Virgin Islands Water Resources Research Institute Annual Technical Report FY 2014

Introduction

The United States Virgin Islands (USVI) is a Territory of the United States of America and consists of a group of several islands and cays located in the Lesser Antilles which separate the Atlantic Ocean and the Caribbean Sea. The USVI is about 1,200 miles southeast of Miami, Florida and 80 miles east of Puerto Rico. The principal islands in the USVI are St. Croix, St. Thomas, St. John and Water Island. Several of the other smaller islands in recent years have undergone various stages of development. In total, the islands have a combined area of approximately 137 square miles, are of volcanic origin and are mountainous. Tourism is the principal source of support for the economy.

With an annual rainfall of just over 40 inches, the USVI is one of the few places in the world where rain water harvesting is required by law. Buildings are constructed with cisterns that are sized and managed to provide a reliable and relatively safe water supply for users. Because of the hilly terrain, there are virtually no natural surface water supplies. Ground water is limited due to the geology and the risk of salt-water intrusion that could occur from coastal wells. The increasing potable water demands are met largely through use of desalination plants that provide water to the public water distribution systems. The islands experience challenges in collecting and disposing wastewater and water conservation and increasing efficiency in water-use are critical components of effective water resources management in the USVI.

The Virgin Islands Water Resources Research Institute (VI-WRRI) is hosted by the University of the Virgin Islands (UVI). UVI is the Territory's only institution of higher education and has campuses on the islands of St. Croix and St. Thomas and a research station and a learning center on St. John. It is a Historically Black College or University (HBCU) and a land-grant institution. It was started in 1962. Though UVI is primarily an undergraduate institution, it offers graduate programs in teacher education, business administration, public administration, marine science and mathematics for secondary education teachers. The University's demographics reflect the local population in that it consists of a diversified mix of USVI residents and persons from the Caribbean region, the United States' mainland and other areas of the world.

The VI WRRI maximizes all resources available to it to serve the water resources research, information dissemination and training needs of the people of the U. S. Virgin Islands that might otherwise not be a priority in other settings. It works collaboratively with other units at UVI, with researchers in the U. S. Geological Survey s Islands Region and others to address particularly, though not exclusively, those issues that might be peculiar to tropical insular regions. Areas of focus in the past have included quantity and quality issues of water harvesting, development of alternative on-site sewage disposal systems and non-point source pollution in island environments. This year s program investigated the enhancement of the quality of harvested rainwater using engineered pervious layer technology, the rainfall and erosion patterns in the USVI, active and passive irrigation alternatives and quantification and molecular typing of bacteria from watersheds.

This year the VI-WRRI also prepared and submitted material for its periodic evaluation by the U. S. Geological Survey. The evaluation resulted in the VI-WRRI being determined by the USGS to be eligible for continued support under the provisions of Section 104 of the Water Resources Research Act of 1984, as amended.

Research Program Introduction

The Virgin Islands Water Resources Research Institute at the University of the Virgin Islands supported five research projects in the 2014 2015 VI-WRRI program year. They all addressed efficient use of the limited water supplies that are accessible to the people of the U. S. Virgin Islands. One of these projects, Plant Nutrient Management in Aquaponic System for Zucchini (Cucurbita pepo) Production, was a continuing project from the previous year. Two of the projects were implemented on St. Croix, two on St. Thomas and one was executed with a collaborator at the University of Puerto in Mayaquez, Puerto Rico. Two of the projects addressed principally water quality issues and the other three centered on investigation of methods that would best use available quantities of water.

Summaries of these projects follow.

Plant Nutrient Management in Aquaponic System for Zucchini (Cucurbita pepo) Production

Basic Information

Title:	Plant Nutrient Management in Aquaponic System for Zucchini (Cucurbita pepo) Production
Project Number:	2013VI243B
Start Date:	3/1/2013
End Date:	8/31/2014
Funding Source:	104B
Congressional District:	USVI
Research Category:	Biological Sciences
Focus Category:	Nutrients, Agriculture, Methods
Descriptors:	None
Principal Investigators:	Dilip Nandwani, Donald Bailey

Publication

1. Balkaran, Seti, Donald Bailey and Dilip Nandwani, 2014, Effect of Foliar Spray Application of Calcium and Phosphorus on Fruit Production of Zucchini (Cucurbita pepo), Poster presented at the Twelfth Annual Spring Student Research Symposium, University of the Virgin Islands, St. Croix, VI. (March 22, 2014).

PLANT NUTRIENT MANAGEMENT IN AQUAPONIC SYSTEM FOR ZUCCHINI (*CUCURBITA PEPO*) PRODUCTION

Problem and Research Objectives

The UVI aquaponic system is a commercially viable system for the production of tilapia, and lettuce (Bailey 1997). The abundance of nitrogen in fish waste promotes vegetative growth and is an advantage for producing leafy vegetables. Less well known are the production capabilities of the system for the production of fruiting vegetable crops. Fruiting crops require phosphorus for fruit set and a proper balance with nitrogen to prevent excessive vegetative growth. Calcium is required to prevent nutritional diseases like blossom end rot which reduce product marketability. Blossom end rot (BER) is a condition observed in aquaponic zucchini production. Calcium in the aquaponic system water cannot be transported quickly enough to the growing end of the fruit for proper closing of the bud scar. Bacteria enter the open tissue and cause a secondary infection of rot which causes the fruit to be unmarketable. These nutrients were supplemented by foliar spray to zucchini (*Cucurbita pepo)* as a model crop to understand their requirements and application in commercial aquaponics.

The primary waste from fish production is nitrogen in the form of ammonia excreted from their gills. Nitrifying bacteria growing throughout the aquaponic system convert the ammonia to nitrate. This nitrate is used by plants for vegetative growth. Leafy crops are especially amenable for production in the system because of their high requirement for nitrate. The process of nitrification produces acid and the pH of the system water is depressed daily because of this production. Normal operational protocol calls for the daily addition of base, either calcium hydroxide ($Ca(OH)_2$) or potassium hydroxide (KOH) to return the system to neutral pH, 7.0. Calcium added as a base is not sufficient to supplement the nutrient requirement of zucchini fruit growth. Foliar application is needed to reduce incidence of BER.

The objective of this research was to study the foliar application of calcium, phosphorus and combined calcium/phosphorus to reduce the incidence of BER and to promote fruiting. Different application rates were sprayed to leaves and flower buds to determine appropriate dosage. Successful application rates will be those that yield a higher mass production per square meter and higher fruit count per square meter.

