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Principal Investigator: Michael P. McCann, Ph.D.
Co-Principal Investigator: Clint Springer, Ph.D.

None of the information included in this report is subject to any limitations on distribution. Preliminary data from various studies that are underway is referenced herein but specific data has not been included since these studies are on-going with the intent of producing manuscripts for submission to peer-reviewed journals. Data will be shared with DOE on request but this data is not to be freely distributed.

Executive Summary

Task A: Examination of the physiological, morphological, and reproductive responses of *Panicum virgatum* (switchgrass) cultivars identified as potential biofuel producing cultivars as well as naturally-occurring varieties of switchgrass to projected changes in climate for the central portion of the United States.

This project was a multi-year field study that was performed at the Konza Prairie Biological Station near Manhattan, KS USA. The major objective of the study was to understand the physiological and growth responses of the important biofuel grass species, *Panicum virgatum* (switchgrass) to simulated changes in precipitation expected for the Central Plains region of the United States. Population-level adaptation to broad-scale regional climates or within-population variation in genome size of this genetically and phenotypically diverse C_4 grass species may influence the responses of this species to future precipitation variability associated with climate change. Therefore, we investigated switchgrass responses to water variability between natural populations collected across a latitudinal gradient and among individuals spanning a range of genomes sizes within these populations. *P. virgatum* plants from natural populations originating from Kansas, Oklahoma, and Texas, U.S.A, received frequent, small precipitation events ("ambient") or infrequent, large precipitation events ("altered") to simulate contrasting rainfall variability expected for this region. We measured leaf-level physiology, aboveground biomass, and genome size for each individual. Gas exchange rates and aboveground biomass varied significantly by population origin but did not differ by genome size. Altered precipitation treatments reduced leaf-level physiological rates; however this result did not vary by population or genome size (Tables 1-5). Our results suggest that trait variation in *P. virgatum* is primarily attributed to population-level adaptation across a latitudinal gradient, not genome size, and that neither population-level adaptation nor genome size may be important predictors of *P. virgatum* responses to future climatic conditions. Based solely on the data presented here, the most important consideration when deciding what varieties of switchgrass to cultivate for biofuel

feedstocks under future climate scenarios is local adaptation and not necessarily genome size as has been hypothesized in the literature.

Task B: Installation of an extensive green roof system on the Science Center at Saint Joseph's University for research, research-training and educational outreach activities.

An experimental green roof system was designed and installed by an outside contractor (Roofmeadows) on the roof of the Science Center at Saint Joseph's University. The roof system includes four test plots, each with a different drainage system, instrumentation to monitor storm water retention, roof deck temperature, heat flux into and out of the building, rain fall, wind speed and direction, relative humidity and heat emission from the roof system. The vegetative roof was planted with 28 species of plants, distributed throughout the roof area, to assess species/variety growth and coverage characteristics, both in terms of the different drain layer systems, and in terms of the different exposures along the north to south axis of the building.

Analysis of the drain layer performance, in terms of storm water retention, shows that the aggregate (stone) drainage layer system performed the best, with the moisture management mat system second, and the geotextile drain layer and reservoir sheet layer systems coming in last. This information is of value in the planning and design of vegetative roof systems since the different types of drainage layer systems have different installation costs (the geotextile drain layer system is the most expensive in terms of material cost but the lightest in weight and the thinnest, which has important implications in retrofit installations where the total weight and permissible height of the system are limited by existing conditions), and different weights (the stone drainage is much heavier than the other drainage systems). The different drainage layer systems also seem to be having an impact on plant growth and spread (see below) with the test plot with the reservoir sheet layer (which holds additional water in the space below the separation fabric, which should be accessible to the plant roots) actually having the poorest plant coverage and plant spread of all areas of the roof studied.

Plant growth performance analysis is ongoing, but significant differences have been observed in the third growing season ('13) along the north to south axis, with most species doing better towards the northern end of the roof (in terms of percent ground coverage and plant spread and reproduction). Interestingly, plant growth in all four of the test plots was reduced relative to the lower areas of the roof (the lower area was ca. 2 inches lower than the test plots, due to the space needed for sensors under the plots. The lower roof area uses an aggregate drain layer comparable to that in the third test plot), even when accounting for the north to south differences. The reasons for these differences are not clear and studies are underway to examine the impact of wind scour, drainage rates, temperature, and other factors. This information will be of value to planners of extensive vegetative roof systems in the Philadelphia (and broader) region, since plant growth and roof system overall performance is influenced by local climate, making broad generalizations of performance difficult. If it is determined that the 2" elevation differences are actually driving the reduced plant growth and spread in the raised plots relative to the lower roof areas, this will be important in the design of vegetative roof systems, as changes in roof elevation frequently require changes in the finished depth of installed systems. It may thus be of value to use different plant varieties in different areas of vegetative roof systems to minimize such effects, even with small elevations changes.

Task C: Education and community outreach efforts by the IES involving conferences at SJU, presentations by faculty and students off campus, and educational signage.

The Institute for Environmental Stewardship hosted three storm water management workshops on the SJU campus in Philadelphia, in collaboration with the Lower Merion Conservancy, a not-for-profit organization located in Montgomery County, PA. These workshops were free and open to the public. The three workshops (held each year in March) drew more than 200 participants total. The presenters included local and state government agencies, not for profit organizations involved in storm water and open space preservation, designers, engineers, planners and others. Feedback was uniformly positive and we plan to continue the workshops for the foreseeable future. The success of these workshops has also now resulted in a grant from the William Penn Foundation to continue this program for the next three years as part of their regional effort to improve watershed quality in the regions surrounding Philadelphia. Mitigation of stormwater discharge from residential and commercial properties has been identified as a key goal of this new project and educational efforts providing low-cost on-site solutions are a primary area of effort.

Educational signage has been installed at four locations on campus to explain campus infrastructure related to storm water (rain gardens, vegetative roof and green facades), as well as detailed signage installed on the Science Center roof for the vegetative roof system. More than 100 people (from in and outside of SJU) have thus far participated in tours of the roof system. A digital signage system has been installed in the adjacent library and this system provides information about the vegetative roof project and other efforts. A web camera system for the roof has also been installed and the video will be simulcast to the digital signage and with web site (www.sju.edu/ies) in the near future.

