effective way a building can express differences in environmental attitudes (Dunnett and Kingsbury 2008),and gain points for LEED certification.

The interaction of people with nature may create positive emotions and lead to psychological and physiological benefits (Ulrich 1981). Ulrich (1984) found that patients who were in rooms with views of a natural scene had shorter post-operative hospital stays, needed less potent analgesics, and received fewer negative evaluative comments in nurses' notes than patients in similar rooms with windows facing a brick wall. Medical facilities have taken a proactive approach to include green roofs on their buildings as an integral healing component of a patient's recovery, well-being and therapy; and examples of this approach may be seen at St. Louis Children's Hospital in St. Louis, Missouri, Ball Memorial Hospital in Indiana, Betty H. Cameron Women's and Children's Hospital in Wilmington, North Carolina, Columbia St. Mary's Hospital in Milwaukee, Wisconsin and Massachusetts General Hospital Cancer Center's Howard Ulfelder Healing Garden in Boston, Massachusetts.

Ecological

Green roofs provide sufficient ecological incentives to encourage their installation and expanded use. These incentives include mitigation of the "urban heat island effect" (UHIE), reduction of dust and smog levels, increased biodiversity, and increasing food security. In major metropolitan areas, Cantor (2008) states UHIE occurs when dark-colored pavements and building materials without intervening plantings, absorb heat during the day and slowly release this heat at night. Rooftops contribute significantly to the reflective, non-vegetated surfaces in urban areas. Wong (2005) reported that the rooftops of the cities of Baton Rouge, Houston, Sacramento and Salt Lake City were the hottest surfaces with temperatures reaching 71°C, while the coolest surface areas were those with vegetation and water with temperatures ranging between 24° and 35°C. This explains why major cities are several degrees warmer than the surrounding suburban and rural areas. The solar energy converts to heat, which hovers in the air around buildings, increasing energy costs and requirements for air conditioning (Cantor 2008). A modeling scenario of the New York City Regional Heat Island Initiative (Mitigating New York City's Heat Island with Urban Forestry, Living Roofs, and Light Surfaces 2006) determined that providing 50 % coverage of buildings in the metropolitan area with vegetation could lead to a 0.1 to 0.8°C reduction in surface temperatures. For every degree reduction in UHIE, approximately 495 million kilowatts (KWh) of energy could be saved. New York City government, in response to the modeling scenario, recently launched a tax rebate for building owners who install green roofs within the metropolitan area (Lanza 2008).

Toronto has estimated that the effect of green roofs on city rooftops would lead to a 0.05 - 2°C decrease in the UHIE. A reduction of this magnitude could lead to an indirect energy savings citywide from reduced energy requirements for cooling of $12 million (Banting et al. 2005).

Many cities in Japan are struggling from the severe effects of the UHIE. The average temperature in Tokyo has risen 3°C in the last century, four times higher than what could be associated with the effects of global warming (Ngan 2004). If one half of the roofs in the city were to become green roofs, the daytime temperatures in the summer would fall by approximately 0.084°C, a savings of 110 million Yen in reduced air conditioning costs (Traulein 2003). The city has introduced policies to require green roofs to be installed on 20% of all new flat surfaces on governmental buildings and 10% of all flat roofs on private dwelling (Ngan 2004)

Additionally, air contaminants absorb infrared radiation emitted at ground level at nightfall, when temperatures begin to drop, therefore reducing the amount of cooling. Further exacerbating the problem, dust and smog formation associated with UHIE, tax the energy requirements for large already overheated metropolitan areas like Los Angeles, Tokyo, and London (Cantor 2008). Klinkenborg (2009) stated that “Green roofs remind us what a moderating force natural biological systems can be.” Cantor (2008) states that the processes of evaporation from green roofs and transpiration of plants releases water, and cool the ambient temperature of the building. In addition, the green roofs, through its vegetation, can filter out fine airborne particles like dust and other pollutants which contribute to the heating effect (Tilston 2008). The air passes over the plants and the particles settle on leaf and stem surfaces. This material will be washed off into the media by rainfall or remain on the plant surfaces. Foliage can also absorb gaseous pollutants, like carbon, sequestering the material in their tissues (Dunnett and Kingsbury 2008).

Green roofs potential to support life in an otherwise largely barren and sterile environment is of vital consideration. Originating in Switzerland, the concept of green roofs for biodiversity concentrated primarily on habitat creation on green roofs (Dunnett and Kingsbury 2008). Cities, like London, are creating green habitats for rare endangered species such as the black redstart, a robin-like bird (Lee 2009). Exotics, such as non-native trees, vines, plants or grasses are and have been invading and threatening the continued existence of local ecosystems. In order to correct this, exotics need to be replaced with native plants. In the native hierarchy, native plants support native insect populations which, in turn, support native bird populations and on up the native food chain. Green roofs provide an excellent opportunity to support an area's native population and help restore the native balance (Dunnett et al. 2008).

Urban Agriculture

Sometimes called "metropolitan-intensive agriculture" (Smit et al. 2001), urban agriculture is an abstract term and poorly understood industry. The Council on Agriculture, Science and Technology (CAST) states that: "Urban agriculture is a complex system encompassing a spectrum of interests, from a traditional core of activities associated with the production, processing, marketing, distribution, and consumption, to a multiplicity of other benefits and services that are less widely acknowledged and documented". These include recreation and leisure; economic vitality and business entrepreneurship, individual health and well-being; community health and well-being; landscape beautification; and environmental restoration and remediation (Butler and Maronek 2002).

Urban agriculture is found world-wide on rooftops, walls, windowsills, inside buildings, vacant lots and even on the water according to Green Roofs for Health Cities (Agoada 2011) and is one strategy for addressing the consequences of the current food system--hunger (Brown and Carter 2003).

Brown and Carter (2003) indicated that an unacceptable number of American children do not get enough to eat on a daily basis. Thirty-three million people, thirteen million of which are children, live in households that experience hunger or the risk of hunger (Weinreb et al. 2002).

Brown and Carter (2003) state that food insecurity in the U.S. is “represented by people who frequently skip meals or eat too little, sometimes, going without food for a whole day”. Further, they state that these individuals “tend to have lower quality diets or must resort to seeking emergency food because they cannot afford the food they need.” Food insecurity and malnutrition are more widespread in low-income urban areas necessitating food production in urban areas to provide non-money benefits to the poor (Smit et al. 2001). By 2050, the United Nations estimates that food production will need to increase by 70% to feed the world’s expanding population (Agoada 2011).

Brown and Carter (2003) report that over 80% of the US population lives in urban metropolitan areas. Just one hundred years ago, 50% of the population lived on farms or small rural communities where they fed themselves and their families with locally raised meats, fruits, and vegetables. Food must now be shipped into areas where people are far removed from the actual production of those foods (Brown and Carter 2003).

Fresh produce typically must travel between 1,550-2,500 miles from farm to table, a 25% increase since 1980 (Halweil 2002). This long-distance food supply system is the norm for most of the US and the rest of the developed world. Fruits and vegetables shipped from distant states or other countries can be in transit seven to fourteen days before reaching local supermarkets (Brown and Carter 2003). They also found that almost 50% of food transported is lost to spoilage even though the fruit and vegetable varieties sold in supermarkets are selected for their ability to withstand the rigors of harvesting, processing, and shipping. While these foods may be appealing to the eye, taste and nutritional value are not prime considerations (Halweil 2002).

A wide variety of entities direct urban agriculture projects, including the public sector, corporate offices, non-profit community based organizations, for-profit entrepreneurial ventures, co-operative organizations, restaurants, hotels, educational institutions and individuals (Agoada 2011). Worldwide, it is estimated that 800 million people are engaged in urban agriculture and of these, 200 million are producing products primarily to supply local markets (Halweil 2002). Urban agriculture is making significant contributions to the socioeconomic development of towns and cities throughout the world (Smit et al. 2001). It is an easy-in, easy-out entrepreneurial activity for people of all income levels. For some, urban agriculture offers the possibility of savings and a return on their investment in seed, time and effort. For small or large entrepreneurs, it can be a profitable venture, not only in agricultural production, but also in related input and output industries and services (Smit et al. 2001).

Urban agriculture is intensive and makes the best use of available space with a preference for shorter-cycle, higher-value market commodities (Smit et al. 2001). Space at roof level has the advantage to control access limiting social problems such as vandalism in neighborhoods where little, if any, ground-level green space exists (Dunnett and Clayden 2007). Green roof food production utilizes multi-cropping and integrated farming techniques and makes use of both horizontal and vertical spaces. Intensive urban agriculture can yield several times as much produce per unit area as rural agriculture (Smit et al. 2001).

Urban green roof food production areas can reap many of the benefits that this type of installation provides such as reduction of energy consumption, increased building insulation, improved biodiversity, reduction of storm water runoff, mitigation of the UHIE, improved air quality while eliminating the necessity for long distance shipping of perishable food products, like vegetables, and helping to reduce hunger. Local production of fresh produce on a green roof can foster and establish more cohesive urban communities through urban regeneration, increased awareness of where food comes from, opportunities for entrepreneurship, improved health and well-being, better diets and increased food security (Agoada 2011).