Methodology

Zucchini, variety Profit, was used as the model plant for research. Seeds were planted in PRO-MIX® in seedling flats in a greenhouse and grown for three weeks to a seedling size having 4 true leaves. These seedlings were transplanted to the aquaponic system on floating rafts at a density of $2.7/m^2$. Each treatment area was 7.4 m^2 with 20 plants. Plants grew normally and were treated with DiPel® Biological Insecticide, an organic insect control, for caterpillars. Once flowering began the plants received a once-weekly foliar spray of either calcium chloride, $CaCl_2$, or mono-ammonium phosphate, $NH_4H_2PO_4$. Four foliar application rates for each compound were tested. Additionally, two areas were used as control plots and received foliar spray of water (Table 1). As fruits matured they were harvested, counted, weighed and measured. Fruits were harvested 3 times each week for a total of 15 harvests (Figure 1:A-D). Water samples and leaf tissue samples were sent to a commercial laboratory for analysis of nutrients.

A second trial was conducted with Zucchini, variety Profit, comparing the best treatment rate with calcium, the best treatment rate with phosphorus and the combined treatment rate with both calcium and phosphorus. A control treatment of water was also included. Seeds were planted in PRO-MIX® as before and transplanted into rafts after 3 weeks of growth. These seedlings were transplanted to the aquaponic system on floating rafts at a density of 2.7/m^2. Each treatment area was 17.8 m^2 with 48 plants total. DiPel® Biological Insecticide was used to control caterpillars. Treatment with foliar spray began with the initiation of flowering with the 4 treatments (Table 2). As fruits matured they were harvested, counted, weighed and measured. Fruits were harvested 6 times over an 18 day period.

Principal Findings and Significance

In the calcium treatment, foliar application of calcium at 3.75 mg/l yielded the greatest mass of marketable fruit, the greatest number of marketable fruit and the lowest number of unmarketable fruit (Fig.2A and Fig 3A). The control treatment with calcium produced less marketable than unmarketable fruit (47% vs. 53%) showing the result if no calcium is applied. The treatment with 3.75 mg/l calcium application produced more marketable than unmarketable (74% vs. 26%).

In the phosphorus treatment, foliar application of phosphorus at 1.0 mg/l yielded the greatest mass of marketable fruit (Fig 2B). The phosphorus treatment of 1.0 mg/l also yielded the most fruit and the greatest percent of marketable vs. unmarketable fruit (Fig 2B). A treatment effect was observed with a phosphorus rate of 1.0 mg/l which increased the number of marketable fruit and the total biomass. The treatment with 1.00 mg/l phosphorus application produced more marketable than unmarketable. (64% vs. 36%).

The second trial compared a combined treatment of the best concentration of calcium (3.75 mg/l) and phosphorus (1.0 mg/l) with individual applications of those nutrients and a control of no nutrients (Table 2). The combined treatment of phosphorus and calcium yielded the highest mass, 1.28 g/m^2, and calcium alone yielded the lowest, 0.61 g/m^2. Throughout the trial the number of unmarketable fruits, with BRE, exceeded the number of marketable fruits.

Conclusions

The application of calcium as a foliar spray at a rate of 3.75 mg/l increased the mass of zucchini fruit. Calcium also improved the number of marketable versus unmarketable fruit by the reduction of BRE in the fruit. The poor mobility of calcium is a major factor in calcium deficiency symptoms in plants. In vegetables, classic symptoms of calcium deficiency include BRE, tip burn, blackheart, and death of the growing regions in many plants. All these symptoms show soft dead necrotic tissue at rapidly growing areas which is generally related to poor translocation of calcium to the tissue rather than a low external supply of calcium. Plants under chronic calcium deficiency have a much greater tendency to wilt than non-stressed plants.

The addition of phosphorus at 1.0 mg/l applied as a foliar spray increased yield in mass and count for zucchini. Fruiting vegetable crops need nitrate to be balanced with phosphorus for fruit set after pollination. Nitrate will promote vegetative growth but without adequate phosphorus there will be few fruit produced. Nitrogen concentration must also not exceed that of potassium or fruit quality will be low. Foliar applied phosphorus was an effective treatment to increase yield.

Table 1. **Treatments in Trial 1 with application of calcium or phosphorus on zucchini, variety Profit.**

Calcium mg/l	Phosphorus mg/l
0.0	0.0
1.25	0.5
2.50	1.0
3.75	1.5
5.00	2.0

Table 2. **Treatments in Trial 2 with calcium, phosphorus or combined application on zucchini, variety Profit.**

Treatment	Concentration mg/l
Control	0.0
Calcium	3.75
Phosphorus	1.0
Combined	Ca 3.75 + P 1.0

Figure 1. A-D: A: Zucchini, variety Profit growing in the UVI Aquaponic System. B: Blossom End Rot on young zucchini fruit. C: Student employee, Seti Balkaran, applying a foliar spray to zucchini plants. D: Marketable harvest of zucchini fruit.

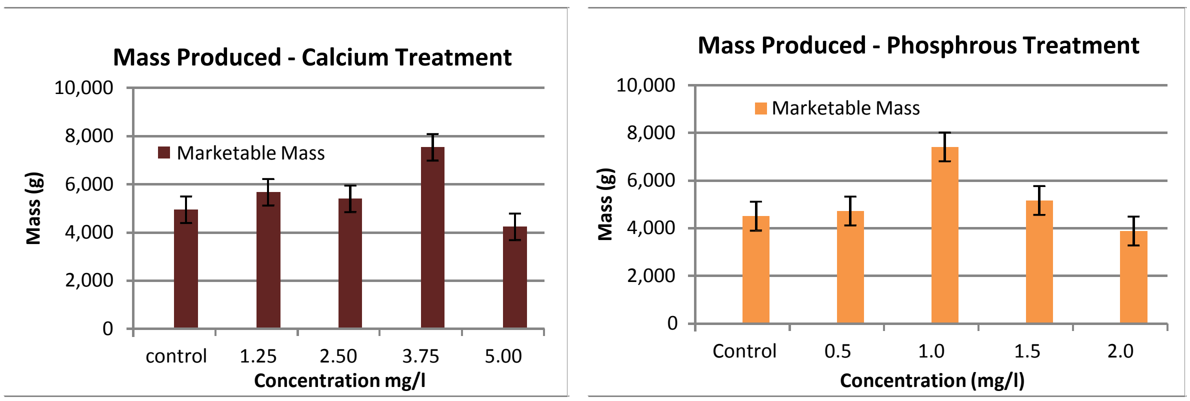


Figure 2. A-B. Marketable mass of zucchini, variety Profit, receiving different concentrations of A. Calcium or B. Phosphorus. Error bars indicate significant differences for treatments.