4. Objectives versus Accomplishments

Task A Objective: Examine the physiological, morphological, and reproductive responses of *Panicum virgatum* cultivars to projected changes in climate for the central portion of the United States.

We successfully examined the physiological, morphological, and reproductive responses of *Panicum virgatum* genotypes collected from Kansas, Oklahoma, and Texas. As well as the response of several cultivars used for biofuel production using growth chambers. From this work we published four articles, two Master's theses, and presented several presentations at national and international scientific conferences.

Task B Objective: Installation of an extensive green roof system on the Science Center at Saint Joseph's University for research, research-training and educational outreach activities.

The experimental vegetative roof system was designed and installed by Roofmeadow, a for-profit company based in Philadelphia, PA. The roof system was designed to be "many roofs in one roof" in terms of having four test plots with different drain layer systems, embedded in an extensive roof system. The vegetative roof covers half of the lower roof of the Science Center. The system was installed in the fall of 2010 with most of the 28 plant species being installed at that time (several were delayed, due to availability issues, until the spring of 2011). The original goals of the project were met and research continues using the data from the roof system, the plants and the sensors.

The four test plots incorporated different drain layer systems. Plot A (northern most) uses a moisture management mat system (Type I system, composed of recycled closed-cell polyethylene foam), Plot B (northwestern) uses a geotextile sheet system (Type II system, composed of a tangled filament sheet drain with adhered polypropylene non-woven separation fabric, forming a three-dimensional mesh), Plot C (southwestern) uses a light-weight aggregate drainage layer (Type III) and Plot D (southern) uses a reservoir drain sheet system (modified Type II system, consisting of a perforated formed polyethylene membrane with water retention reservoirs). Each test plot incorporates a lysimeter system consisting of four load cells and a fiberglass plate. These lysimeters underlie a ca. 1 meter square section of the vegetative roof system in each test plot, with both the growth medium and drainage layers running continuously throughout the test plot, eliminating edge effects on the lysimeters. In addition, three K-type temperature sensors were installed in the roof system along with a fourth for air temperature readings. Two heat flux sensors were also installed under the roof system and one was installed on the east side of the building where there is no vegetative roof system. In addition, a weather station with rain gauge, anemometer, relative humidity sensor and radiometer, were installed (in and adjacent to Plot B) to allow for estimates of evapotranspirational rates. All sensors are connected to a datalogger system. Data is collected daily and transferred to the SJU servers. This data is also backedup off-site in the SJU disaster recovery center at least once per week. Data is accessible to the public via the web site from the SJU data warehouse, and "scrubbed" data sets (manually-curated sets with "bad" data due to instrument issues removed) will be posted in the near future, along with calibration parameters and other technical information. Analysis of the instrumentation data was performed in conjunction with Roofmeadows. They established a relationship with two faculty in the Engineering School at Villanova University (they worked as sub-contractors to Roofmeadow) and a graduate student and much of the data "scrubbing" and analysis of the drainage layers was performed by Villanova University, Villanova, PA. This has now moved into a formal collaboration between SJU, Villanova and Roofmeadow for on-going studies beyond the grant period.

Twenty-eight plant species, including nine sedum species/varieties and 19 forbs and grasses, were planted on the roof. The sedums were planted as cuttings distributed by hand across all roof areas. The grasses and forbes were planted as plugs (114 plugs of each species) on a grid system to ensure that they were present on all areas of the roof, including throughout the four test plots. The roof was watered after planting in the fall of 2010. Other than a four-week period during a drought in the summer of 2012, there was no supplemental watering. Nutrient levels are checked twice yearly and thus far no fertilization has been done. Studies on plant survival, growth, spread and reproduction, were initiated in the third growing seasons (2013) and will be continued. SJU has assumed the costs of the on-going routine maintenance contract with Roofmeadow and will continue to do so throughout at least the next three years.

Task C: Education and community outreach efforts by the IES involving conferences at SJU, presentations by faculty and students off campus, and educational signage.

The original goals in this area, namely hosting two storm water management conferences, installing educational signage on campus, and supporting SJU faculty and students to present their research findings, have been meet and exceeded.

Three storm water conferences were held throughout the 2011 - 2013 periods, in March of each year. These conferences were free and open to the public. The first conference focused on homeowners and techniques to mitigate storm water impact on residential properties. The second was targeted at professionals (system designers, installers and property managers) and continuing education credit through the AIA was provided. The third workshop focused on issues relating to the intersection of storm water management with historic structures and other resources.

Educational signage has been installed in several areas of the SJU campus, including the Science Center roof and two lawn areas with storm water management features. A digital signage system has also been installed in the SJU Library atrium and a web site detailing the work of the Institute for Environmental Stewardship has been established (www.sju.edu/ies). Access to the data from the greenroof system will be provided via the web site and refinements to the access system are being made.

SJU students and faculty have presented research related to both the switchgrass project and the vegetative roof project at various professional society meetings and additional abstracts have been submitted (see section 6, Task B, below).

5. Summary of Project Activities

Task A: Examination of the physiological, morphological, and reproductive responses of *Panicum virgatum* (switchgrass) cultivars identified as potential biofuel producing cultivars as well as naturally-occurring varieties of switchgrass to projected changes in climate for the central portion of the United States.