Recent Research

Various entities, namely Sky Vegetables with locations in Massachusetts and California, Brooklyn Grange in Brooklyn, New York, Uncommon Ground in Chicago, Illinois, are utilizing available green roof space for urban agricultural production of such items as vegetables, fruits, herbs, and honey. However, limited research exists on using green roof space as a form of urban agriculture food production; and there is little published research on the production of annual herbs on green roofs. Most research relates to planted perennial species and colonizing species (Dunnett et al. 2008) or the use of a shallow rooted vegetable crop (Elstein et al. 2008). Additionally, limited research has been conducted into plant selection for green roof application (Dunnett et al. 2008; Dunnett and Nolan 2004), and many of the green roof studies examine growing media, since media weight is of significant importance. Most green roof systems currently installed range in weight from 97.65 kg/m^2 to 732.36 kg/m^2. Elstein et al. (2008) looked at the potential for alternative light weight media such as potting soil, foam, and fiberglass for shallow-rooted vegetable production. Controlled drip irrigation with fertigation was utilized to limit the effect of transplant shock. The study concluded that potting soil was inappropriate for green roof installations as it is difficult to contain, may leach minerals and had limited water retaining capacity. Additionally, the study determined that while, kale (*Brassica oleracea var. acephala*), had greater biomass when grown in potting soil, there was less variation in plant tissue mineral content among the different media types.

Other studies have investigated the effect of media depth in green roof systems. Depth of media for most green roof systems range from 2.0 cm to 20 cm or more (Dunnett and Kingsbury

2008) and is directly associated with the weight of growing media used and the type of green roof system that can be installed. Dunnett and Nolan (2004) indicated that depth of media had a profound effect upon plant performance. A 200 mm depth had greater potential than 100 mm depth in terms of visual and ecological diversity. However, Dunnett et al. (2008) indicated that increased depth of media produced no significant benefit in plant performance but strongly suggested that additional irrigation during the establishment phase was the greatest limiting factor to plant growth. Further Elstein et al. (2008) and VanWoert et al. (2005) found that successful establishment of transplants is possible in different depths of media.

Vermicompost has been reported to produce the best plant growth responses on vegetable plants including bell peppers and tomatoes and flowering plants including sunflowers, poinsettias, marigolds, and petunias with all needed nutrients supplied when vermicompost constituted 10 % to 20% of the total volume of the media (Atiyeh et al. 2000). The finer structure of vermicompost possesses a greater and more diverse microbial activity containing nutrients in forms that are readily available for plant uptake (Atiyeh et al. 2000b; Gilot 1997; Edwards et al.1988). Many herbs do not require very fertile soil (Russ and Pertuit 1999). Adi and Noor (2009) indicated that coffee grounds can be decomposed through vermicomposting and play an important role in stabilizing kitchen waste producing a high-end quality vermicompost product. Coffee grounds are high in nitrogen (Dinsdale et al.1996) and can improve the texture, increase moisture retention, stabilize pH, increase aeration and reduce temperature making it easier for the earth worms to digest and reproduce (Dickerson 2004). Morais and Queda (2003) found that a C/N ratio below 20 is acceptable although a ratio of 15 or lower is preferable. Limited research has been conducted using vermicomposted coffee grounds as an organic matter component in a green roof media mixture.

Southern Illinois University Carbondale Green Roof (SIUC)

The Agriculture Building of SIUC was retrofitted in September, 2010, which included a section to support a 367 m^2 semi-intensive green roof. All areas of this installation had an initial root barrier placed over the existing thermoplastic polyolefin (TPO) single-ply roofing membrane. The areas included a classical European sedum dominated section, a second sedum dominated section with a modern drainage membrane, two wildflower meadow sections, and areas for research.

The classical European sedum dominated area differs from the other areas in that a single layer of media, composed entirely of light weight aggregate (LWA) (Midwest Trading, 48W805 Route 64, Virgil, Illinois 60151) without the addition of organic matter, serves as the only drainage layer (GRS 1.5). The second sedum area has two layers of media. The lower-most is LWA, which functions as the drainage layer. A filtration fabric (FF35) was laid between this layer and the upper-most media layer. The upper-most layer is a commercially available semi-intensive green roof media (GRM) from Midwest Trading Company. The mix is primarily mineral based, components of which, include various gradations of expanded clay lightweight aggregate (LWA) with 4-5% organic matter (mass%) with additions of two pounds per cubic yard (2#/cy) Blue Chip nitrogen (Nu-Gro America Corporation, c/o Nugro Technologies, Inc. 10 Craig Street, Brantford, Ontario M5H 1W7 CA and Hercules Powder Company, 900-902 Market Street, Wilmington, DE), a non-burning slow-release organic nitrogen, and eight pounds/cubic yard (8#/cy) of iron sulfate ($FeSO_4$). Thus, the layer system in this area, from top to bottom, is media, filtration fabric, drainage layer (GRS1.5), root barrier (RB20), waterproof membrane (TPO), insulation, and finally the roof deck. Both sedum dominated areas were pre-planted sedum mats rolled out over the respective drainage layers. The wild flower area and research area received the identical system except for planting. Additional area was reserved within the wide pathways to allow modular tray research.

A weather monitoring station was established on the green roof. The HOBO U30 WIF Data Logger (Onset Computer Corporation, Cape Cod, MA), a remote data logging and monitoring system, recorded temperature (ambient air at 2m above the roof, bare roof, and under 5 cm of media), pressure in mercury (Hg), dew point, relative humidity, wind speed at 7.2m above the roof, wind direction, gust speed, precipitation, water content, and solar radiation. The data is recorded every five minutes, 24 hours a day. Information, such as soil temperatures and daily high and low temperatures, were recorded over the course of the mid-summer study, and are presented to provide supporting documentation to the insulating benefits of a green roof (Appendix A)

Roof top agriculture presents opportunities to expand food production areas in locally grown urban food systems. To promote these opportunities, two annual herb research projects were conducted on the SIUC green roof. The purpose was to evaluate two commercially available green roof modular trays, two types of green roof media, and two types of annual herbs.

CHAPTER 2

ANNUAL HERB PRODUCTION IN GREEN ROOF MODULAR TRAYS.

The American Industrial Revolutions of 1790-1860 and 1860-1924 led to an exodus from rural to urban dwelling. To meet the needs of the increased urban population, green or vegetated areas of cities were transformed into built environments. This expansion and the removal of urban green areas created significant environmental problems. Green roofs have been shown to reduce the negative environmental effects caused by these changes. The majority of green roof systems today are installed for financial and ecological benefits such as storm water mitigation, reduction of carbon dioxide levels, energy reduction costs, mitigation of the Urban Heat Island Effect (UHIE), and restoration of biodiversity. An additional opportunity for the use of these available urban spaces is local urban food systems.

Currently in the United States (US), there are three main categories of green roofs: extensive, intensive, and hybrid, which refer to the weight limit of the roof and the depth of planting media. One limiting factor in determining the type of green roof system installation is the weight load limit of the building's roof. The American Society for Testing and Materials (ASTM) under Standard Practice E2397 has developed a "standardized procedure for predicting the system weight of a green roof system" (American Society for Testing and Materials 2011). Weight load limits determine, not only the type of green roof system installation, but also the types of plants and the depth of the media that can be used in a green roof system. Depth of media for most green roof systems can range from 2.0 cm to 20 cm or more (Dunnett and Kingsbury 2008).

There are two main types of green roof system installations, layer or tray (modular), each having benefits and drawbacks. The layer system involves installation of multiple components on top of the roof deck bordered by an edge restraint. The typical components include a waterproof membrane, root protection barrier, drainage layer, filter mat, growing media and plants. The tray or modular system is individual units which contain the growing media, a drainage system, and plants (Dunnett and Kingsbury 2008). One advantage of the tray system is the modular size. Sizes start at a weight one person can handle to larger trays that require two strong workers to handle (Cantor 2008). Modular systems work well in areas that are flat and rectilinear as modular trays are square or rectangular in shape, and can be pre-planted before the installation. However, there are numerous considerations to review when determining which green roof system is appropriate.

Typical media utilized in a green roof system is soil-less, lighter in weight, and less fertile than ordinary garden or top soil (Dunnett and Kingsbury 2008). Green roof media may be crushed expanded shale, light weight expanded clay, terra cotta, pumice, lava (scoria), expanded slate or crushed brick (Cantor 2008; Dunnett and Kingsbury 2008). Cantor (2008) indicated that about 3-10 % organic materials (mass, based on dry weight) can be added to provide initial nutrients to a newly planted green roof. Dunnett and Kingsbury (2008) state typical commercial green roof mixtures include organic matter between 10% and 20% by volume. They further state that unless the organic matter is completely decomposed it will rob the media of nitrogen as it completes its decomposition.

One form of organic matter added to green roof mixtures is vermicompost, more specifically, composted coffee grounds. Coffee grounds are high in nitrogen (Dinsdale et al. 1996) when decomposed through vermicomposting which makes nutrients such as nitrogen, phosphorous and potassium more concentrated and available for plant uptake (Dickerson 2001). Nutrient uptake is critical for plant growth and development particularly in a green roof environment.

Another factor to consider is the texture of the media and its water retaining capacity. This may also limit plant selection and growth. Coarse media tend to have a lot of porous spaces allowing for excellent aeration, but water retaining capacity is limited, while the opposite can be true regarding the finer media. The ideal green roof media has both sufficient aeration and water retaining capacity allowing the root systems to absorb rainfall quickly while allowing the overflow to drain into the lower layers of the green roof system (Cantor 2008).

As city governments and municipalities mandate the installation of green roof systems, a normally underutilized portion of the urban landscape presents opportunities for expanding local urban food systems. Locally produced fruit and vegetables are fresher, higher quality, more nutritious, and can offer greater variety than the supermarket counterparts.