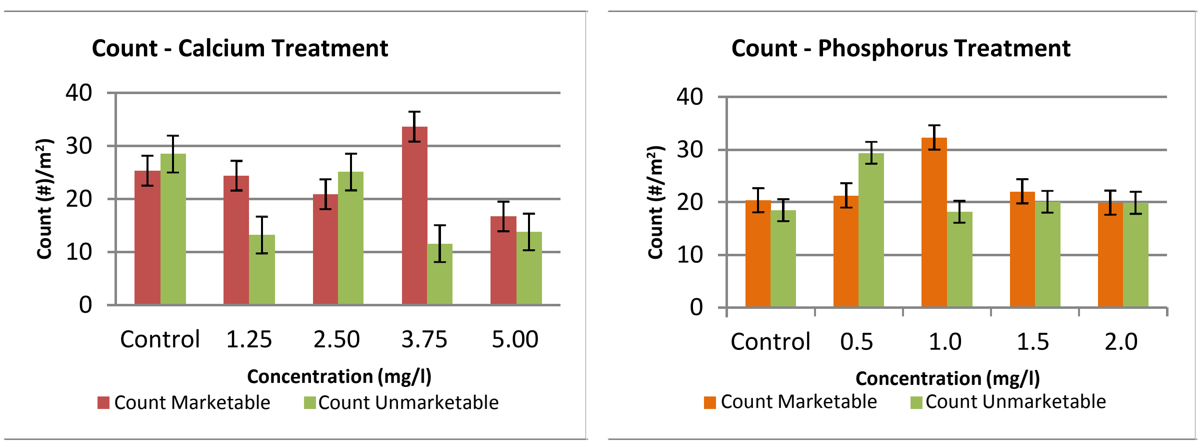


Figure 3. A-B. Count of marketable and unmarketable yield from treatments of A. Calcium or B. Phosphorus. Error bars indicate significant differences for treatments.

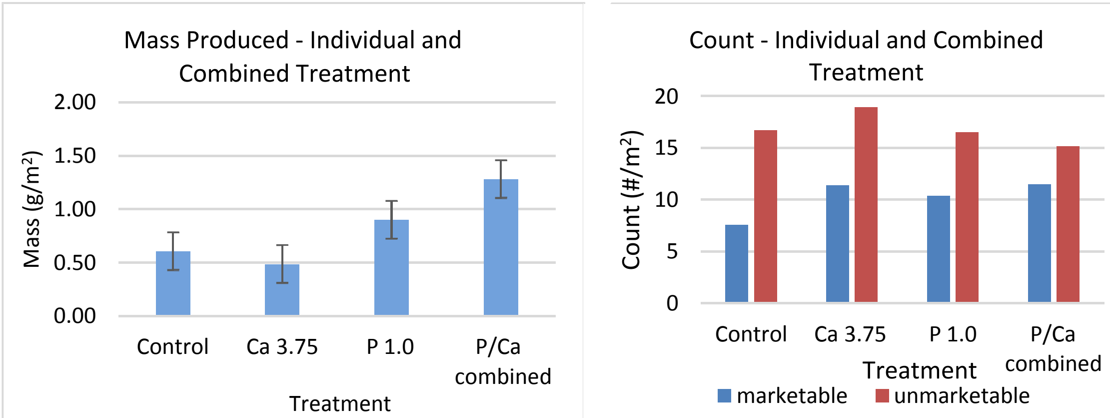


Figure 4. A-B. A. Mass Produced of marketable zucchini, variety Profit, with treatments of calcium, phosphorus or combined nutrients. B. Count of marketable vs. unmarketable fruit.

References

Bailey, D.S., J.E. Rakocy, W.M. Cole and K.A. Shultz. 1997. Economic analysis of a commercial-scale aquaponic system for the production of tilapia and lettuce. Pages 603-612 in K. Fitzsimmons, ed. Tilapia Aquaculture: Proceedings of the Fourth International Symposium on Tilapia in Aquaculture, Orlando, Florida.

Engineered Pervious Layer for Rooftop Rain Harvesting and Solar/Dark Inactivation of E. coli

Basic Information

Title:	Engineered Pervious Layer for Rooftop Rain Harvesting and Solar/Dark Inactivation of E. coli
Project Number:	2014VI246B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	
Research Category:	Water Quality
Focus Category:	Water Quality, Water Supply, Water Use
Descriptors:	None
Principal Investigators:	Sangchul Hwang, Henry H. Smith

Publications

1. Jo, M., L. Soto, M. Arocho, J. St John, S. Hwang. Optimum mix design of high volume fly ash geopolymer paste and its use in pervious concrete for removal of fecal coliforms and phosphorus in water. Construction and Building Materials (under review).
2. Soto, L., J. St John, C. Suarez, M. Jo, H. Smith, S. Hwang. Inactivation of fecal coliforms during rain harvesting with engineered pervious layer. 23rd Caribbean Water & Wastewater Association Annual Conference, Paradise Island, The Bahamas, Oct 6-9, 2014.
3. Soto, L., N. Vázquez, O. Molina, S. Hwang. Physicomechanical properties and durability of cement pastes containing fly ash and iron-oxide nanoparticles. Cement and Concrete Composites (under review).

ENGINEERED PERVIOUS LAYER FOR ROOFTOP RAIN HARVESTING AND SOLAR/DARK INACTIVATION OF *E. COLI*

Problem and Research Objectives

The Millennium Development Goal targeted for halving the proportion of the world population without sustainable access to safe drinking water between 1990 and 2015. With international collaborative efforts, the Millennium Development Goal was met in 2010. Nevertheless, over 780 million people still lack access to improved sources of drinking water. In Latin America and the Caribbean, 14% of the population is still without access to piped water supplies on premises in 2010 (UNICEF and WHO, 2012).

Rain harvesting and reuse have been a principal source of potable water for the residents of the United States Virgin Islands (USVI). As rainfall is very seasonal, over 50% of the USVI residents rely on rainwater cistern. It should be noted that rainwater is not contaminant-free (Houston et al., 2012). There might be contamination in rainwater before collected to the cisterns due to urban pollution, bird and reptile waste materials, roof material deterioration, and particulate matter deposition (Evans et al., 2006; Lee et al., 2012). Chemical and microbiological contaminations were also reported in the cistern water (Al-Khatib and Arafat, 2009; Crabtree et al., 1996).

Engineered pervious layer (EPL) would benefit many communities that rely on rainwater as their potable water source (e.g., USVI). EPL has two-fold benefits. First, the pervious property of EPL will be served as rainwater drainage with additional potential for the reduction of large particles and organic and inorganic contaminants (Luck et al, 2008; Mbabaso et al., 2013). Second, pathogens potentially present in rainwater will be removed and inactivated with the topical photocatalytic reactions of nano-titanium dioxide (nano-TiO_2) coated on the EPL in the presence of sunlight in daytime and the antimicrobial inactivation by nano-zinc oxide (nano-ZnO) embedded in depth of the EPL in nighttime (Hossain et al., 2014; Sanchez and Sobolev, 2010). In addition, rainwater retained in the meso- and micro- pores in EPL will reduce energy consumptions used for building cooling by the latent heat of moisture evaporation (Santamouris, 2010).