This project was a multi-year field study that was performed at the Konza Prairie Biological Station near Manhattan, KS USA. The major objective of the study was to understand the physiological and growth responses of the important biofuel grass species, *Panicum virgatum* (switchgrass) to simulated changes in precipitation expected for the Central Plains region of the United States. Population-level adaptation to broad-scale regional climates or within-population variation in genome size of this genetically and phenotypically diverse C_4 grass species may influence the responses of this species to future precipitation variability associated with climate change. Therefore, we investigated switchgrass responses to water variability between natural populations collected across a latitudinal gradient and among individuals spanning a range of genomes sizes within these populations. *P. virgatum* plants from natural populations originating from Kansas, Oklahoma, and Texas, U.S.A, received frequent, small precipitation events ("ambient") or infrequent, large precipitation events ("altered") to simulate contrasting rainfall variability expected for this region. We measured leaf-level physiology, aboveground biomass, and genome size for each individual. Gas exchange rates and aboveground biomass varied significantly by population origin but did not differ by genome size. Altered precipitation treatments reduced leaf-level physiological rates; however this result did not vary by population or genome size (Tables 1-5). Our results suggest that trait variation in *P. virgatum* is primarily attributed to population-level adaptation across a latitudinal gradient, not genome size, and that neither population-level adaptation nor genome size may be important predictors of *P. virgatum* responses to future climatic conditions. Based solely on the data presented here, the most important consideration when deciding what varieties of switchgrass to cultivate for biofuel feedstocks under future climate scenarios is local adaptation and not genome size as has been hypothesized in the literature

Table 1. Physiological responses of *P. virgatum* populations to water treatments. Significant differences in the physiology among *P. virgatum* populations, whereby Texas originating plants generally showed the highest chlorophyll fluorescence (Fv/Fm), foliar nitrogen concentrations (%N), and water potential. Water availability did not significantly affect any of the physiological parameters measured.

	Kansas		Oklahoma		Texas	
	Ambient	Altered	Ambient	Altered	Ambient	Altered
F_v/F_m						
July	0.79 ± 0.01	0.79 ± 0.002	0.79 ± 0.004	0.79 ± 0.003	0.80 ± 0.003	0.79 ± 0.002
Sept	$0.76^a \pm 0.01$	$0.76^a \pm 0.01$	$0.77^a \pm 0.01$	$0.77^a \pm 0.01$	$0.78^b \pm 0.01$	$0.78^b \pm 0.01$
%N						
July	2.091 ± 0.11	1.87 ± 0.08	1.80 ± 0.08	1.87 ± 0.12	1.98 ± 0.17	2.04 ± 0.17
Sept	$1.39^a \pm 0.07$	$1.42^a \pm 0.10$	$1.26^a \pm 0.08$	$1.35^a \pm 0.16$	$1.73^b \pm 0.23$	$1.96^b \pm 0.16$
Ψ_{mid}						
July	-1.71 ± 0.12	-1.80 ± 0.20	-2.36 ± 0.29	-1.70 ± 0.37	-1.60 ± 0.33	-1.15 ± 0.19
Sept	-1.83 ± 0.20	-2.02 ± 0.19	-1.82 ± 0.16	-1.53 ± 0.34	-1.58 ± 0.15	-1.24 ± 0.29

Notes: Presented data are mean (± 1 SEM) of physiological traits measured in July and September. Significant differences (α=0.05) between populations are indicated by superscript. For each population x treatment group, n=4-11.

Table 2. Biomass characteristics of *P. virgatum* populations to water treatments. Generally, Texas populations grew the largest as indicated by the highest total biomass (Total Biomass) observed in each measurement recorded. The biomass of each tiller (Biomass/tiller), the biomass of each flowering tiller (Biomass/FT), and the biomass of each non-flowering tiller (Biomass/NFT) were significantly higher in Texas populations. Water availability did not significantly alter biomass flowering tiller biomass (FT), non-flowering tiller biomass (FT Biomass), the percent of tillers that produced flowers (% reproductive), the total tiller number, the number of non-flowering tillers (NFT #) nor differences among populations in these parameters.

	Kansas		Oklahoma		Texas	
	Ambient	Altered	Ambient	Altered	Ambient	Altered
Total Biomass (g)	$372.95^a \pm 54.52$	$430.39^a \pm 81.92$	$443.66^a \pm 419.13$	$419.13^a \pm 57.44$	$678.04^b \pm 104.04$	$735.10^b \pm 164.03$
FT Biomass (g)	$347.94^a \pm 52.71$	$418.06^a \pm 79.59$	$429.78^a \pm 54.48$	$385.96^a \pm 55.81$	$653.34^b \pm 95.08$	$715.36^b \pm 162.84$
NFT Biomass (g)	25.01 ± 6.02	12.33 ± 4.54	19.86 ± 10.86	33.16 ± 24.30	24.70 ± 11.75	19.74 ± 9.96
% Reproductive	92.41 ± 2.26	97.08 ± 0.75	95.63 ± 2.01	92.96 ± 4.54	96.90 ± 1.20	97.30 ± 1.31
Total Tiller #	132.50 ± 18.96	155.88 ± 29.23	121.88 ± 22.92	148.00 ± 30.40	102.40 ± 13.81	93.20 ± 15.98
NFT #	20.40 ± 4.56	13.63 ± 3.82	11.63 ± 5.19	23.25 ± 16.58	13.20 ± 5.16	10.60 ± 3.36
Biomass/tiller (g)	$3.02^a \pm 0.30$	$2.96^a \pm 0.40$	$3.92^a \pm 0.40$	$3.16^a \pm 0.32$	$6.65^b \pm 0.58$	$7.67^b \pm 1.06$
Biomass/FT (g)	$3.20^a \pm 0.19$	$3.13^a \pm 0.40$	$4.45^a \pm 0.59$	$3.30^a \pm 0.32$	$7.32^b \pm 0.69$	$8.31^b \pm 1.10$
Biomass/NFT (g)	2.21 ± 1.23	0.91 ± 0.21	1.44 ± 0.35	1.35 ± 0.26	1.61 ± 0.22	1.49 ± 0.46

Notes: Presented data are mean (± 1 SEM). Significance differences (α=0.05) between groups is indicated by superscript. For each population x treatment group, n=5-10.

Table 3. ANCOVA results for *P. virgatum* physiology and leaf chemistry. No significant relationships among genome size and the physiological parameters presented here: photosynthesis (Amax), stomatal conductance (gs), transpiration (E), water potential, chlorophyll fluorescence, and foliar nitrogen.