Green roofs or “roof gardens” (Osmundson 1999) create opportunities for farmers, chefs, homeowners and others to produce fresh local fruits, vegetables, and herbs. Herbs have been prized for their culinary and medicinal properties dating back to a 2000 BC papyrus found in Ancient Egypt (Wood 1975). Furthermore, according to Wood (1975), the Egyptians passed their knowledge to the Greeks, who passed it on to the Romans. The first planned herb gardens, found in castles and monasteries, were planted for its culinary and medicinal uses and to attract bees and flavor their honey, the only sweetener available at that time. By the sixteenth century, herbs were widely grown. The early herb gardens were more utilitarian in form, but later developed into the popular Knot Garden (Wood 1975). During World War I in Great Britain, herbs were used for medicinal purposes when they could no longer be imported from abroad (Grieve 1996). Today, herbs are highly valued for flavoring and enhancing everyday meals.

Information on green roof herb production could be important to cities and municipalities, community groups, student and garden clubs, organic farmers, and individuals. Little research has been conducted on growing herbs on a green roof environment. More specifically, it is unknown if the production of annual herbs in green roof modular trays is possible given restrictions of limited weight load capacity and shallow depth of media.

Urban agriculture, utilizing available green roof space, can provide local communities and residents with the education, experience, knowledge, and incentives, through locally produced quality food products, to become more self-reliant as many Americans once were. The modular tray system could be the perfect “tool”. Urban green roof food systems can reap many of the same benefits of a typical green roof such as reduction of energy consumption, increased building insulation, and mitigation of the UHIE while eliminating the necessity for long distance shipping of perishable food products, like vegetables and herbs.

This research may provide important information for the production of local urban green roof food systems using a modular tray system.

OBJECTIVES

The objectives of this research are to:

(1) Evaluate two types of commercially available green roof modular trays

(2) Evaluate two types of green roof medial for annual herb production

(3) Evaluate two types of annual herbs for green roof production feasibility

METHODS AND MATERIALS

This research was conducted on the extensive green roof of the Agriculture Building on the SIUC campus. Two common herbs were grown in commercial green roof modular trays placed in two locations on the green roof with two green roof media also evaluated in the late spring and mid-summer.

LATE SPRING STUDY

Green Roof Modular Trays

Twenty-four green roof modular trays were utilized in this study. Twelve trays were manufactured by GreenGrid (GreenGrid, 750 East Bunker Street, Suite 500, Vernon Hills, Illinois 60061), Standard Extensive Model, 61 x 61 x 10 cm, .37 m2, made from 100% pre-consumer recycled high molecular weight polyethylene protected with UV inhibitor and stabilizers with 1.27 cm drainage clearance above the roof. The trays were lined on the bottom with Preen Max Strength Weed Control Fabric (The Master Gardener Co., Spartanburg, SC). The other twelve trays were manufactured by American Hydrotech,(American Hydrotech, Inc., 303 East Ohio Street, Chicago, Illinois 60611) Garden Tray GT15, 46 x 56 x 10 cm, .26 m2. GT15 trays were made from recycled polyethylene molded into a three-dimensional tray. The floor of these trays provides retention cups on the top side, drainage channels on top and bottom, and holes in the tops of the “domes” for ventilation and evaporation. The trays were lined on the bottom with manufacturer provided Systemfilter filter fabric.

Types of Growing Media

Two types of media were evaluated in this study: commercially available semi-intensive green roof media (GRM) from Midwest Trading Company (Midwest Horticultural Supplies, A

Midwest-Drum Company, 48W805 Route 64, Virgil, IL 60151) and a custom blended green roof media composed of light weight aggregate (LWA) from Midwest Trading Company and vermicompost (VLWA). The GRM was formulated following the FLL Guidelines. The LWA was a 100 % inert inorganic mineral, composed of fine and coarse granules, which does not decompose, affect pH, or react chemically. The LWA increases porosity and retains 12 to 35 % of its weight in absorbed water and water soluble nutrients. The vermicompost, composed of used coffee grounds from Starbucks and vegetable and fruit waste from campus dining halls, was produced at the SIUC Vermicompost Center. VLWA was mixed at a ratio of 4 parts light weight aggregate to 1 part vermicompost by volume.

Depth of media was restricted to 5.72 cm as the weight load limit of the building was determined to be 122 kg/m^2.

Plants

The plants chosen for this study were annual herbs including sweet basil (*Ocimum basilicum*) and ‘Italian flat leaf’ parsley (*Petroselinum crispum var. neapolitanum*). The plants were obtained from a local grower as plugs. Taxa were selected for their culinary value and relative ease of care in normal gardening situations. All plants of the same species were of a consistent height and spread.

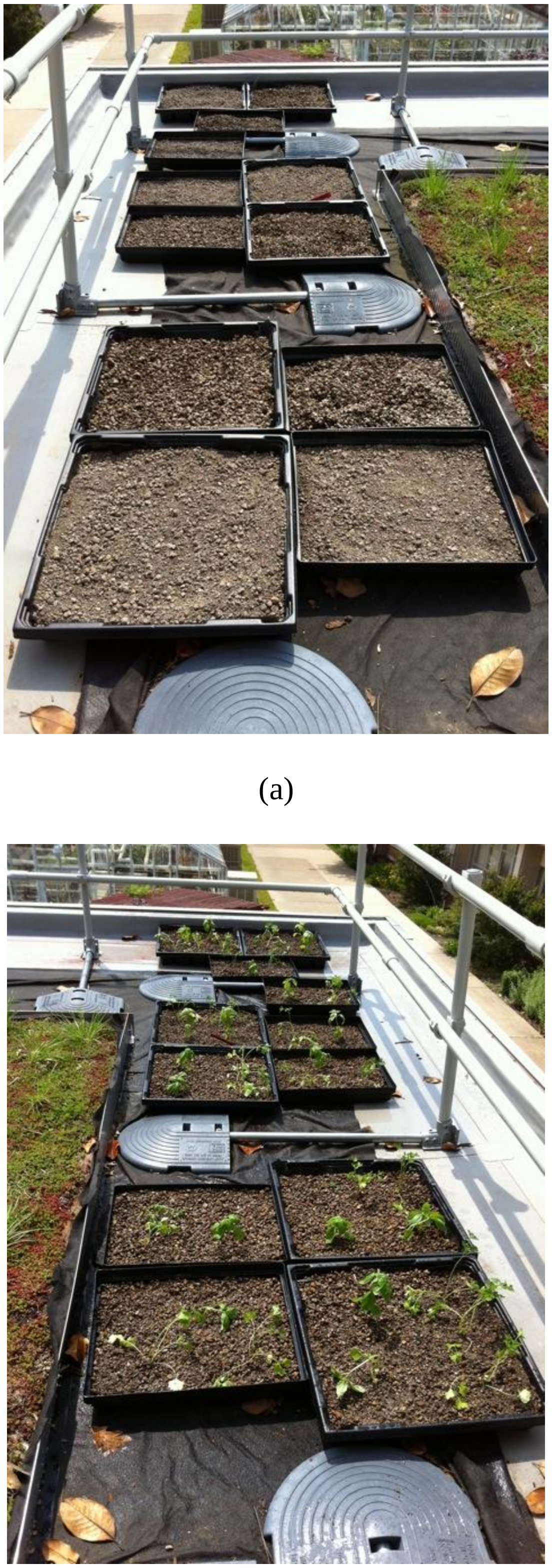
One day prior to transplantation into the modular trays, all plants were drenched using a blend of one packet of Miracle-Gro Singles, an All Purpose Water Soluble Plant Food 24-8-16 (Scotts Miracle-Gro Products, Marysville, OH) to 2.5 gallons of water , resulting in a solution of approximately 6,000 ppm of N (Nitrogen).

Methodology

The experiment was designed as a 2 x 2 x 2 completely randomized factorial experiment, with two (2) locations, two (2) tray types and two (2) media types. Twelve trays (6 of each type-American Hydrotech and GreenGrid and each media type-GRM and VLWA) located in an area receiving partial shade of six (6) hours per day, was designated as Location 1 (Fig. 2.1) and 12 trays located in an area receiving full day sun of more than six (6) hours per day, was designated as Location 2 (Fig. 2.2). These locations were further divided into three replications of groups of four trays each, two trays of each type (American Hydrotech and GreenGrid) and each media type (GRM and VLWA). The trays were randomly placed within each replication.

The study was initiated on the green roof on 20 May, 2011. Six trays of each type, American Hydrotech (Fig. 2.3) and GreenGrid (Fig. 2.4) were filled to a depth of 5.72 cm with GRM. Six trays of each type, American Hydrotech and GreenGrid, were filled to a depth of 5.72 cm with VLWA. Each American Hydrotech tray consisted of two basil plants and three parsley plants. Each GreenGrid module consisted of one basil plant and two parsley plants due to the modular tray size difference. Basil plants were spaced ten (10) inches apart and parsley plants were spaced six (6) inches apart within the trays. The weight of a planted American Hydrotech Garden Tray GT 15 was approximately 107 kg/m^2. The weight of a planted GreenGrid Standard Extensive Model module was approximately 87.9-107.4 kg/m^2. Weight is based on bulk density at maximum water holding capacity.

Irrigation was by hand filling to container capacity or the point at which water drained freely from the tray. No fertilizer treatments were applied during the course of the study. All weeds were removed as needed. All flowers were removed from the evaluated plants, which is a common practice for herb production.