The proposed EPL study was the first stage of a long-term development plan. Especially, it aimed to evaluate structural and mechanical properties of EPL as a construction material, to assess hydraulic properties of EPL to quantify the effectiveness of rain harvesting, and more importantly to test pathogen reduction by pervious concrete specimens. The overall goal of the investigation was to provide an alternative way of harvesting and reuse of rooftop rainwater that is safer and sustainable.

Methodology

The major components of EPL were nano-TiO_2, nano-ZnO, nano-Fe_3O_4, gravels (4.75 - 9.5 mm), coal fly ash (FA) and ordinary Portland cement. The manufacturing of cement accounts for about 5% of the total anthropogenic release of CO_2 to the atmosphere (Metha and Monteiro, 2014). In an effort to reduce cement production/consumption and thereby CO_2 emission, FA was used to partly replace the Portland cement. In addition to this environmental benefit, studies have shown that replacing part of the cement with some of these admixtures results in an improvement of the strength of hardened concrete (Senhadji et al., 2014). In order to be pervious, EPL did contain fine aggregates (i.e., sand). Nano-TiO_2 was the key component for the photocatalytic oxidative removal and inactivation of *E. coli* in sun-lit water, whereas nano-ZnO was added to EPL to utilize their antimicrobial properties in the dark (Ge et al., 2012; Hossain et al., 2014). Potential reductive contaminant removal was to assessed with nano-Fe_3O_4. Nano-TiO_2 was coated on the surface of the EPL after curing, whereas nano-ZnO and nano-Fe_3O_4 were embedded in the EPL mix prior to curing.

Preliminary studies done by the Principal Investigator's group showed that pervious concrete pavements containing nano-Fe_3O_4 had compressive strengths of 6.3 - 11.1 MPa while maintaining permeability of 0.8 - 1.2 mm/sec with a water-to-cement ratio of 40% and gravels in sizes of 4.75 - 9.5 mm. Both the compressive strength and permeability fell into the reported values (ACI, 2010). The optimum amount of nano-TiO_2, nano-ZnO and nano-Fe_3O_4 to be embedded in EPL will be determined based on *E. coli* removal and inactivation efficiency. For the assessment of *E. coli* removal and inactivation, EPL specimens were cast in a wooden mold (12" in width x 12" in length x 2" in depth) on top of a flat, stone base. After demolding at 24 hours, the specimen was put in water for curing. The test was done with the specimens cured for 28 days.

Photo 1. Environmental chamber.

The system will be set up in an environmental chamber that is currently under construction (Photo 1). The chamber will be equipped with a solar simulator and rainwater application unit. A solar simulator will be used as the light source of the sunlight for the photocatalytic inactivation of *E. coli* by nano-TiO_2. For the dark inactivation of *E. coli* by nano-ZnO and nanoFe_3O_4, the experiment will be run without the light in the environmental chamber. *E. coli*-containing rainwater will be applied to EPL and the harvested rainwater in the sun-lit or dark condition will be tested for *E. coli* concentration. EPL without engineered nanoparticle addition will be tested as a control under the same experimental conditions. Different levels of nano-TiO_2, nano-ZnO and nanoFe_3O_4, EPL slope, and sunlight intensity and duration will be tested for their influence on *E. coli* removal and inactivation. Different EPL slopes should be determined as they change the retention time of rainwater in EPL that, in turn, affects the exposure duration of the rainwater to the embedded nanomaterials in EPL.

E. coli will be quantified by a membrane filtration technique with a 0.45 μm membrane filter. The filtered membrane will be put the petri dish containing m-ColiBlue24® from the HACH Company and then will be incubated at 35˚C for 24 hours. Blue colonies will be reported as *E. coli*. Source and harvested rainwater will also be tested for turbidity, pH and conductivity. Turbidity will be measured with a HACH 2100P Turbidimeter. Conductivity and pH will be measured with an Orion model 162 conductivity meter and an Orion pH meter, respectively.

Principal Findings and Significance

Pervious concrete specimens containing nano-Fe_3O_4 were made with the optimized mix ratios for the pastes based on a central composite design followed by Response Surface Methodology. Two optimum mix ratios for the pastes are shown in Table 1. For making pervious concrete specimens, the mass ratio of gravels to cement was fixed at 4:1. A control pervious concrete specimen was also made for the purpose of comparison with the treatment pervious concrete specimens (i.e., Opt. A and Opt. B).

As shown in Table 1, the Opt A specimens resulted in slightly lower compressive strength compared to the Opt B specimens, with average values of 17.8 and 19.2 MPa, respectively. The main reason for this behavior is that the Opt A specimens contained greater amounts of FA, consequently it needed longer than 28 days of curing for the pozzolanic reaction to be fully achieved. It is known that the pozzolanic reaction is very slow and occurs at later ages of curing (Senhadji et al., 2014). On the other hand, control specimens resulted in significantly lower compressive strength than the Opt A and B specimens, with an average value of 8.1 MPa.

Table 1. Optimum paste mix ratios and resulting properties of pervious concretes.

EPL	W/B (%)	FA/B (%)	ENP/B (%)	WR/B (%)	Comp. (MPa)	Perm. (mm/s)	Void (%)	Density (kg/m³)	pH	FC removal (%)
Control	34	0	0	0	8.1	16.6	44	1,850	10.1-10.5	95-100
Opt. A	36	35	6	1.2	17.8	10.0	34	1,950	9.8-10.1	55-100
Opt. B	32	10	0.5	0.8	19.2	12.4	36	1,960	9.6-10.0	31-100

* W/B: water to binder ratio, FA/B: fly ash to binder ratio, ENP/B: iron oxide nanoparticles (nano-Fe_3O_4) to binder ratio, WR/B: water reducer to binder ratio, FC: fecal coliforms.

As compressive strength increases, permeability is lowered. This is in agreement with Bhutta et al. (2012) who described that an increase in compressive strength implied a reduction in permeability due to a reduction in the pore structure of the specimen. The average permeability of the Opt A and Opt B specimens was 10.0 and 11.9, respectively. In this case the affecting factor for the higher permeability of the Opt B specimens was the volume of the cementitious paste. Since cement is heavier than FA and all calculations were made in percentage by weight, the total volume of the powder for the Opt A specimens was higher than for the Opt B specimens. However, the permeability of the EPL specimens met the specifications for a pervious concrete, which must be in a range of 1.4-12.3 mm/s (ACI, 2010).