	July			September		
	d.f.	*F*	*p*	d.f.	*F*	*p*
A_{max}						
Treatment	1,27	< 0.01	0.95	1,29	11.86	< 0.01*
DNA	1,27	0.39	0.54	1,29	2.03	0.17
T x D	1,26	4.08	0.05	1,28	0.33	0.57
g_s						
Treatment	1,27	0.10	0.76	1,29	10.63	< 0.01*
DNA	1,27	1.01	0.32	1,29	1.95	0.17
T x D	1,26	1.78	0.19	1,28	< 0.01	0.98
E						
Treatment	1,27	1.44	0.24	1,29	12.94	< 0.01*
DNA	1,27	4.23	0.05*	1,29	6.42	0.02*
T x D	1,26	1.16	0.29	1,28	0.11	0.74
WUE						
Treatment	1,27	1.25	0.27	1,29	0.15	0.71
DNA	1,27	0.68	0.42	1,29	0.52	0.48
T x D	1,26	0.07	0.79	1,28	0.32	0.58
Ψ_{mid}						
Treatment	1,42	1.02	0.32	1,40	0.01	0.93
DNA	1,42	2.00	0.17	1,40	5.90	0.02*
T x D	1,41	0.29	0.59	1,39	0.87	0.36
F_v/F_m						
Treatment	1,32	0.12	0.73	1,29	13.93	< 0.01*
DNA	1,32	< 0.01	0.97	1,29	1.78	0.19
T x D	1,31	0.573	0.46	1,28	14.65	< 0.01*
%N						
Treatment	1,31	1.77	0.19	1,31	< 0.01	0.97
DNA	1,31	0.12	0.35	1,31	0.92	0.35
T x D	1,30	0.05	0.13	1,30	0.55	0.46

Notes: Statistics are presented for July and September separately. All water treatment x DNA content interactions (T x D) are presented, regardless of significance. However, main effects (Treatment and DNA) are presented from the simplified model in which non-significant interaction terms were removed, when applicable. Significance at the α=0.05 level is indicated by an asterisk (*).

Table 4. ANCOVA results for *P. virgatum* biomass. No significant relationships among genome size and biomass were detected.

	d.f.	*F*	*p*		d.f.	*F*	*p*
Total Biomass				NFT #			
Treatment	1,29	2.52	0.12	Treatment	1,29	0.09	0.76
DNA	1,29	10.55	< 0.01*	DNA	1,29	0.02	0.89
T x D	1,28	0.43	0.52	T x D	1,28	< 0.01	0.95
FT Biomass				Biomass/tiller			
Treatment	1,29	2.60	0.12	Treatment	1,29	0.79	0.38
DNA	1,29	11.65	< 0.01*	DNA	1,29	0.18	0.67
T x D	1,28	0.52	0.48	T x D	1,28	1.28	0.27
NFT Biomass				Biomass/FT			
Treatment	1,29	0.01	0.92	Treatment	1,29	1.08	0.31
DNA	1,29	0.03	0.87	DNA	1,29	0.38	0.54
T x D	1,28	0.22	0.64	T x D	1,28	1.71	0.20
Total Tillers				Biomass/NFT			
Treatment	1,29	3.67	0.07	Treatment	1,29	0.79	0.38
DNA	1,29	5.13	0.03*	DNA	1,29	0.03	0.88
T x D	1,28	0.40	0.53	T x D	1,28	0.84	0.37
FT #				% Reproductive			
Treatment	1,29	4.47	0.04*	Treatment	1,29	0.16	0.69
DNA	1,29	6.77	0.02*	DNA	1,29	0.06	0.82
T x D	1,28	0.60	0.44	T x D	1,28	0.57	0.46

Notes: All water treatment x DNA content interactions (T x D) are presented, regardless of significance. However, main effects (Treatment and DNA) are presented from the simplified model in which non-significant interaction terms were removed, when applicable. Significance at the α=0.05 level is indicated by an asterisk (*).

Table 5. Least-squares linear regression results for *P. virgatum* physiology and leaf chemistry.

	July			September		
	y-intercept	Slope	r^2	*y*-intercept	Slope	r^2
A_{max}						
Ambient	18.98	-5.71	0.22	31.74	-3.18	0.11
Altered	38.07	1.43	0.04	15.75	-1.43	0.05
All	10.03	-1.16	0.02	14.62	-0.08	< 0.01
g_s						
Ambient	0.27	-0.04	0.15	0.14	-0.01	0.05
Altered	0.10	< -0.01	< 0.01	0.09	-0.01	0.07
All	0.15	-0.01	0.03	0.08	< -0.01	< 0.01
E						
Ambient	12.93	-0.72	0.21	5.59	-0.68	0.16
Altered	6.56	-2.01	0.10	3.45	-0.52	0.22
All	7.76	-0.91	0.10	3.11	-0.25	0.03
WUE						
Ambient	2.82	0.17	0.01	7.59	-0.04	< 0.01
Altered	2.75	0.38	0.05	4.38	0.91	0.04
All	3.25	0.14	0.01	5.75	0.45	0.01
Ψ_{mid}						
Ambient	-1.16	-0.16	0.06	-1.00	-0.21	0.14
Altered	-1.17	-0.19	0.11	-1.30	-0.13	0.08
All	-1.32	-0.08	0.01	-0.74	-0.29	0.18
F_v/F_m						
Ambient	0.78	< 0.01	0.02	0.68	0.02	0.44
Altered	0.79	< -0.01	0.03	0.80	-0.01	0.23
All	0.79	< -0.01	< 0.01	0.76	< 0.01	< 0.01
%N						
Ambient	2.84	-0.20	0.19	1.88	-0.12	0.18
Altered	1.85	0.01	0.31	1.49	-0.03	0.39
All	2.04	-0.03	0.32	1.61	-0.06	0.03

Note: Statistics are presented for water treatments separately (Ambient and Altered), as well as ambient and altered treatments combined (All), for data collected in July and September.