(a)

(b)

Figure 2.1. Location 1- (a) before and (b) after planting

(a)

(b)

Figure 2.2. Location 2- (a) before and (b) after planting

Figure 2.3. American Hydrotech GT 15 Module

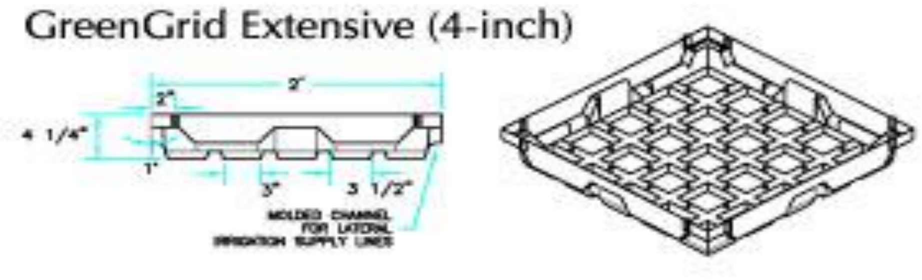


Figure 2.4. GreenGrid Standard Extensive Model module
(Source: GreenGrid Roofs, www.greengridroofs.com)

Recorded Data

Initial height for each plant species was recorded to provide a baseline. Additionally, media temperatures were recorded randomly over the course of the study using a Taylor Bi-Therm soil thermometer (Taylor Precision Products, 2311 West 22nd Street, Oak Brook, Illinois 60523) inserted into the center of the media to the bottom of the tray.

The study was terminated on 22 July, 2011. All parsley plants died in the late spring study. Final height, spread, and number of shoots for each basil plant was recorded. Weight of fresh stems, fresh leaves, and fresh roots were recorded. All evaluated plant components, specifically, shoots (stems and leaves) and roots were oven-dried at 66°C for 72 hours. Dried weights were recorded. Shoot biomass was determined for each plant from dry-weight.

The data were analyzed as a two-way ANOVA (SAS Institute Inc., SAS Campus Drive, Cary, NC 27513) with main effects of sunlight type, media type, and tray type. Interactions were also examined. Means were separated using a Student’s t ($p \leq 0.05$).

MID-SUMMER STUDY

The mid-summer study was identical in most respects to the late spring study, except the differences noted below.

Plants

The plants chosen for the mid-summer study were the annual herbs; Thai basil (*Albahaca tailandesea*) and three types of parlsey, Italian flat leaf parsley (*Petroselinum crispum var. neapolitanum*), curled parsley (*Petroselinum crispum crispum)* and triple curled parsley (*Petroselinum crispum ‘Krausa’)*. Different cultivars of basil and parsley were chosen to compare feasibility for potential green roof food production. The plants were obtained locally as grower produced plants. Plants were selected for their culinary value and relative ease of care in normal gardening situations. All plants of the same species and same cultivar were of a consistent height and spread.

The experiment was initiated on 12 August, 2011 and terminated 23 September, 2011. Planting and installation of modular trays onto the green roof was conducted in the early evening to reduce plant stress.

Recorded Data

Initial weight and height for each plant was recorded. Additionally, SPAD (Special Products Analysis Development) measurements for chlorophyll using portable leaf chlorophyll meter (Konica Minolta Sensing, Inc., Tokyo, Japan) were recorded for individual plants from three different leaf positions: uppermost, middle, and lower. Additional SPAD readings were taken at 21 DAT and 42 DAT intervals on individual plants and recorded.

Media temperature and moisture readings were taken 2, 4, and 6 week intervals. Media temperatures and moisture content were taken from the center to the bottom from five (5) locations in each tray.

RESULTS AND DISCUSSION

Although the late spring and mid-summer studies were two separate studies, they shared the same objectives. The objectives for this research were to evaluate two types of commercially available green roof modular trays, two types of green roof media for annual herb production, and two types of annual herbs for green roof production feasibility.

Late Spring Study Results.

Although tray type had no influence on basil shoot height, differences ($P \leq 0.05$) were observed between sunlight and media type for basil shoot height. Full sunlight increased basil shoot height by 26% compared to only partial shade, while GRM media improved basil shoot height by 21% compared to VLWA (Appendix B, Table 2.1).Sunlight and tray type were not significant for basil shoot width; however, media type was highly significant ($P \leq 0.05$) for basil shoot width. GRM produced 43% greater basil shoot width than VLWA. An interaction of tray type and media was detected for basil shoot width with GreenGrid/GRM increasing basil shoot width by 76% over GreenGrid/VLWA and 36% increase over American Hydrotech/VLWA (Appendix C, Table 2.2). While tray type did not influence basil shoot weight, sunlight and media were significant with full sun increasing basil shoot weight by 72% over partial shade and GRM improving basil shoot weight by 51% over VLWA (Appendix D, Table 2.3). There were no differences ($P \leq 0.05$) regarding basil root weight, basil dry shoot weight or basil dry root weight for the main effects of sunlight, tray type or media nor were any interactions detected suggesting that basil responded similarly to the variables evaluated (Appendix E, Table 2.4; Appendix F, Table 2.5, Appendix G, Table 2.6). Although tray type and media did not influence basil shoot-root ratio, partial shade enhanced basil shoot-root ratio by 81% over full sun (Appendix H, Table 2.7) and no interactions were detected between the main effects. No data is presented for parsley which all perished.

While this study primarily focused on the interactions of the main effects of sunlight, tray type and media type for all variables evaluated, the main effects were examined in the absence of any interactions for the variables evaluated.

Table 2.1. Basil shoot height as influenced by sunlight, tray, and media in a green roof environment during spring 2011.

Main Effect/Interaction	Shoot Height (cm)		
		Mean	Prob. > F
Sunlight			
	Full sun	48.6[a]	
	Partial shade	38.7[b]	
	Significance		0.0121*
Tray			
	American Hydrotech	43.7[a]	
	GreenGrid	44.0[a]	
	Significance		ns
Media			
	GRM	47.8[a]	
	VLWA	39.5[b]	
	Significance		0.0308*

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P < 0.05$.

Table 2.2. Basil shoot width as influenced by sunlight, tray, and media in a green roof environment in spring 2011.

Main Effect/Interaction		Shoot Width (cm)	
		Mean	Prob > F
Sunlight			
	Full sun	35.0^{a}	
	Partial shade	38.1^{a}	
	Significance		ns
Tray			
	American Hydrotech	36.9^{a}	
	GreenGrid	36.1^{a}	
	Significance		ns
Media			
	GRM	43.1^{a}	
	VLWA	30.0^{b}	
	Significance		<0.0001*
Tray * Media			
	GreenGrid, GRM	46.1^{a}	
	American Hydrotech, GRM	40.1^{ab}	
	American Hydrotech, VLWA	33.8^{b}	
	GreenGrid, VLWA	26.2^{c}	
	Significance		0.0036*

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.3. Basil shoot weight as influenced by sunlight, tray, and media in a green roof environment during spring 2011.

Main Effect	Shoot Weight (gms)		
		Mean	Prob. > F
Sunlight			
	Full sun	219.9^{a}	
	Partial shade	127.5^{b}	
	Significance		0.0113*
Tray			
	American Hydrotech	185.4^{a}	
	GreenGrid	166.7^{a}	
	Significance		ns
Media			
	GRM	209.0^{a}	
	VLWA	138.4^{b}	
	Significance		0.0474*

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.4. Basil root weight as influenced by sunlight, tray, and media in a green roof environment during spring 2011.

Main Effect	Root Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	86.5[a]	
	Partial shade	91.3[a]	
	Significance		ns
Tray			
	American Hydrotech	81.7[a]	
	GreenGrid	96.1[a]	
	Significance		ns
Media			
	GRM	90.8[a]	
	VLWA	87.0[a]	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.5. Basil dry shoot weight as influenced by sunlight, tray, and media in a green roof environment in spring 2011.

Main Effect	Dry Shoot Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	86.5^{a}	
	Partial shade	91.3^{a}	
	Significance		ns
Tray			
	American Hydrotech	81.7^{a}	
	GreenGrid	96.1^{a}	
	Significance		ns
Media			
	GRM	90.8^{a}	
	VLWA	87.0^{a}	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.6. Basil dry root weight as influenced by sunlight, tray, and media in a green roof environment in spring 2011.

Main Effect	Dry Root Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	17.8^{a}	
	Partial shade	17.6^{a}	
	Significance		ns
Tray			
	American Hydrotech	17.4^{a}	
	GreenGrid	18.0^{a}	
	Significance		ns
Media			
	GRM	20.3^{a}	
	VLWA	15.1^{a}	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.7. Basil shoot-root ratio as influenced by sunlight, tray, and media in a green roof environment during spring 2011.

Main Effect	Shoot-Root Ratio		
		Mean	Prob > F
Sunlight			
	Partial shade	2.79[a]	
	Full sun	1.54[b]	
	Significance		0.0076*
Tray			
	American Hydrotech	2.2[a]	
	GreenGrid	2.2[a]	
	Significance		ns
Media			
	GRM	2.4[a]	
	VLWA	1.9[a]	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Mid-Summer Study Results.