Makhloufi et al. (2012) found that the pH of concrete ranged between 12 and 13 and the solubility of its hydration products increased in the environments with lower pH. Calcium hydroxide (CH) is one of the principal hydration products of concrete and is highly soluble in water, contributing to the high alkalinity of concrete (Mehta and Monteiro, 2014). After a two-hour contact time with the EPL specimen, the pH increased from ~7.5 to ~10.0 (Table 1). It was also noticed that water treated with the Opt A and B specimens resulted in lower pH than the control specimens. This behavior can be attributed to the partial substitution of cement with FA. Since FA consumes CH to form calcium silicate hydrate gel, less CH leaches out of the specimen thus resulting in a less alkaline effluent.

In general, the Control specimens obtained a higher percentage of inactivation throughout the experiment, with an average of 98.5% inactivation (Table 1). Although FC inactivation with the Opt A and Opt B specimens was lower than for the Control specimens, it is observed that in day 4 they all were able to achieve a 100% FC inactivation. The average FC inactivation for the Opt A and Opt B specimens was 67.5% and 63.7%, respectively. It is important to notice that FC inactivation was achieved better at higher water pHs.

Engineered pervious layers (Photo 2) containing either nano-TiO_2, nano-ZnO or nano-Fe_3O_4 were made and tested for structural and hydraulic properties. They ranged ~18 MPa and ~10 mm/s, respectively. They were placed in the environmental chamber and were preliminarily tested under different intensity, duration and frequency (IDF) of precipitation and lighting.

The data and findings from the study will help the civil and environmental engineers garner a new alternative way to achieve safer rainwater harvesting and reuse in line with water-energy sustainability.

Photo 2. Engineered pervious layers made with different nanomaterials inclusion.

Conclusions

The following conclusions can be derived from the current study:

- A higher compressive strength was achieved for the EPLs containing nanomaterials than for the control EPL. However, the permeability was lower for the EPLs containing nanomaterials than for the control EPL, although the values fell into the recommended ones.
- A lower FC inactivation was accomplished with the EPL specimens containing nano-Fe_3O_4 than those with the control EPL that developed higher pHs during the experiment.
- As a preliminary design and operation, the EPL were put in the environmental chamber and tested under dissimilar operating conditions such as precipitation and lighting IDFs and slopes.

References

ACI. 2010. Report on Pervious Concrete. ACI 522R-10. American Concrete Institute. Farmington Hills, MI.

Al-Khatib, I.A., H.A. Arafat. 2009. Chemical and microbiological quality of desalinated water, groundwater and rain-fed cisterns in the Gaza strip, Palestine. Desalination 249, 1165-1170.

Bhutta, M.A.R., K. Tsuruta, J. Mirza. 2012. Evaluation of high-performance porous concrete properties. Construction and Building Materials, 31, 67-73.

Crabrtee, K.D., R.H. Ruskin, S.B. Shaw, J.B. Rose. 1996. The detection of *Cryptosporidium* oocysts and *Giardia* cysts in cistern water in the U.S. Virgin Islands. Water Research 30, 208-216.

Evans, C.A., P.J. Coombes, R.H. Dunstan. 2006. Wind, rain and bacteria: The effect of weather on the microbial composition of roof-harvested rainwater. Water Research 40, 37-44.

Ge, Y., J.P. Schimel, P.A. Holden. 2012. Identification of Soil Bacteria Susceptible to TiO_2 and ZnO Nanoparticles. Applied and Environmental Microbiology 78, 6749-6758.

Hossain, F., O.J. Perales-Perez, S. Hwang,, F. Román. 2014. Antimicrobial nanomaterials as water disinfectant: Applications, limitations and future perspectives. Science of the Total Environment 466-467, 1047-1059.

Huston, R., Y.C. Chan, H. Chapman, T. Gardner, G. Shaw. 2012. Source apportionment of heavy metals and ionic contaminants in rainwater tanks in a subtropical urban area in Australia. Water Research 26, 1121-1132.

Lee, J.Y., G. Bak, M. Han. 2012. Quality of roof-harvested rainwater – Comparison of different roofing materials. Environmental Pollution 162, 422-429.

Luck, J.D., S.R. Workman, M.S. Coyne, S.F. Higgins. 2008. Solid material retention and nutrient reduction properties of pervious concrete mixtures. Biosystems Engineering 100, 401-408.

Makholoufi, Z., E.H. Kadri, M. Bouhicha, A. Benaissa. 2012. Resistance of limestone mortars with quaternary binders to sulfuric acid solution. Construction and Building Materials 26, 497-504.

Mbanaso, F.U., S.J. Coupe, S.M. Charlesworth, E.O. Nnadi. 2013. Laboratory-based experiments to investigate the impact of glyphosate-containing herbicide on pollution attenuation and biodegradation in a model pervious paving system. Chemosphere 90, 737-746.

Metha, P., P. Monteiro. 2014. Concrete microstructure, properties and materials. 4th Ed. McGraw-Hill Education.

Sanchez, F., K. Sobolev. 2010. Nanotechnology in concrete – A review. Construction and Building Materials 24, 2060-2071.

Santamouris, M. 2010. Using cool pavements as a mitigation strategy to fight urban heat island—A review of the actual developments. Renewable and Sustainable Energy Review 26, 224-240.

Senhadji, Y., G. Escadeillas, M. Mouli, H. Khelafi, Benosman. 2014. Influence of natural pozzolan, silica fume and limestone fine on strength, acid resistance and microstructure of mortar. Powder Technology 254, 314-323.

UNICEF and WHO. 2012. Progress on Drinking Water and Sanitation: 2012 Update. Joint Monitoring Programme for Water Supply and Sanitation. UNICEF and World Health Organization.

Monitoring Precipitation Patterns and Erosion Indicators Across the St Thomas Microclimates

Basic Information

Title:	Monitoring Precipitation Patterns and Erosion Indicators Across the St Thomas Microclimates
Project Number:	2014VI247B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	Not Applicable
Research Category:	Climate and Hydrologic Processes
Focus Category:	Water Use, Water Supply, Sediments
Descriptors:	None
Principal Investigators:	David C Morris, Donald M Drost, Michael L Larson, Avram Gerald Primack, Raymond Torres

Publication

1. There are no publications as yet resulting from this project.

MONITORING PRECIPITATION PATTERNS AND EROSION INDICATORS ACROSS THE ST. THOMAS MICROCLIMATES

Introduction

Like many Caribbean islands, Saint Thomas has a hilly topography that leads to varied precipitation and erosion patterns around the island. The prevailing east to west winds combined with the islands 1500 foot elevation results in distinctly arid eastern region in contrast the distinctly lush western end. Located on the border between the Atlantic Ocean and Caribbean Sea, there are significant changes in sea temperature, and thus air temperature, on the southern and northern sides of the island.