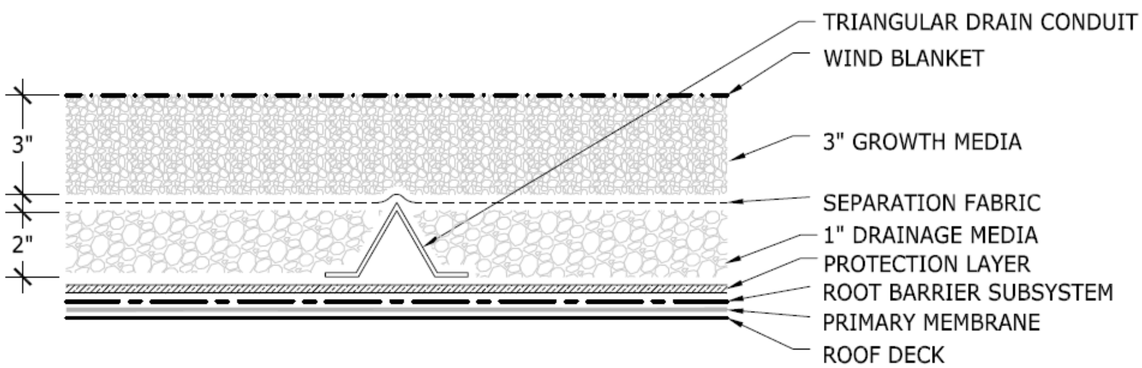
Task B

Vegetative roof system design:

The vegetative roof was installed in the fall of 2010. The bulk of the vegetative roof area was installed as an extensive type roof system, using a stone aggregate drain layer (Figure 1, below). In order to test the effect of different types of drain layers on stormwater retention, four test plots with different drain layers were installed within the system (Figure 2 and Table 1, below). The roof system was also designed to allow assessments of the growth and success of different plant varieties and types (28 different species of plants were installed on the roof, including 9 species/varieties of sedums and 19 species of forbs and grasses). The types of plants used were selected based on their prevelance in vegetative roof systems already installed or being planned for the Philadelphia and tri-state region. The plants survival, growth and spread was monitored starting in 2013.

A typical cross-section of the vegetative roof system (outside of the test plots) is shown below.

Figure 1: Typical cross-section of the vegetative roof system outside of the four test plots.



Within the vegetative roof system, four areas (test plots A - D, going from north to south on the roof) were constructed to examine the effects of different drainage layers on stormwater retention and on plant survival, growth and spread.

To assess stormwater retention, each test-plot contained a lysimeter system, which used load-cells to measure changes in the weight of a 1.22 m x 1.22 m (4 ft x 4 ft each) segment of each test plot. Each of the test-plots resembled background area in having identical growth layers, while the drainage layer was unique to each of the lysimeters (Fig. 2 and Table 1).

Table 1: Test plot composition

Lysimeter system / plot ID	Growth layer		Drainage layer	
	Name	Description	Name	Description
Background (main area)	growth media	3" of proprietary mix of sand, organics, supplied by Roofmeadows	Drainage media	2 inches of fine, light-weight aggregate
LYS A	growth media	Same as above	moisture management mat	Recycled plastic sheets with drain channels
LYS B	growth media	Same as above	geocomposite sheet drain	Engineered composite root barrier and drain layer system
LYS C	growth media	Same as above	lightweight aggregate drainage media	2 inches of fine, light-weight aggregate
LYS D	growth media	Same as above	molded reservoir sheet	Interconnected "cups"

Figure 2: Typical test-plot and lysimeter profile

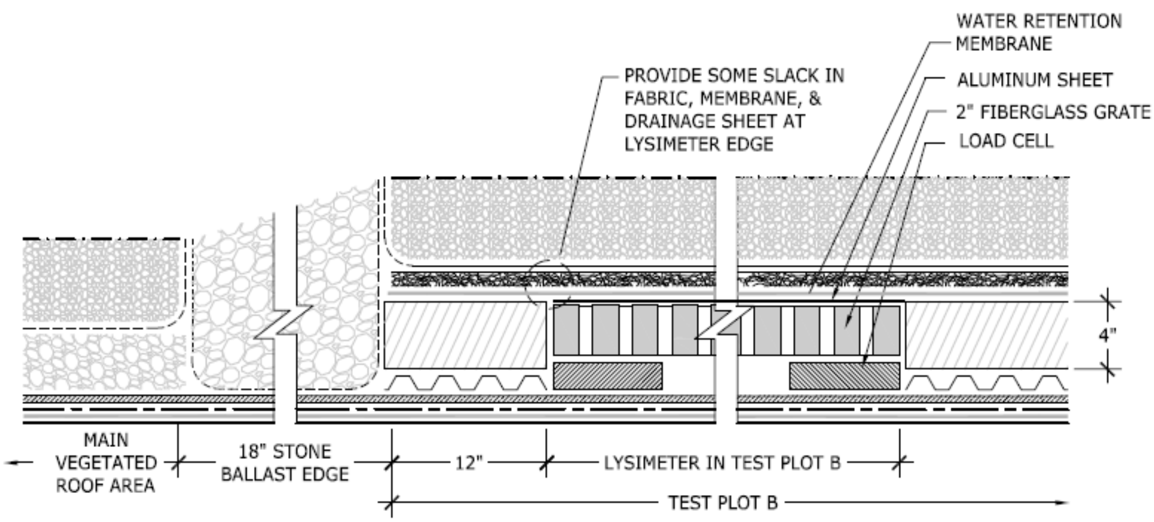
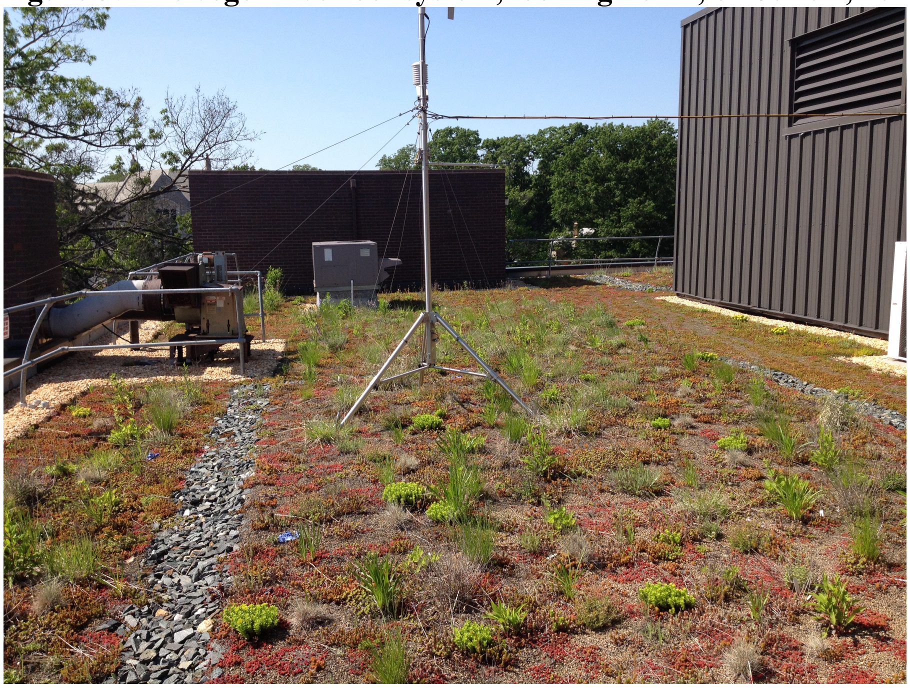