An interaction of tray by media was detected for basil shoot width, while all main effects were insignificant (Appendix I, Table 2.10). American Hydrotech/VLWA combination increased basil shoot width by 39% over GreenGrid/VLWA combination and 50% increase over American Hydrotech/GRM combination. The analyses (Appendix H and Appendices J-N) indicated no interactions ($p \leq 0.05$) between sunlight, tray type, or media type for all variables evaluated. Parsley shoot height was affected by media ($p \leq 0.05$) with an interaction of sunlight by media also detected (Appendix O, Table 2.15). Parsley grown in GRM had a 40% height increase compared to VLWA. Further, parsley grown in the GRM media receiving partial shade, increased height by 76% over than those grown in VLWA in partial shade. Additionally, parsley grown in GRM receiving partial shade grew 50% taller than those grown in the same media under full sun conditions; and, 32% better than plants grown in VLWA under full sun conditions. An interaction of sunlight by media was detected for parsley shoot width with plants grown in GRM receiving partial shade producing 36% more shoot width compared to plants grown in the same media in full sun. Parley grown in partial shade in GRM had a 31% greater spread than plants grown in full sun in VLWA and a greater 50% spread than plants grown in partial shade in VLWA. All other variables evaluated were not significant ($p \leq 0.05$) (Appendix P, Table 2.16). Media was found to be significant ($p \leq 0.05$) for shoot weight with GRM increasing plant mass by 69% compared to those grown in VLWA (Appendix Q, Table 2.17). An interaction was detected of tray by media for parsley shoot weight with plants in American Hydrotech/GRM combination outperforming plants in American Hydrotech/VLWA combination by 194% (Appendix Q, Table 2.17). Media for parsley dry shoot weight was significant ($p \leq 0.05$) with interactions of tray by media detected (Appendix S, Table 2.19). GRM increased parsley dry shoot weight by 36% over

VLWA. Parsley in American Hydrotech/GRM combinations produced 95% more dry shoot weight than those in American Hydrotech/VLWA. The analyses (Appendix R, and Appendices T-U) indicated no interactions ($P > 0.05$) between sunlight, tray type, or media type for parsley root weight, dry root weight and shoot to root ratio.

Table 2.8. Basil shoot height as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect	Shoot Height (cm)		
		Mean	Prob > F
Sunlight			
	Full sun	23.2[a]	
	Partial shade	27.4[a]	
	Significance		ns
Tray			
	American Hydrotech	23.1[a]	
	GreenGrid	27.7[a]	
	Significance		ns
Media			
	GRM	29.9[a]	
	VLWA	23.8[a]	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.9. Basil shoot width as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect/Interaction	Shoot Width (cm)		
		Mean	Prob > F
Sunlight			
	Full sun	31.1[a]	
	Partial shade	32.2[a]	
	Significance		ns
Tray			
	American Hydrotech	33.1[a]	
	GreenGrid	32.7[a]	
	Significance		ns
Media			
	GRM	34.8[a]	
	VLWA	31.0[a]	
	Significance		ns
Tray * Media			
	American Hydrotech, VLWA	37.9[a]	
	GreenGrid, GRM	37.6[a]	
	GreenGrid, VLWA	27.3[a]	
	American Hydrotech, GRM	24.0[b]	
	Significance		0.0496*

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.10. Basil shoot weight as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect	Shoot Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	116.0[a]	
	Partial shade	116.8[a]	
	Significance		ns
Tray			
	American Hydrotech	105.3[a]	
	GreenGrid	127.6[a]	
	Significance		ns
Media			
	GRM	126.0[a]	
	VLWA	106.8[a]	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.11. Basil root weight as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect	Root Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	105.2^{a}	
	Partial shade	101.7^{a}	
	Significance		ns
Tray			
	American Hydrotech	103.1^{a}	
	GreenGrid	103.8^{a}	
	Significance		ns
Media			
	GRM	103.8^{a}	
	VLWA	103.1^{a}	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.12. Basil dry shoot weight as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect	Dry Shoot Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	86.5^{a}	
	Partial shade	91.3^{a}	
	Significance		ns
Tray			
	American Hydrotech	81.7^{a}	
	GreenGrid	96.1^{a}	
	Significance		ns
Media			
	GRM	90.8^{a}	
	VLWA	87.0^{a}	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).

ns = non-significant at $P \leq 0.05$.

Table 2.13. Basil dry root weight as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect	Dry Root Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	40.3[a]	
	Partial shade	41.5[a]	
	Significance		ns
Tray			
	American Hydrotech	41.0[a]	
	GreenGrid	41.0[a]	
	Significance		ns
Media			
	GRM	41.8[a]	
	VLWA	40.1[a]	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.14. Basil shoot-root ratio as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect	Shoot-Root Ratio		
		Mean	Prob > F
Sunlight			
	Full sun	0.91^{a}	
	Partial shade	0.91^{a}	
	Significance		ns
Tray			
	American Hydrotech	0.87^{a}	
	GreenGrid	0.97^{a}	
	Significance		ns
Media			
	GRM	0.95^{a}	
	VLWA	0.87^{a}	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.15. Parsley shoot height as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect/Interaction	Shoot Height (cm)		
		Mean	Prob > F
Sunlight			
	Full sun	21.5^a	
	Partial shade	26.2^a	
	Significance		ns
Tray			
	American Hydrotech	23.8^a	
	GreenGrid	23.9^a	
	Significance		ns
Media			
	GRM	27.8^a	
	VLWA	19.9^b	
	Significance		0.179*
Sunlight * Media			
	Partial shade, GRM	33.4^a	
	Full sun, GRM	22.2^b	
	Full sun, VLWA	20.8^b	
	Partial shade, GRM	19.0^b	
	Significance		0.0436*

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.16. Parsley shoot width as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect/Interaction	Shoot Width(cm)		
		Mean	Prob > F
Sunlight			
	Full sun	26.1^a	
	Partial shade	29.0^a	
	Significance		ns
Tray			
	American Hydrotech	29.6^a	
	GreenGrid	26.6^a	
	Significance		ns
Media			
	GRM	29.7^a	
	VLWA	25.7^a	
	Significance		ns
Sunlight * Media			
	Partial shade, GRM	34.8^a	
	Full sun, VLWA	26.6^b	
	Full sun, GRM	25.6^b	
	Partial shade, VLWA	23.2^b	
	Significance		0.0385*

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.17. Parsley shoot weight as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect/Interaction	Shoot Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	76.6[a]	
	Partial shade	78.9[a]	
	Significance		ns
Tray			
	American Hydrotech	79.8[a]	
	GreenGrid	75.1[a]	
	Significance		ns
Media			
	GRM	97.8[a]	
	VLWA	57.8[b]	
	Significance		0.0347*
Tray * Media			
	American Hydortech, GRM	119.0[a]	
	GreenGrid, GRM	76.6[ab]	
	GreenGrid, VLWA	75.0[ab]	
	American Hydortech, VLWA	40.5[b]	
	Significance		0.0409*

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.18. Parsley root weight as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect	Root Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	105.2[a]	
	Partial shade	79.1[a]	
	Significance		ns
Tray			
	American Hydrotech	91.4[a]	
	GreenGrid	93.0[a]	
	Significance		ns
Media			
	GRM	97.3[a]	
	VLWA	87.0[a]	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.19. Parsley dry shoot weight as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect/Interaction	Dry Shoot Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	27.8^{a}	
	Partial shade	30.0^{a}	
	Significance		ns
Tray			
	American Hydrotech	28.9^{a}	
	GreenGrid	28.8^{a}	
	Significance		ns
Media			
	GRM	33.2^{a}	
	VLWA	24.5^{b}	
	Significance		0.0475*
Tray * Media			
	American Hydortech, GRM	38.2^{a}	
	GreenGrid, VLWA	29.5^{ab}	
	GreenGrid, GRM	28.2^{ab}	
	American Hydrotech, VLWA	19.6^{b}	
	Significance		0.0238*

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.20. Parsley dry root weight as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect	Dry Root Weight (gms)		
		Mean	Prob > F
Sunlight			
	Full sun	43.8^a	
	Partial shade	35.4^a	
	Significance		ns
Tray			
	American Hydrotech	41.9^a	
	GreenGrid	37.3^a	
	Significance		ns
Media			
	GRM	42.7^a	
	VLWA	36.5^a	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.21. Parsley shoot-root ratio as influenced by sunlight, tray, and media in a green roof environment during summer 2011.

Main Effect	Shoot-Root Ratio		
		Mean	Prob > F
Sunlight			
	Full sun	0.73[a]	
	Partial shade	0.87[a]	
	Significance		ns
Tray			
	American Hydrotech	0.75[a]	
	GreenGrid	0.85[a]	
	Significance		ns
Media			
	GRM	0.85[a]	
	VLWA	0.75[a]	
	Significance		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Discussion

Late Spring Study.

Within four days of initial transplanting (DAT), all plants in the late spring study, basil and parsley, were exhibiting signs of chlorosis (Fig. 2.5).This was most likely due to transplant shock. One week after planting, the parsley plants were exhibiting a reduction in vigor possibly contributed to hand irrigation (Fig 2.6). The trays containing VLWA had greater water-retaining capacity due to greater porosity than GRM, reducing the soil oxygen, and promoting root rot. Several studies, including Waldbaum (2011) and Sing et al. (2004), indicated that while media must store sufficient water and nutrients for the vegetation and allow surplus water into the drainage layer, at saturation it must contain appropriate air volume for movement of air through the media. The parsley plants that subsequently perished had rotted root systems. Additional irrigation was required by having both types of evaluated plants in one tray (Fig.2.7). Thuring et al. (2010) and Elstein et al. (2008) suggest that single plants of the same species may be easier to maintain.

Media Type

Within two weeks of planting, all plants in both trays and media types were exhibiting a trait that became more apparent throughout the study (Fig. 2.7) as being associated with the different media types, i.e. the VLWA plants were yellowish-green and the GRM plants were deeper green. A pre-plant analysis may have determined the mineral content of the use of vermicompost, a component in the VLWA blend, thus helping to explain the yellow-green color.

Basil plants grown in GRM were from 21% to 51% taller, wider and heavier than counterparts grown in VLWA for shoot height, shoot width and shoot weight (Appendix A, Table 2.1; Appendix B, Table 2.2 and Appendix 3, Table 2.3). Plant available nitrogen in the

GRM in slow-release form may have contributed to these results. According to Dinsdale, et al. (1996), coffee grounds, a major component in the VLWA blend, are high in nitrogen; however in this study the plants grown in VLWA did not perform as well as those grown in GRM.