These broad descriptions of the effects at work over the island oversimplify its microclimatology. It is cut by deep valleys with small intermittent streams (ghuts) that create many localized microclimates which leads to a rich complexity in the weather patterns with localized rainfall levels that are important to many commercial, civil, and scientific activities. One particular interest is the level to which precipitation patterns are correlated with near shore particulate measurements.

From 1927-present weather stations have been maintained on St. Thomas at various locations for various period of time ranging from a few months to many years, continuously. We aim to restart and update this historical effort to track weather data and infer weather patterns across St. Thomas with our new weather station network. We also aim to consolidate historical data and begin to seek long-baseline patterns as well as to link weather data to erosion statistics.

This work describes an ongoing effort begun in 2012 to build out the infrastructure necessary to track and correlate rainfall levels and erosion measurements on St Thomas. Here we begin archiving a database of weather station measurements useful for this and other related studies and present preliminary correlation studies and comparison to historical data where available.

Problem Description

Small islands are often dependent on rainfall for their primary water supply, either directly or from shallow aquifers (Falkland 2002, Urish 2010). To meet the fundamental needs for accurate and continuous weather data and generate a dataset capable of providing insight into questions regarding the climate of St Thomas we have been constructing and maintaining a network of weather monitoring stations across St Thomas, USVI. The data already gathered by this weather network have been of value to St Thomas researchers, as evidenced by their use in graduate student theses that will be completed in the near future by Moriah Sevier and Pedro Nieves. As our baseline of weather events grows we hope to address long-standing issues in atmospheric microphysics including the nature of the statistical distribution of rainfall rates within an individual storm, and whether commonalities exist in the evolution of rainfall rates across all storms.

Research Objectives

The PI and Co-Is have investigated and continue to investigate a broad range of scientific questions including the following:

A comparison of current monthly rainfall rates to historical rainfall rates as evidence of climate change in the Caribbean

Global climate change has produced important changes in weather patterns throughout the Caribbean region over the past 20-40 years. We will compare our 2012-14 daily and monthly rainfall data for St. Thomas to archival data (from the USGS archives as well as more recent data collected by the VI-WRRI University of the Virgin Islands (UVI) monitoring station) to address the role of climate change on the rainfall water supply across the island.

A comparison of relative rainfall rates across different geographical regions to quantify the contrast in water supplies across the island

It is well-known that rainfall rates differ across distinct geographic regions of St. Thomas. One need only drive from one end of the island to the other to see the effect of varying levels of rainfall on vegetation from the dry eastern end to the lush northern and western end of the island. An accurate mapping of rainfall rates across these various regions is lacking, however. Such a rainfall map would be valuable to residential cistern planning as well as public works projects. We will generate rainfall maps of the island over monthly and year-long timescales.

A study of the variation of rainfall rates in Doppler images to validate meteorological "ground-truth" models

Using multiple field data measurements within a single Doppler radar pixel will go a long way to establishing the validity of regional ground-truthing methods. If multiple sensors within the same pixel measure accumulation differences of >20%, as has been found in similar studies conducted in other regions, one can infer the true number of ground-truth observations required to calibrate local meteorological instrumentation. Such studies help to determine the density of meteorological rain measurement stations required to satisfy weather prediction requirements.

A study of the scale-invariant properties of Caribbean rainfall events and comparison to similar studies of rainfall events in the US Great Plains region

Larsen et al. (2010) demonstrated that scaling properties of ambient rainfall can be identified with tipping-bucket rain gauges similar in performance characteristics to the sensors in our study. The fractal dimensions of rainfall events in that study were shown to vary substantially from storm to storm. Larsen et al. (2010) also showed that nearly all significant Great Plains storms followed a distinct intensity pattern (strong, weak, strong, weak). No similar study has ever been conducted in the Virgin Islands. We will test whether a similar statistical technique to that used in the Great Plains study (namely the box-counting method of determining the fractal dimension of a time series) can accurately characterize Caribbean storms. We will also search for a common storm evolution intensity pattern in Caribbean systems and compare any such identified pattern to the strong-weak-strong-weak pattern of Great Plains storms.

A study of erosion and infiltration rates under varying land-use patters

A study of erosion and infiltration rates under varying land-use will help characterize the effect of human land cover alterations on sediment production and water balance in the small watersheds that make up the USVI. This information will provide important information about links between upland land use and inshore marine habitats.

A study of the relationship between measured precipitation and Doppler radar images

A study of the relationship between measured precipitation and Doppler images will allow results from the St. Thomas climate stations to be generalized to other nearby islands.

Methodology

The rain gauge stations include a Davis Vantage Vue weather sensor suite. Student Sharone Richards worked throughout the summer of 2014 analyzing results from the accumulated dataset.

Student Stephen Santana worked to create a land use change map for the section of Saint Thomas near Frenchtown and the eastern end of Charlotte Amalie.

Weather stations are currently installed at a total of 10 locations on St Thomas. All 10 stations are currently active and reporting data though maintenance of various sensors is required as a result of deterioration due to exposure to the elements.

Principal Findings and Significance

The main historical findings of the project have been detailed in reports presented at both the local UVI ECS research symposium and at the 2014 Emerging Researchers National Conference in Washington, DC. Among the results of this work are:

1) Comparisons of the historical rainfall rates at the St Thomas East End Reserve to current rainfall rates measured in this region. The East End was chosen because it had the most consistent historical data archive as well as one of the earliest installed WRRI-funded weather stations. These results show general agreement between average seasonal rainfall amounts between the 2013-2014 operational seasons and the historical data, with allowances made for unique and unusual rainfall events (hurricanes). The one marked difference between rainfall data in the current 2013-2014 period and historical data is a relatively wet summer, followed by a relatively dry hurricane season. Additional years of data will be required to determine the statistical significance of any perceived changes in these preliminary data. Nevertheless, the precision and regular collection intervals of the current data demonstrate the power of the newly established weather monitoring network.