Figure 3: The vegetative roof system, looking north, on June 2, 2014



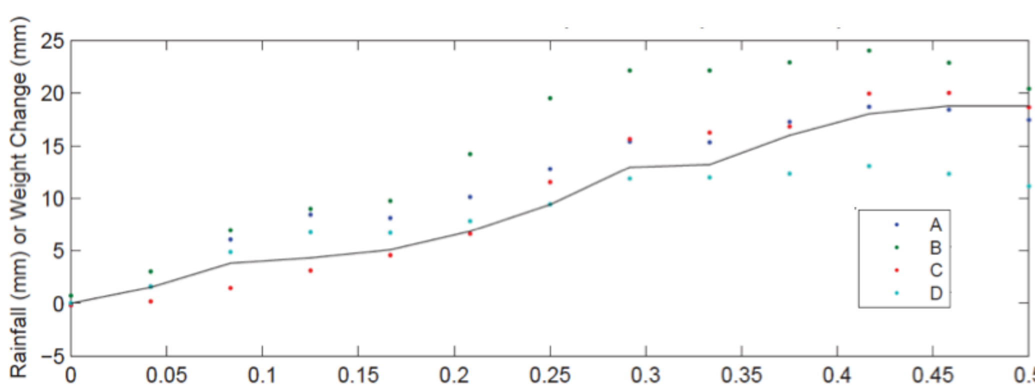
This is the view from north of the elevator shaft. Test plot 2 is in the foreground (bordered by grey stones) and the western edge of test plot one is visible at the top of the photo. The weather station is installed on the tower assembly in the center of the frame and the rain gauge is attached to the railing on the left (not shown). This picture was taken on June 2, 2014.

Figure 4: The vegetative roof system, looking south, on June 2, 2014

This is the view from the south of the elevator shaft. Test plot 3 is in the foreground (bordered by grey stones) and test plot 4 is visible further away. The walkway on the left is for maintenance purposes and for access to the greenhouse facilities.

Drain-layer impacts on storm water retention:
Among the research objectives for the vegetative roof system was a hydrologic performance comparison of the different drainage layers on a green roof. Four configurations were devised and implemented at four "research plots". Each of the plots was equipped with a 1.22 m by 1.22 m weighing lysimeter to monitor changes in weight that can be correlated to water loss from the system. Lysimeter systems A (northern most) through D (southern most) were constructed, respectively, with the following drainage layers: moisture management mat, geocomposite sheet drain, lightweight aggregate drainage media, and molded reservoir sheet. The lysimeter construction, in contrast to a traditional "box" system, was unique in having no pronounced lateral boundary. Continuous monitoring had been performed at the site since November 2010. For the purpose of the analysis the rain events were isolated from dry periods and the hydrologic responses of four lysimeter systems were compared. The drainage systems were ranked in terms of relative potential for stormwater retention, where a higher performance index indicates more stormwater retained in the plot over time and a lower performance index indicating that stormwater drained out of the plot more quickly. Preliminary results indicate that the differences are statistically significant. The highest retention performance was achieved in lysimeter system C featuring aggregate drainage layer (performance index 1.0), followed by system A with moisture management mat (performance index 0.40). Lysimeter system D with reservoir sheet and system B with geocomposite sheet drain had performance indices of 0.30 and 0.22, respectively.

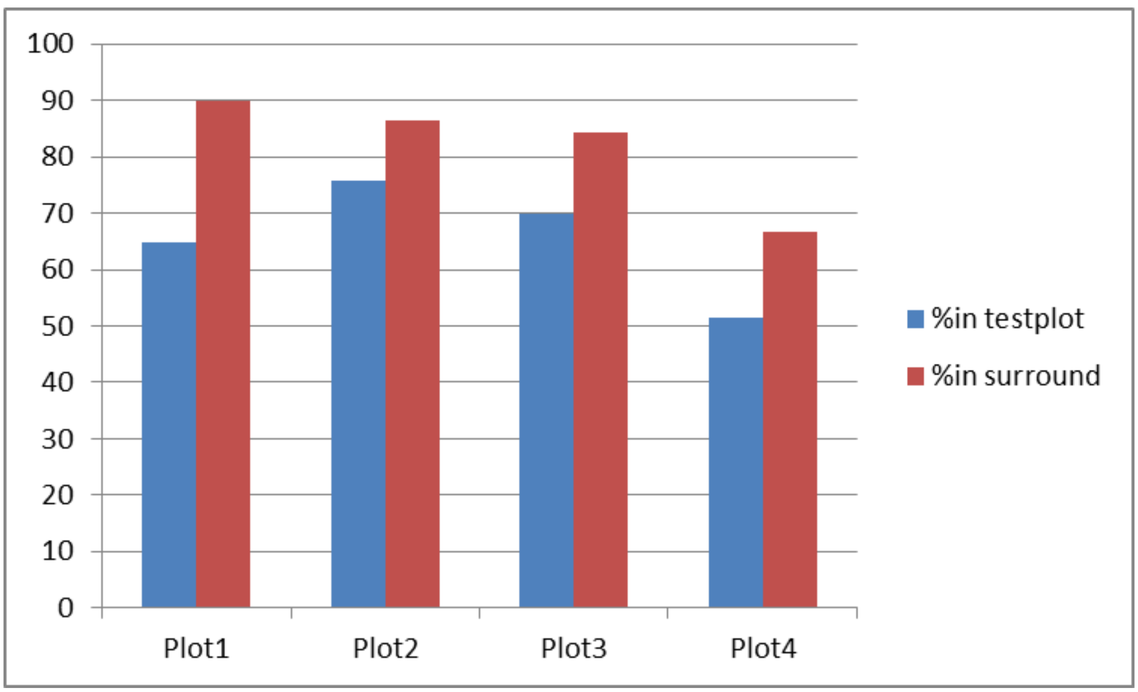
Figure 1: Lysimeter measurements from a typical rain event.