Sunlight

Full sun was shown to increase basil shoot height over partial shade by 26% (Appendix A, Table 2.1). Full sun was also shown to increase basil shoot weight by 72% over partial shade (Appendix C, Table 2.3). Although tray type and media type did not influence the basil shoot-root ratio, partial shade was shown to produce an 81% increase in the shoot-root ratio compared to basil grown in full sun (Appendix G, Table 2.7). The late spring and early to mid-summer weather was reported to have been the hottest in 15 years. All plants suffered minor to severe scorching of plant leaf material due to the extreme heat (Fig. 2.10). Plants receiving partial shade may have increased above ground growth through photosynthetic processes while limiting the effects of increased respiration caused by extreme temperatures. For plants receiving full sun, the rate of respiration may have exceeded declining photosynthesis resulting in diminished basil shoot-root ratio.

Tray Type

Although tray type revealed no differences ($P>0.05$) with regards to the variables evaluated, there was an interaction detected for tray type and media type for basil shoot width (Appendix B, Table 2.2). In this interaction, GreenGrid/GRM combination increased basil shoot width by 76% over Green Grid/VLWA combination and 35% over American Hydrotech/VLWA combination. While this interaction suggests the tray type is a cause of the interaction, a more compelling conclusion may be the highly significant difference of <0.0001 between media types.

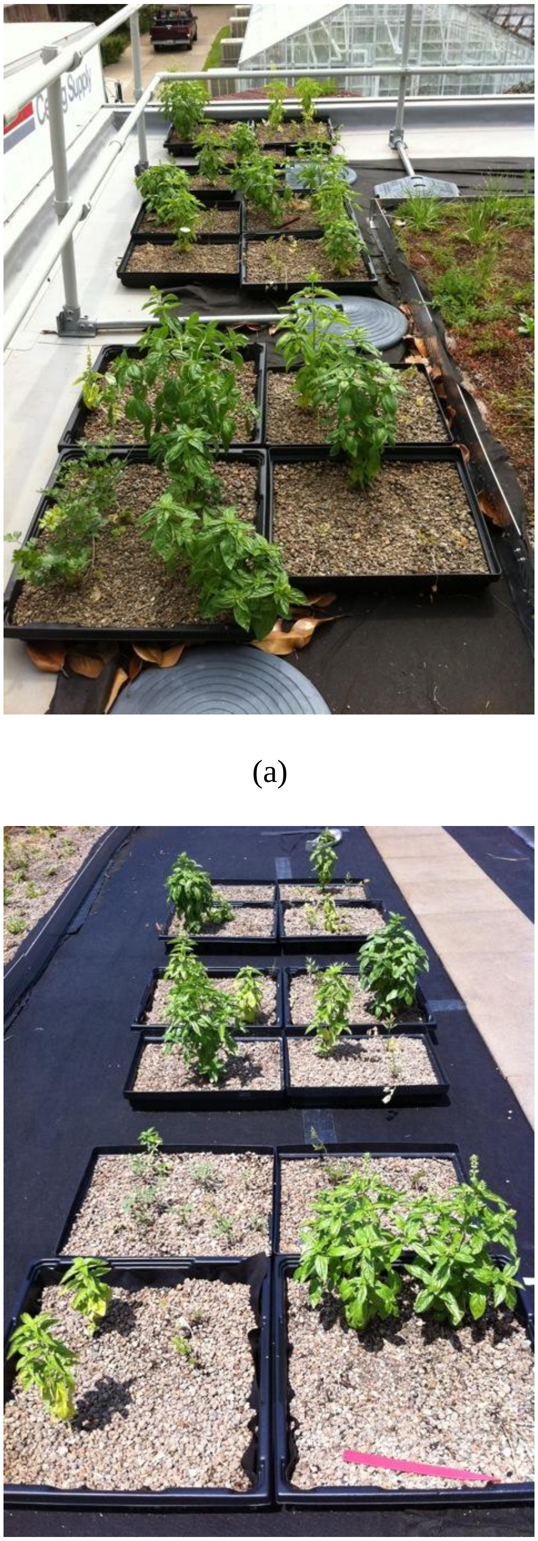
Figure 2.5. Spring Study 4 DAT

(a)

(b)

Figure 2.6. Spring Study (a) and (b), 7 DAT, parsley exhibiting reduced vigor

Figure 2.7. Plants grown in VLWA (upper trays) and plants grown in GRM (lower trays)



(a)

(b)

Figure 2.8. Location 1 (a) and Location 2 (b) 30 DAT

(a)

(b)

Figure 2.9. Location 1 (a) and Location 2 (b) 60 DAT

Figure 2.10. Heat damage

Mid-Summer Study.

Within four days of initial transplanting (DAT), over 58 % of the parsley plants were chlorotic. While the symptoms resemble transplant shock caused by the yellowing of leaves, nitrogen deficiency was most likely the cause due to the pH levels. Chlorosis tends to result when the pH is too high (Kluepfel and Lippert 1999). Basil and parsley require a pH range of 5.5 – 6.5, and 5.5- 6.0, respectively (Anonymous, 2011). The initial soil analysis (Brookside Laboratories, Inc., 308 South Main Street, New Knoxville, OH 45871) indicated pH levels of 6.1 for GRM media and 7.6 for VLWA media (Table 2.22). The initial pH level for GRM media was appropriate for both types of herbs; however, the pH level for GRM media rose to 7.1 by the end of the experiment, which is too high for optimum growth of either herb. Additionally, the GRM media had a timed-release fertilizer as a component of the mixture, which slowly provided plant-available nitrogen to the herbs throughout the study; and both basil and parsley, were a darker green color compared to the herbs grown in the VLWA. The VLWA media provided pH levels of 7.6 and 7.8, respectively, for the initial and final samples (Table 2.22). While these levels are also within the FLL Guidelines recommendation for extensive green roofs (Waldbaum 2011), they are too high for either herb to grow and develop properly.

VLWA analysis indicated excess levels of potassium in the initial sample (Table 2.23). Elevated levels of potassium can interfere with ammonium uptake as cations of potassium and ammonium are undifferentiated (Klubek 2011). Most of the nitrogen in the pre-study samples was also in organic form and therefore, unavailable for plant uptake. Nitrogen must be released by microbial mineralization, or ammonification, for use in synthesis of plant protein (Raven et al. 2003). Partially decomposed vermicompost releases a lower percentage of nitrogen robbing the plants of required nutrients (Brady and Weil 2002) leading to general chlorosis.

Although VLWA had an acceptable degree of maturity for compost with a C/N ratio of 9.28 and 9.99, for initial and final C/N ratios respectively, (Morais and Queda 2003), the nitrogen levels for these two ratios remained unchanged at 0.81% (Table 2.23). The yellowing of the plants could be associated with lack of nitrogen uptake even though coffee grounds are reportedly high in nitrogen (Dinsdale, et al.1996). Nitrogen limitation is a regulator of vegetative growth (LeBauer and Treseder 2008). Another contributing factor may be the percentage of organic matter (OM) in the initial and final soil analyses, 13.80 and 23.78, respectively. (Table 2.22). The 2002 FLL Guidelines recommendation for OM for an extensive green roof is 8% by mass (Waldbaum 2011), and the OM content of the media used in this study was significantly higher. Furthermore, the OM levels may have risen through the course of the study through decomposition of roots and leaf matter after the death of 33 % of the parsley plants; and any available nitrogen would be utilized by the soil microbes to breakdown the excess OM. Therefore, nitrogen, a major constituent for biological process of photosynthesis and respiration (Marschner 1995) was unavailable for plant uptake to optimize growth and/or survive under specific environmental conditions such as a green roof (Chapin et al., 1990; Evans and Poorter 2001, Herms and Mattson 1992; Verkroost and Wassen 2005).

The media, specifically GRM with slow-release nitrogen, provided an increase in basil shoot width, parsley shoot height, shoot width, shoot weight and dry shoot weight compared to VLWA (Tables 2.9, 2.15, 2.16, 2.17, and 2.19).

Additionally, these results indicate that parsley, a shade tolerant plant (Russ and Pertuit, 1999), produces more growth when receiving partial shade along with a media containing sufficient plant-available levels of nitrogen. For shoot height, parsley grown in GRM receiving partial shade increased height by 76% over plants grown in VLWA in the same light conditions.

Furthermore, for shoot weight, parsley receiving only morning sunlight was 50% heavier in GRM than plants grown in VLWA. For this herb, sunlight duration and intensity, and appropriate media are important factors to consider when placing this herb on a green roof environment.

Chlorophyll, specifically, Chlorophyll *a* and Chlorophyll *b,* are the key light absorbing pigments in higher plants involved in the biochemical process of photosynthesis, the conversion of light energy to stored chemical energy (Gitelson et al. 2003; Samdur et al. 2000). Photosynthesis plays an important role in the metabolic activities of the plant. More chlorophyll content in leaves may allow more efficient photosynthesis. Thus, the economic yield of a crop depends on plant chlorophyll content. In field studies, stimulatory effects of vermicompost in conjunction with a biofertilizer like *Azophos* and inorganic fertilizers may improve photosynthetic activity and increase dry weight content of plants (Chatterjee 2010). Increased leaf chlorophyll content can be associated with higher mineral elements such as iron, magnesium and manganese when compost and manure are added to the soil in field studies (Mohammadi , et al. 2009). Media, specifically GRM, have higher SPAD values ($p \leq 0.05$) in parsley at 21 DAT (days after transplanting) by 22% over VLWA, but tended to decline toward the end of the study (Table 2.24 and Table 2.25). The addition of nitrogen through fertigation during the study would most likely increased chlorophyll content, since higher levels of plant-available nitrogen has been shown to produce increased chlorophyll content (Chatterjee, 2010; Mohammadi, et al, 2009).

