My Special Thanks to these Wonderful Businesses:

Benary Seeds
Blooms of Bressingham
Center Greenhouse
Centerton Nursery
Conard-Pyle Company
Creek Hill Nursery
Darwin Plants
Devroomen Nursery
Greenleaf/Yoders
Hoffman Nursery
Itrinsic Perennials
Jelitto Perennial Seeds
North Creek Nursery
Plant Haven
Pride of Plants
Rick Darke
Song Sparrow Nursery
Stonehouse Perennials
Sunny Border Nursery
Terra Nova Nursery
Walters Nursery
Woodside Gardens

Plants and Substrates Are the Heart of the Green Roof©

David J. Beattie and Robert D. Berghage
Center for Green Roof Research, Department of Horticulture, The Pennsylvania State University, University Park, Pennsylvania 16802 U.S.A.

Edmund Snodgrass
Emory Knoll Farms, 3410 Ady Rd. Street, Maryland 21154 U.S.A.

Although ground-level garden perennials have the widest range of landscape uses, the building roof presents a new and unique environment and opportunity where a wide range of perennials can not only beautify, but also serve several unique environmental functions, including storm water management and urban heat island reduction.

Green roofs, sometimes called eco-roofs, are roofs planted with vegetation and have been used for centuries, especially those characterized by deep soil layers. Examples include 5000-year-old passage tombs in Ireland covered with sod roofs. Settlers in Nebraska covered their roofs with sod, and more recently the rooftop gardens of Rockefeller Center have created an oasis in the center of Manhattan. These deep roof-type gardens have served a number of protective and aesthetic functions. They are usually constructed with soils more than 1 ft deep and have been designated, in the modern vernacular, as intensive roof gardens.

About 30 years ago, a new type of green roof, called an extensive green roof, was developed in Germany and Switzerland. Extensive roofs are lightweight, with thin layers of substrate, and are used mostly for storm water mitigation in the densely populated cities of Europe where building density is higher than in the U.S.A. Today, nearly 24% of the flat roofs in the city of Stuttgart, Germany, have been greened. Germany boasts more than 1 billion square feet of extensive green roofs, mostly on flat industrial roofs. Today, in the city of Basel, Switzerland, every new flat roof must be greened. Green roofs are just beginning to be used in the U.S.A., the most famous being the one on the Ford River Rouge auto plant in Detroit. The

main function of these roofs is to mitigate storm water. On an annual basis a 3- to 4-inch-deep extensive green roof can retain about 50% of the storm water that falls on the roof in most areas of the eastern U.S.A.

In addition to storm water mitigation, green roofs can be installed for beauty, air filtration, and trapping air-borne particles, wildlife habitat, noise suppression, insulation — especially for air conditioning savings — and urban heat island reduction.

While other technologies can out-perform green roofs in achieving any of these individual benefits, none have the potential to encompass all of the benefits on a single roof the way extensive green roofs can.

As America continues to urbanize and pave (seal) more land for roads, parking lots, and building footprints, storm water systems cannot handle the increased runoff loads. All large cities east of the Mississippi have storm water problems. The traditional (engineering) method of coping with this problem has been to install increasing larger drainage pipes.

Constructions costs and the disruption of urban areas needed to replace storm water drainage systems are so high that the burden on public funding has become excessive. Therefore, public policy is gradually shifting the cost of dealing with storm water to the individual developer. One of the least expensive and most environmentally sound methods has been to install extensive green roofs. While the technology has been well developed in Germany, experience has shown that their methods and systems cannot be directly applied to all American situations. Not only can green roof technology help solve increased runoff problems, it represents a wide range of new market opportunities for those involved in the design and installation processes (Fig.1). As a new landscape dimension it can beautify the rooftop landscape of our cities and add value to its buildings. In the process it attracts new customers that buy new products. In addition, building owners feel good about improving the local environment, and it will postpone the need to re-roof their buildings for perhaps decades.

However, market inhibitors must also be carefully considered. As a new, immature market, there is a lack of knowledge in some critical areas. There is little R&D investment in the American green roof paradigm. Payback times are often beyond what market analysts are comfortable with. Green roofs are a long-term investment, but the paybacks can be considerable. When considering roof replacement alone (and without considering all the other benefits), a green roof can pay for itself in 30 years. Availability of suitable plants and substrates may also impede growth of this market. Because of the unique requirements of the roof microclimate, plants and substrates must be carefully chosen. After the job is finished, placing its care in the hands of a building superintendent can have disastrous results. Thus, market and horticultural solutions must be adapted to the particular roof. To answer some of these questions, the Center for Green Roof Research at the Pennsylvania State University was founded in 2001.

Two of the most important factors in establishing a successful green roof are choosing the right plants and the right growing medium; choosing the right growing medium is probably the more difficult. Media for extensive green roofs have no soil, but are based on various multifunctional lightweight minerals including expanded clay, slate, shale, or volcanic materials. The FLL, a German industry group, similar in some respects to the American ASTM, sets standards for green roof installation in Germany and publishes general guidelines on substrate physical and chemical

properties. Bulk density, aeration, and pH are particularly important. A synopsis of substrate characteristics is found in Table 1.

Table 1. Synopsis of characteristics for a green roof medium.