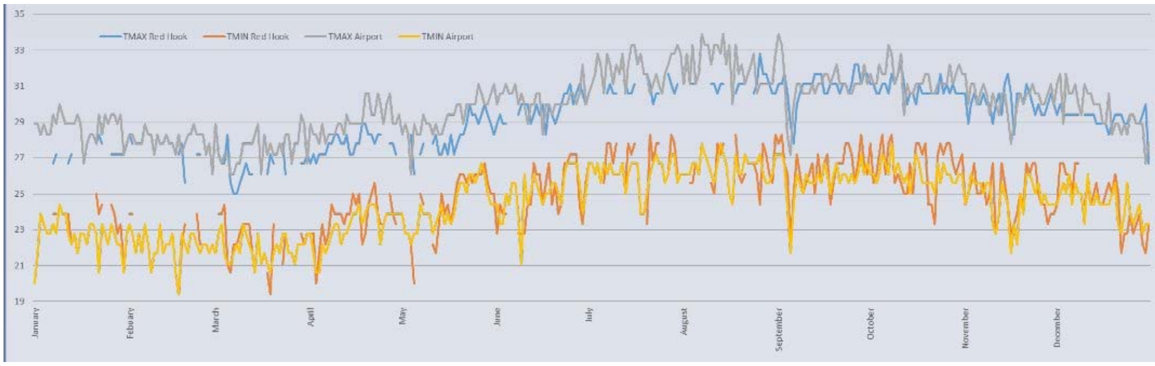


Figure 1: Temperature comparison between weather stations at the St Thomas East End (Red Hook) and from the Airport region. Record of highs and lows show evidence for a modest continental effect believed to be produced from warming of air masses by the St Thomas landmass as they cross the island (from Simmons and Morris, 2013).

2) Comparisons of cross-island weather differences from historical data. Weather monitoring stations installed at the East End of St Thomas (located at the St Thomas East End Reserve) and the West End (located at the Airport) demonstrate marked differences in weather characteristics over a geographic span of only some 10 miles despite a difference in elevation of close to 0 m. Data collected at these two locations appear to show evidence for continental weather effects on the small scale. Temperature patterns recorded at the West End (downwind of the prevailing easterly winds) show generally higher high temperatures and lower low temperatures than do those recorded at the East End. Warming of the western flowing air mass at it crosses the landmass of St Thomas seems the most likely explanation for this noted trend. Analysis of data from the current weather station network appears to support this interpretation.

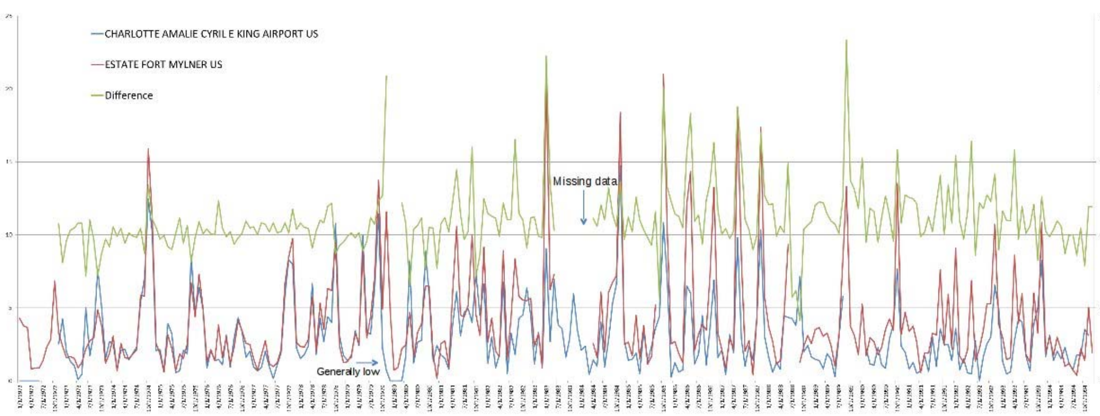


Figure 2: Rainfall comparison between historical weather stations on St Thomas from the period spanning 1972-1994. As the current weather network baseline increases, we will be able to compare frequency of extreme events as well as search for global trends (from Ramsundar and Morris, 2013).

3) Analysis of soil characteristics at various locations in the Magen's Bay area of St Thomas were performed as a proof-of-concept technique for further future analysis of erosion characteristics associated with rainfall measurements at the location of the installed weather stations and rainfall monitoring equipment. Analysis of the Magen's Bay sites demonstrated that in-lab analysis techniques were able to identify differences in soil characteristics including clay content, water content, and organics content.

Results of Microclimatological Zone Comparisons

One of the primary goals of this work is to investigate global relationships between disparate regions of St Thomas as evidenced through temperature, wind, pressure, and precipitation measures. Similar works (e.g. Stow and Dirks, 1998) investigating the nature of rainfall and other weather indicators on small islands have demonstrated the utility of micro-scale categorization of these features for both academic and civil use. As we continue to expand the geographic coverage and temporal baseline of the weather monitoring network built through this project, we are investigating similar topics as related to the island of St. Thomas.

Correlation Studies

General overall correlations are found, as expected, between the dew point and temperature readings at most sites in the network but interesting features are also present. The dew point correlation shows intermittent isolated drops in dew point at selected stations. These isolated drops can also be seen in the dew point versus time relationship. Apparent hysteresis patterns are also seen in temperature correlations across the island.

The presence of the isolated drops in dew point temperature can be understood as the effect of localized precipitation events moving from one region to the other. These dramatic isolated drops in dew point temperature suggest that a more common hysteresis pattern in dew point changes may be masked within the denser regions of these correlation figures. Work is on-going in this regard.

This behavior is also indicative of the small scale size of even those widespread precipitation events that cross the island. Further evidence for the localized nature of these rainfall events can be seen in station-to-station rainfall rate correlations. Not only does these relations show a lack of correlation between rainfall rates, but it shows that in >99% of sampled time intervals, rainfall rates are greater than zero at only one or the other of the two stations.

Ongoing work with these data (and those from the other stations in the network) seeks to map the scale size of rainfall events, as well as their path across the island.

From the correlation studies of temperature prepared by undergraduate Sharone Richards we can see that stations on the northern and eastern sides of the island (Platenberg, Jobsis, Pinkwhale, Cowpet Bay) are strongly positively correlated indicating they are experiencing the same air masses. Stations at extreme ends of the island (Cowpet versus Botany Bay) show negative correlations. Very high and low stations show almost no overall correlation (PinkWhale versus Coral World) as shown in Figure 3.