Table 2.22: Comparison of media properties at initiation (August) and termination (September) of summer 2011study.

Media		pH	P	K	Ca	Mg	CEC	OM	SS
			(ppm)				(meq/100)	(%)	(ppm)
Aug-11	GRM	6.1	166	194	1951	313	16.20	6.84	153
	VLWA	7.6	153	1238	1391	475	15.02	13.80	21
Sep-11	GRM	7.1	170	184	1399	222	9.90	6.17	49
	VLWA	7.8	60	143	1615	319	11.74	23.78	11

Table 2.23. Chemical characteristics of VLWA in pre and post study analyses during summer 2011.

Parameter*	VLWA[1]	VLWA[2]
C/N Ratio	9.28	9.99
pH	7.60	7.80
Nitrate Nitrogen (ppm)**	40.30	2.30
Ammonium Nitrate (ppm)	<0.50	1.00
Soluble Sulfur (ppm)	21.00	11.00
Phosphorous (ppm)		
Melich III	153.00	60.00
Bray II	239.00	129.00
Calcium (%)	46.30	68.78
Magnesium (%)	26.35	22.64
Potassium (%)	21.13	3.12
Sodium (%)	2.40	1.81
Boron (ppm)	0.79	0.73
Iron (ppm)	125.00	91.00
Maganese (ppm)	30.00	23.00
Copper (ppm)	2.20	2.08
Zinc (ppm)	8.22	11.67
Aluminum (ppm)	176.00	105.00
Soluble Salts (mmhos/cm)	0.64	0.11

[1] Pre-study analysis [2] Post-study analysis

*Units-ppm=parts per million mmhos/cm=millimhos per centimeter

**Nitrate nitrogen = nitrogen in the sample that is immediately available for plant uptake by the roots

Table 2.24. Basil chlorophyll content as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Main Effect	Chlorophyll (SPAD 502 value)	21 DAT		42 DAT	
		Mean	Prob > F	Mean	Prob > F
Sunlight					
	Full sun	36.0^{a}		37.7^{a}	
	Partial shade	34.5^{a}		35.6^{a}	
	Significance		ns		ns
Tray					
	American Hydrotech	33.5^{a}		38.1^{a}	
	GreenGrid	37.0^{a}		35.2^{a}	
	Significance		ns		ns
Media					
	GRM	34.9^{a}		38.2^{a}	
	VLWA	35.6^{a}		35.0^{a}	
	Significance		ns		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0.05$).
ns = non-significant at $P \leq 0.05$.

Table 2.25. Parsley chlorophyll content as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Main Effect	Chlorophyll (SPAD 502 value)	21 DAT		42 DAT	
		Mean	Prob > F	Mean	Prob > F
Sunlight					
	Full sun	36.5^{a}		35.9^{a}	
	Partial shade	36.2^{a}		36.4^{a}	
	Significance		ns		ns
Tray					
	American Hydrotech	37.0^{a}		36.6^{a}	
	GreenGrid	35.7^{a}		35.7^{a}	
	Significance		ns		ns
Media					
	GRM	39.9^{a}		37.6^{a}	
	VLWA	32.8^{b}		34.6^{a}	
	Significance		0.0064*		ns

Means within the table followed by the same letter do not differ significantly according to a Student's t test ($P \leq 0$
ns = non-significant at $P \leq 0.05$.

CHAPTER 3

CONCLUSIONS AND RECOMMENDATIONS

These studies indicate that the feasibility of producing annual herbs in modular trays on a green roof environment in shallow media is possible. Utilizing available green roof space creates the potential opportunity for expanding urban agricultural food production. Type and depth of media, plant selection and environmental factors are important considerations for green roof food production. Media type, especially the nutrients availability of, are critical for optimum plant growth and development as our study indicated. In our evaluations, GRM media, with slow-release fertilize, provided greater annual herb growth than VLWA. The media depth is an important criterion to determine the types of plants that can be grown in modular trays. Plant selection requires careful consideration as both basil plants performed better than parsley, but parsley may perform better in early spring and late summer, if protected at critical times when air temperatures are low. The habit of the plant, height and spread, and cultural requirements may also limit choices. For example, tall, leggy plants, like dill, may not perform as well as the shorter, spreading habits of plants like parsley, oregano, thyme or majoram. Environmental factors, such as wind and sun, may further limit plant choices. In our study, parsley tolerated the occasional windy days better than the taller basil. However, many annual herbs and vegetables are shallow rooted and well suited for green roof food production.

Several critical factors that could contribute to the success of green roof food production are the use of a shade cloth, drip irrigation with fertigation, and row cover. During seedling or transplant establishment, shade is essential to allow the plants to acclimate to a harsher green roof environment and provide protection for maturing plants during unseasonably high temperatures. A drip irrigation system linked to a roof top weather monitoring system would provide for water when necessary and prevent overwatering by hand therefore reducing the potential for plant mortality related to root rots. The drip irrigation system could also provide for periodic fertigation insuring proper plant growth and development. The row cover is another important consideration for use in green roof food production. The cover would allow a grower to protect plants from insects, birds, and animals during critical periods in the plant’s production cycle. A row cover can also extend the growing season; and, this type of protection could make a significant impact in the productivity of the herbs grown.

Future research recommendations include the comparison of additional media types specifically formulated with fertilizer for a green roof environment, additional herbs and vegetables suitable for green roof urban food production using modular trays, and additional media depth evaluations. The use of shade cloth, row covers and drip irrigation with fertigation for protection of plants and extension of the growing seasons is also recommended. Due to the limited research regarding herb and vegetable production on green roofs, more research is essential to support urban agricultural food systems.

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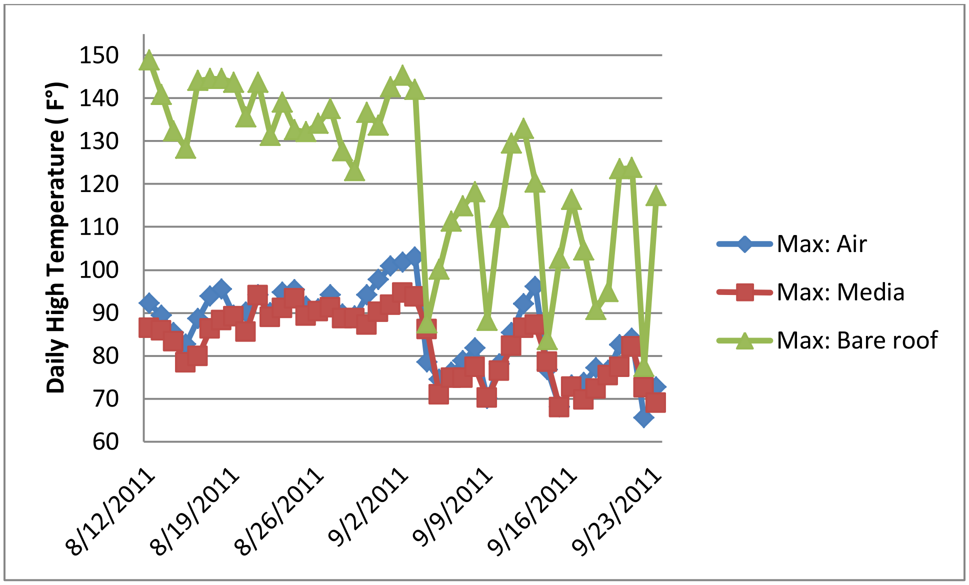
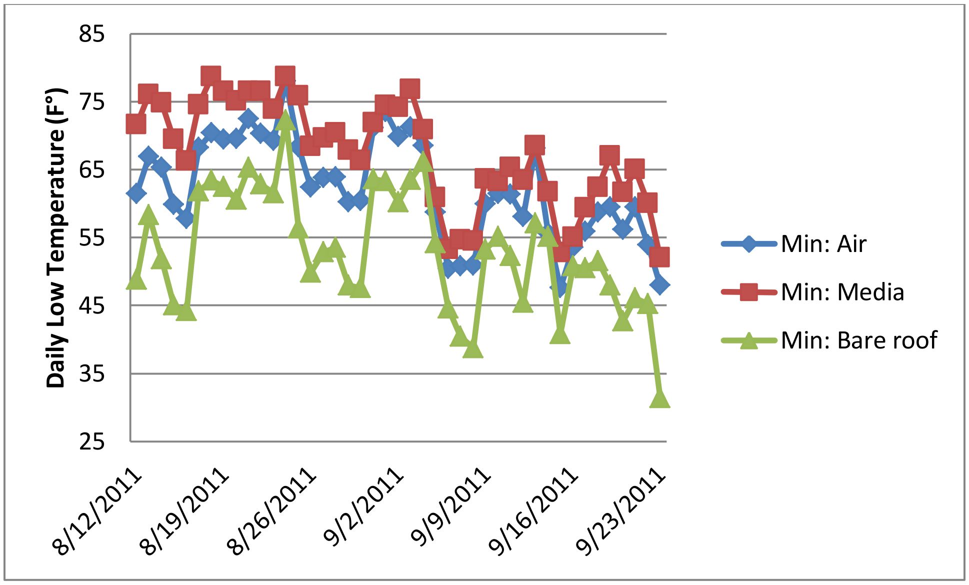
APPENDICES

Appendix A. Green roof daily high (a) and low (b) temperatures in August and September during summer 2011. Temperatures were logged on the bare roof surface, under 5 cm of media, and ambient air at 2 m above the bare roof surface. All temperatures were recorded by HOBO U30-WIF (Onset Computer Corporation, Cape Cod, Massachusetts).