80%–90%	Light-weight aggregate Particle size Dry weight	Expanded slate, shale, or clay $^1/_8$–$^5/_8$ screen 32-42 lbs/ft^3
10%–20%	Organic matter	Weed, soil, and herbicide free
Mixed medium weight		40–46 lbs/ft^3
Saturated medium weight		55–60 lbs/ft^3
3-inch depth dry medium		10–13 lbs/ft^2
3-inch depth saturated medium		17–20 lbs/ft^2
Medium ordering calculations		Medium depth (inches) × square footage of roof divided by 324 = yds^3 of medium to order

Many American roofs have lower weight-bearing capacities than European roofs, so mineral bulk density is especially important. Most commercial flat roofs in the U.S.A. cannot support more than 15-25 lbs/ft^2, which would be equal to a saturated medium about 3-4 inches deep. If you are unsure of the weight carrying capacity of the roof, consult an engineer. Roof loading, wet weight per square foot, can be changed by reducing medium depth or using a lighter weight substrate. However, roof substrate depth in the Northeastern U.S.A., for most situations, should not be less than 3 inches for good plant growth. Aeration is also important because plant roots need a well-aerated environment to actively take up water and nutrients. Aeration is also important for hydraulic conductivity, allowing excess water to exit the roof through drains. Likewise, pH is also important for good plant growth. A substrate with long-term pH stability between 6 and 7 is desirable. Many think that a green roof medium should contain lots of organic matter. However, organic matter will break down with bacterial action thus reducing the effective growing depth and compromising plant growth. No more than 20% (by volume) organic matter is recommended and only that amount when the roof is planted in late summer. If planted in spring, 10% organic matter is sufficient. Organic matter adds water-holding capacity, especially for late summer planting, and some cation exchange capacity. Finally a small amount of a slow-release fertilize can be added to the medium at planting time. All green roof media used in Germany adhere to FLL physical and chemical standards. Recently, Penn State University's Soil Testing Lab has begun testing media using FLL standards. This service should result in more uniform and reliable green roof media and fewer mistakes.

The second most important consideration for a successful green roof is the proper choice of plants. Europeans have found that succulents, like sedums and delospermas, have been most reliable in these shallow roof systems. Sedums and delospermas are members of the botanical family Crassulaceae, a close relative of the cactus. These taxa are heat-, cold-, and drought-tolerant perennials. Most are low

Figure 1. Green roof can even adorn Smart Car roofs.

Figure 2. New bamboo culms and many grass stolons are sharp enough to penetrate the roof membrane.

growing, so produce relatively little biomass. Large amounts of biomass on a roof can present problems for both maintenance and fire safety. Generally, if grasses are used, short varieties like fescues should be selected and used only as accent plants. In this way biomass accumulation can be minimized.

Choosing low-growing succulents does not exclude the use of other plants like native herbaceous perennials or annuals, but succulents have a proven track record. Further, we have almost no information on how most native plants perform in the extensive roof environment. Even succulent choices here must be made carefully. For instance, *Delosperma nubigenum* is reliably winter hardy in Maryland, but not in State College, Pennsylvania. In another example, *Sedum acre* seems to do well in the cool summer weather of State College, but "melts out" in the heat of Washington, D.C. When planting a roof, it is recommended that at least 10 different plant taxa be used. In this way, if something happens to some, others will fill in.

Although plants on most green roofs are placed there for storm water mitigation purposes, there are several other attributes that are important. Aesthetics, particularly flower and foliage color, can be very important when the roof is seen from above. Plants take up water and store it in their leaves. In the process of releasing it through their stomates, not only is water released, but also the air around the roof surface is cooled. If enough green roofs could be installed in a city, the heat island so prevalent in today's mega cities could be substantially reduced. Recent research has also shown that the cooling effect of the plants can increase the efficiency of photovoltaic cells when placed on the roof and reduce the air conditioning demand for an individual building.

There are several ways green roof plants, especially succulents, can be propagated. Depending on the needs of the job, propagation can occur either off-site, or on the roof, using either cuttings or seed. Sedum seeds are very small and, while best propagated off site, they can be mixed with hydro mulch and sprayed directly over the roof substrate. No reliable formulas for how much seed of each taxon to use for each method have been published.

Finally, green roof plants should not have strong, sharp stolons or rhizomes. Bamboos are NOT a recommended green roof plant as are several grasses with aggressive stolons. They may be expected to puncture the membrane creating leaks (Fig. 2).

The best time to establish a green roof is in spring, although roofs can be planted until frost. Some type of irrigation should be available at planting to provide for successful establishment. In some especially dry areas, permanent irrigation can be installed, but beyond establishment irrigation systems, particularly in-ground (roof) systems are probably unnecessary.

Green roof maintenance should not be overlooked. Yearly inspections should be no different that that for a ballasted roof. The same regular inspections should be practiced for green roofs. Occasional hand pulling of tree seedlings is sufficient. However, plants like clover, because of their extensive underground root and shoot system, may require the application of small amounts of an herbicide. Good maintenance, though, starts with a weed-free medium. Finally, yearly applications of a slow-release fertilizer at a rate of 5 g N per 1000 ft^2 will maintain plant health, but not result in excessive nitrogen runoff. Liming every 5–10 years is also recommended.

Green roofs are gradually being introduced into American markets. However, lack of installation experience, substrate standards, and plant performance information slow market acceptance. With time, these market inhibitors will be overcome and green roofs could be as common as they are in Europe.