This is from a rain event on April 8th, 2011. Time on the x-axis is shown in days (this graph is a 12 hour period). Lysimeter weight readings were converted into equivalent mm of water absorbed by each plot. Cumulative rainfall amounts are shown by the solid black line. Each dot is the one-hour average weight for each lysimeter. Plot designations are as per Table 1 above.

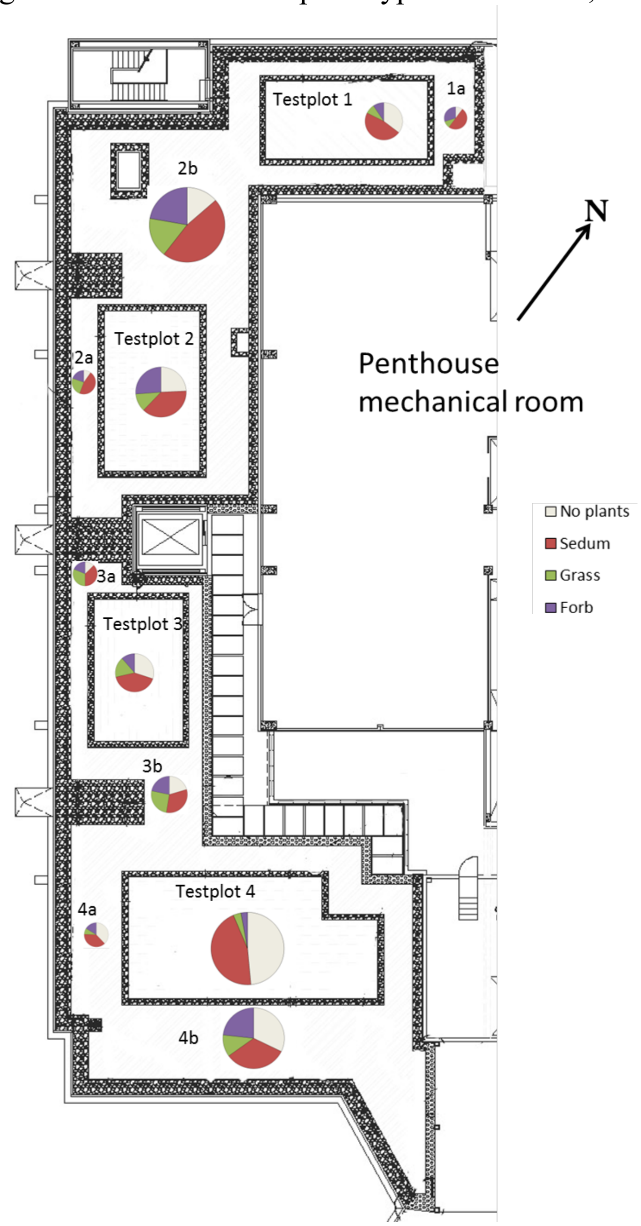
Plant species growth and performance:
In mid-July 2013, data on roof coverage and plant survival were collected as follows. A summary of coverage was achieved by sampling in a grid pattern across the entire roof. At 0.5M intervals the topmost plant was recorded, with the options being *Sedum* sp, grass, forb, or no plant. No data were recorded from within 0.5M of any edge. In addition the entire roof was surveyed as to presence of the 19 species of forbs and grasses. Plants were separately enumerated in each of the plots and in areas surrounding the plots. The initial data from this study will be made available to DOE on request but it is not included here since it is being used for an on-going research project intended to result in a manuscript. The general findings (Figure 1, below) were: percent coverage was greatest on the northern end of the roof (ca. 90%) and lowest on the southern end (ca 51%) with a uniform decline from north to south, likely reflective of the hotter conditions on the southern portion of the roof (temperature studies are underway using "Hobo" temperature sensor recorder buttons).

Figure 1: Total % plant coverage in the four test plots and in the area surrounding each plot, in July, 2013.



Plant coverage in all areas was greater outside of the test plots compared to inside the test plots (Figure 2), although some of this likely reflects repairs to the lysimeters in Plots A and B (in each one load cell failed requiring that area to be dug up for replacement). Even excluding the areas where the lysimeters are located, plant coverage in the test plots is lower than in the adjacent "lower" roof areas with differences ranging from 10 to 20%. The reasons for these differences are being studied and may reflect wind scour (the plots are several inches higher than the rest of the roof), faster water drainage due to the plots being elevated to provide space for the lysimeters (although this seems unlikely in the center areas of the plots and these center areas were consistent with the areas closer to the edges of the plots in terms of plant coverage), or temperature effects (the plots were elevated by using several inches of rigid foam insulation to build up the areas of the plot except where the lysimeters are located, this insulation will reduce heat flow from the building into the test plots). Differences in species survival, distribution and reproduction/spread were also observed and it seems that two species (*Penstemon grandiflorous* and *Antennaria dioica*) seem to be declining while others (*Liatris spicata*, *Bouteloua curtipendula* and *Sporobolis heterolepis*) are spreading. Some of the plants in the roof system bloom early in spring and the July assessment may have undercounted them so these data must be treated as preliminary. Additional assessments will be conducted throughout the spring - fall of 2014. There will also be work to address the spread of the sedums throughout the roof.

Figure 2: Distribution on plant types on the roof, July 2013



Additional Studies Planned:

Additional studies on evapotranspirational rates by different plant species, water movement through the roof system, microbial population dynamics in the growth layer are planned, as are studies on the impact on building heating/cooling load.

Task C

The three storm water management workshops were successful. More than 200 combined people attended the workshops and the feedback received was uniformly positive. SJU intends to continue to partner with the Lower Merion Conservancy, and, in the future, with Villanova University (now a collaborator on the vegetative roof analysis projects) in the future.