(a)



(b)

Appendix B. Analysis of variance for basil shoot height as influenced by sunlight, tray and media in a green roof environment during spring 2011.

Source	df	SS	F	P > F
Sunlight	1	765.4202	7.1982	0.0121*
Tray	1	0.03821	0.0004	0.0985
Media	1	550.275	5.1749	0.0308*
Sunlight * Tray	1	4.76424	0.0448	0.8339
Sunlight * Media	1	54.04842	0.5083	0.4818
Tray * Media	1	0.09757	0.0009	0.976
Error	28			

Appendix C. Analysis of variance for basil width as influenced by sunlight, tray and media in a green roof environment during spring 2011.

Source	df	SS	F	P > F
Sunlight	1	75.8268	2.0982	0.1586
Tray	1	5.1917	0.1437	0.7075
Media	1	1342.944	37.161	<.0001*
Sunlight * Tray	1	2.1323	0.059	0.8098
Sunlight * Media	1	27.5273	0.7617	0.3902
Tray * Media	1	365.2562	10.1071	0.0036*
Error	28			

Appendix D. Analysis of variance for basil shoot weight as influenced by sunlight, tray and media in a green roof environment during spring 2011.

Source	df	SS	F	P > F
Sunlight	1	67143.595	7.3536	0.0113*
Tray	1	4331.372	0.4744	0.4967
Media	1	39267.956	4.3006	0.0474*
Sunlight * Tray	1	2456.825	0.2691	0.608
Sunlight * Media	1	283.304	0.031	0.8614
Tray * Media	1	35700.323	3.9099	0.0579
Error	28			

Appendix E. Analysis of variance for basil root weight as influenced by sunlight, tray and media in a green roof environment during spring 2011.

Source	df	SS	F	P > F
Sunlight	1	178.3884	0.0818	0.777
Tray	1	1630.0806	0.7474	0.3946
Media	1	117.3158	0.0538	0.8183
Sunlight * Tray	1	392.2803	1.7988	0.1906
Sunlight * Media	1	35.629	0.0163	0.8992
Tray * Media	1	6094.9735	2.7946	0.1057
Error	28			

Appendix F. Analysis of variance for basil dry shoot weight as influenced by sunlight, tray and media in a green roof environment during spring 2011.

Source	df	SS	F	P > F
Sunlight	1	2427.075	3.9327	0.0572
Tray	1	0.0866	0.0001	0.9906
Media	1	3704.979	6.0034	0.0208*
Sunlight * Tray	1	51.9146	0.0841	0.7739
Sunlight * Media	1	7.1873	0.0116	0.9148
Tray * Media	1	1342.697	2.1756	0.1514
Error	28			

Appendix G. Analysis of variance for basil dry root weight as influenced by sunlight, tray and media in a green roof environment during spring 2011.

Source	df	SS	F	P > F
Sunlight	1	0.41312	0.0036	0.9523
Tray	1	3.42788	0.0302	0.8633
Media	1	208.4931	1.8363	0.1862
Sunlight * Tray	1	104.331	0.9189	0.346
Sunlight * Media	1	131.608	1.1591	0.2908
Tray * Media	1	274.1495	2.4145	0.1314
Error	28			

Appendix H. Analysis of variance for basil shoot to root ratio as influenced by sunlight, tray and media in a green roof environment during spring 2011.

Source	df	SS	F	P > F
Sunlight	1	12.375119	8.2812	0.0076*
Tray	1	0.000002	0	0.999
Media	1	2.451264	1.6403	0.2108
Sunlight * Tray	1	1.586042	1.0614	0.3117
Sunlight * Media	1	0.60341	0.4038	0.5303
Tray * Media	1	0.465003	0.3112	0.5814
Error	28			

Appendix I. Analysis of variance for basil shoot height as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	108.1	0.8987	0.3522
Tray	1	117.31315	0.975	0.3329
Media	1	19.30298	0.1604	0.6922
Sunlight * Tray	1	8.10902	0.0674	0.7973
Sunlight * Media	1	7.56777	0.0629	0.804
Tray * Media	1	340.88187	2.833	0.1048
Error	25			

Appendix J. Analysis of variance for basil shoot width as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	7.08349	0.0353	0.8524
Tray	1	13.15458	0.0656	0.7999
Media	1	19.05505	0.0951	0.7604
Sunlight * Tray	1	2.98396	0.0149	0.9039
Sunlight * Media	1	0.23825	0.0012	0.9728
Tray * Media	1	853.67194	4.2594	0.0496*
Error	25			

Appendix K. Analysis of variance for basil shoot weight as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	3.42	0.0003	0.9858
Tray	1	2860.85	0.2695	0.6083
Media	1	2117.211	0.2004	0.6583
Sunlight * Tray	1	2761.551	0.2601	0.6145
Sunlight * Media	1	200.96	0.0189	0.8917
Tray * Media	1	25581.453	2.4094	0.1332
Error	25			

Appendix L. Analysis of variance for basil root weight as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	71.8477	0.0122	0.9131
Tray	1	2.2202	0.0004	0.09819
Media	1	3.1061	0.0005	0.9819
Sunlight * Tray	1	75.7647	0.0128	0.9108
Sunlight * Media	1	4330.5832	0.7324	0.4002
Tray * Media	1	1587.7643	0.2685	0.6089
Error	25			

Appendix M. Analysis of variance for basil dry shoot weight as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	1.285	0.0027	0.9587
Tray	1	127.1616	0.2708	0.6074
Media	1	70.1867	0.1495	0.7023
Sunlight * Tray	1	103.6365	0.2207	0.6426
Sunlight * Media	1	1.9484	0.0041	0.9492
Tray * Media	1	1004.5774	2.1392	0.156
Error	25			

Appendix N. Analysis of variance for basil dry root weight as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	9.12503	0.023	0.8807
Tray	1	0.00608	0	0.9969
Media	1	15.4374	0.0389	0.8452
Sunlight * Tray	1	96.31977	0.2428	0.6265
Sunlight * Media	1	177.05961	0.4463	0.5102
Tray * Media	1	330.67826	0.8336	0.37
Error	25			

Appendix O. Analysis of variance for basil shoot to root ratio as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	0.00005906	0.0005	0.9815
Tray	1	0.05777864	0.537	0.4705
Media	1	0.03191753	0.2966	0.5908
Sunlight * Tray	1	0.00988253	0.0918	0.7644
Sunlight * Media	1	0.7113049	0.6611	0.4239
Tray * Media	1	0.1339783	1.2452	0.2751
Error	25			

Appendix P. Analysis of variance for parsley shoot height as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	261.70576	2.1513	0.1494
Tray	1	0.22499	0.0018	0.9659
Media	1	734.22388	6.0355	0.0179*
Sunlight * Tray	1	3.04789	0.0251	0.8749
Sunlight * Media	1	524.42718	4.3109	0.0436*
Tray * Media	1	251.9943	2.0715	0.157
Error	45			

Appendix Q. Analysis of variance for parsley width as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	96.59382	0.9015	0.3475
Tray	1	81.49188	0.7605	0.3878
Media	1	328.01597	3.0613	0.087
Sunlight * Tray	1	5.628	0.0525	0.8198
Sunlight * Media	1	486.89264	4.5441	0.0385*
Tray * Media	1	376.43593	3.5132	0.0674
Error	45			

Appendix R. Analysis of variance for parsley shoot weight as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	60.599	0.0154	0.9018
Tray	1	189.801	0.0483	0.8271
Media	1	18652.856	4.7429	0.0347*
Sunlight * Tray	1	1560.143	0.3967	0.532
Sunlight * Media	1	15053.592	3.8277	0.566
Tray * Media	1	17426.854	4.4312	0.0409*
Error	45			

Appendix S. Analysis of variance for parsley root weight as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	7937.007	1.448	0.2351
Tray	1	32.262	0.0059	0.9392
Media	1	1225.158	0.2235	0.6387
Sunlight * Tray	1	1308.891	0.2388	0.6275
Sunlight * Media	1	0.176	0	0.9955
Tray * Media	1	11097.527	2.0245	0.1617
Error	45			

Appendix T. Analysis of variance for parsley dry shoot weight as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	56.3707	0.2663	0.6084
Tray	1	0.0087	0	0.9949
Media	1	878.7333	4.1507	0.0475*
Sunlight * Tray	1	37.055	0.2388	0.6275
Sunlight * Media	1	674.43233	0	0.9955
Tray * Media	1	1158.6688	5.473	0.0238*
Error	45			

Appendix U. Analysis of variance for parsley dry root weight as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	816.9276	1.5456	0.2202
Tray	1	249.6452	0.04723	0.4954
Media	1	446.9915	0.8457	0.3627
Sunlight * Tray	1	8.3457	0.0158	0.9006
Sunlight * Media	1	58.7282	0.1111	0.7404
Tray * Media	1	1422.337	2.6911	0.1079
Error	45			

Appendix V. Analysis of variance for parsley shoot to root ratio as influenced by sunlight, tray and media in a green roof environment during summer 2011.

Source	df	SS	F	P > F
Sunlight	1	0.24419465	3.9159	0.054
Tray	1	0.10411268	1.6695	0.2029
Media	1	0.12874247	2.0645	0.1577
Sunlight * Tray	1	0.06897904	1.1061	0.2985
Sunlight * Media	1	0.21273638	3.4114	0.0713
Tray * Media	1	0.10229701	1.6404	0.2968
Error	45			

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