The workshops included presentations by government offices, industry leaders, not-for-profit organizations and academics. Each workshop addressed a different area with the 2011 workshop focused on residential property issues, the 2012 workshop on storm water management system design, installation and maintenance, and the 2013 workshop on how storm water issues intersect with historic property/structure preservation issues. Some of the presenting organizations included: The Philadelphia Mayor's Office, Fairmount Park Commission, Philadelphia Parks and Recreation Office, U.S. Army Corps of Engineers, Lower Merion Township, SEPTA, Natural Lands Trust, Friends of the Wissahickon, Philadelphia Water Department, PA Historical and Museum Commission, Hopewell Furnace National Historic Site, Preservation Pennsylvania, Roofmeadow, The American Institute of Architects, Saint Joseph's University, The Lower Merion Conservancy, Philadelphia University, and others.

The educational signage was developed and installed on the science center roof and on two lawn areas of the campus where storm water management features (rain gardens, green facades and vegetative roofs) are located. A digital signage unit was installed in the SJU library atrium and is used to convey information about the work of the Institute for Environmental Stewardship.

The Institute for Environmental Stewardship is being made a permanent institute at SJU and will continue to operate within the Natural Sciences divisions (McCann will continue to serve as director for the foreseeable future) and a small budget ($20,000) has been provided for annual educational efforts, the storm water workshop and other projects.

6a. Publications and presentations:
Task A:

1. O'Keefe**, K., S. Davis, C.J. Springer. *In Review.* Biofuel development of Cellulosic Sources. For Springer Plant Ecology book series.

2. O'Keefe, K.**, N.J. Tomeo**, **C.J. Springer**. 2013. Population origin and genome size do not impact *Panicum virgatum* (switchgrass) responses to variable precipitation. *Ecosphere* 4(3): 37. http://dx.doi.org/10.1890/ES12-00339.1

3. Hartman, J.C.**, **C.J. Springer**, and J.B. Nippert. 2012. Ecotypic responses of switchgrass to altered precipitation. *Functional Plant Biology* 39(2): 126-136.

4. Hartman, J.C.**, J.B. Nippert, R.A. Orozco**, **C.J. Springer.** 2012. Potential ecological impacts of switchgrass (*Panicum virgatum* L.) biofuel cultivation in the Central Great Plains, USA. *Biomass & Bioenergy* 35:3415-3421

Presentations at Scientific Meetings

1. O'Keefe, K., J.B. Nippert, and C.J. Springer. 2013. Genome size as an indicator of plastic responses to drought stress in *Panicum virgatum* L. (switchgrass) exposed to variable precipitation timing. 2013 Annual Meeting of the Mid-Atlantic Chapter of the Ecological Society of America. Dover, DE

2. Tomeo, N.J., K. O'Keefe, J.B. Nippert, and C.J. Springer. 2012. A mycorrhizal community is unresponsive to simulated future precipitation variability. Annual Meeting of the American Society of Plant Biologists, Austin, TX USA.

3. O'Keefe, K., J.B. Nippert, and C.J. Springer. 2012. Genome size as an indicator of plastic responses to drought stress in Panicum virgatum L. (switchgrass) exposed to variable precipitation timing. Annual Meeting of the American Society of Plant Biologists, Austin, TX USA.

4. O'Keefe, K., J.B. Nippert, and C.J. Springer. 2012. Influences of local adaptation and genome size on *Panicum virgatum* (switchgrass) responses to variable precipitation timing. Annual Meeting of the Ecological Society of America, Portland, OR USA.

5. O'Keefe, K., J.B. Nippert, and C.J. Springer. 2011. Phenotypic responses of switchgrass (*Panicum virgatum*) to simulated climate change. Grasslands in a Global Context Symposium, Manhattan, KS, USA.

6. Tomeo, N.J. and C.J. Springer. 2011. The mycorrhizal relationships of the model bioenergy plant *Panicum virgatum* in a changing world. Grasslands in a Global Context Symposium, Manhattan, KS, USA.

Master's Theses

Kimberly O'Keefe, M.S., 2012 Currently: Ph.D. Student, Kansas State University
Nicholas Tomeo, M.S., 2012 Currently: Ph.D. Student, University of Ohio

Task B

Presentations at Scientific Meetings

1. Nemirovsky, E., Wadzuk, B. M., McCann, M. P., and Berg, S. (submitted, under review). Comparing Green Roof Drainage Layers. Proceedings of the World Environmental & Water Resources Congress 2014, Portland, OR, June 1-5, 2014
2. Nemirovsky, E., Wadzuk, B. M., McCann, M. P., and Berg, S. (submitted, under review). A protocol for SCM long-term data collection. Proceedings of the World Environmental & Water Resources Congress 2014, Portland, OR,

June 1-5, 2014

6b. Web Sites

www.sju.edu/ies - Institute for Environmental Stewardship, links to greenroof web site.

www.sju.edu/stormwater - Storm water workshop site (currently shows the information from the 2013 workshop)

6c. Collaborations Fostered

Collaborators:

Task A

Faculty Collaborators:

Dr. Jesse Nippert, faculty member in the Division of Biology at Kansas State University

Graduate students supported:

Kimberly O'Keefe, M.S. 2012
Nicholas Tomeo, M.S. 2012

Undergraduate Students Supported:

Michael Greco
Nicole Slezak

Task B

Faculty and Other Professional Collaborators:

Dr. Karen Snetselaar, professor and chair, Department of Biology, Saint Joseph's University

Dr. Jonathan Fingerut, associate professor of biology and director, Environmental Sciences Program, Saint Joseph's University

Dr. Jean Smolen, associate professor, Department of Chemistry, Saint Joseph's University

Evgeny Nemirovsky, P.E., Founder, HydroVita LLC, and Research Associate, Villanova University

Dr. Bridget Wadzuk, associate professor, Dept of Civil and Environmental Engineering, Villanova University

Charlie Miller, P.E., Founder, Roofmeadow, Philadelphia, PA

Tim Ressler, Engineer, Roofmeadow, Philadelphia, PA

Stuart Berg, Engineer, Roofmeadow, Philadelphia, PA

6d. Technologies/Techniques

Not applicable

6e. Inventions/Patent Applications

Not applicable

6f. Other Products

The green roof sensor data is stored in the SJU Oracle database and is being made available through the IES web site. Refinements to this system are under way. The manually "scrubbed" data sets will also be posted there in the near future.