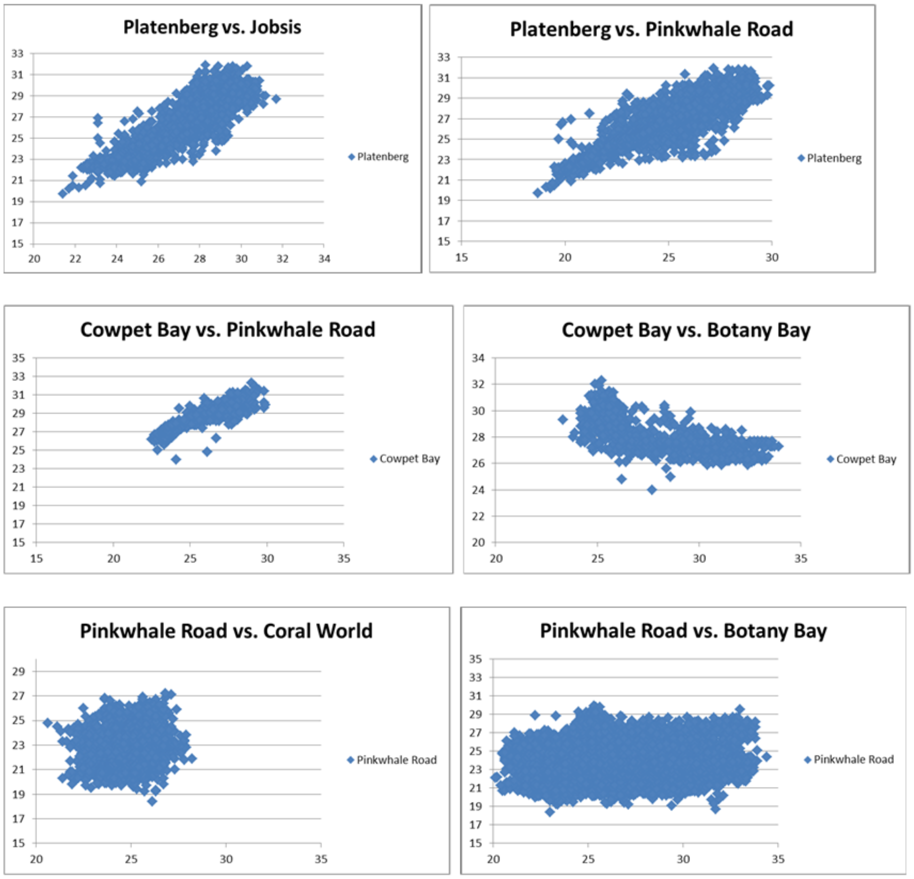
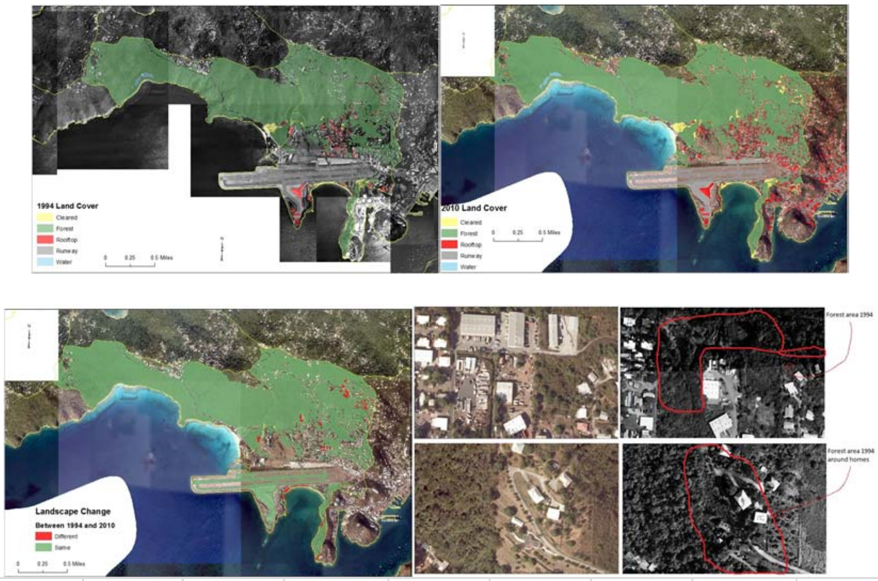


Figure 3: Correlation between temperature reported at separate stations for selected

Erosion and land use

Since landuse is a major contributor to erosion we also began a study of how land use has changed over the period in which we have aerial photography. The GeoCAS Institute at UVI has access to aerial photography for Saint Thomas going back to the mid 1940's. Graduate students at UVI have been using the most recent aerial images from 2010 to characterize impervious surfaces. Building on their work we have continued to add land cover types and began comparing older images to the most recent ones from 2010. Student Stephen Santana drew land cover polygons for watersheds from Perseverence Bay into Frenchtown and parts of Charlotte Amalie for both 2010 and 2004 (Figure 4) and calculated the amount of transfer between land cover types (table in Figure 4). This analysis shows a general trend towards conversion of forest to cleared and rooftop. We expect to continue this analysis, extending to new parts of Saint Thomas and farther back in time.



		2010						
	Row Label	Cleared	Forest	Rooftop	Runway	Water	Total	
1994	Cleared	47970	8001	1548	0	71	57590	
	Forest	33784.02	4513516	13587	0	0	4560888	
	Rooftop	1209.769	220.6121	113386	0	0	114817	
	Runway	0	0	0	378707	0	378707	
	Water	0	0	0	0	19413	19413	
	Total	82964	4521738	128522	378706.7	19484	5131414	

Figure 4: Land use change analysis on Saint Thomas in the Airport Region using images from 2010 and 2004.

Objectives and Ongoing Work

Short-term objectives

One of the main short-term objectives of this project is to make all weather data collected by the new weather network available to the public for use in scientific, private and public sector use. To this end, rainfall and weather data from our network of weather stations is connected to the publicly accessible Davis Instruments Inc. cloud archive. They are also available through the GeoCAS web page at http://geocas.uvi.edu/datacatalog.php#Climate and Weather. The data recorded by the weather stations are downloaded daily to the GeoCAS web server and available to the public on request. Locally, graduate students in the UVI Center for Marine and Environmental Science (CMES) center have are making use of these new data to inform a variety of research programs. Graduate student Moriah Sevier is accessing these data to correlate rainfall and erosion rates with measurements of Sea fan coral disease that she has measured through an in-situ observation campaign. Graduate student Pedro Nieves will use the data to ground-truth erosion models.

Long-term objectives

The PI and Co-Is have begun to explore patterns present in the growing data archive being built by the new weather network and to compare to historical data. While this is a long-term project requiring significantly more data than has been collected to this point, some features are already becoming clear. The scale size of rainfall events across St Thomas is evidently far smaller than the distance separating the most widely separated nodes in the network. This is evidenced by the nearly complete lack of simultaneous precipitation events seen at these nodes. Additionally, the continental warming effect that was believed to be seen in historical temperature data is made clear through data from the new network.

A study of the variation of rainfall rates within a single Doppler radar pixel to validate meteorological ”ground-truth” models is on-going and significant progress is being made in developing a method of comparing radar images to rainfall point measurements. Work continues on incorporating a rainfall layer into the UVI GIS database system which will be informed by data from the new weather network.

Remaining Tasks and Research Elements

This ongoing project will continue to collect data from the weather station network as long as the hardware survives. This provides both the UVI and broader geophysics research community a valuable opportunity to analyze and mine these data for years to come. Current projects by UVI undergraduate students, graduate students, and faculty researchers alike continue to investigate topics identified above as well as a host of others not yet published or presented at conferences. As the baseline of our current data-run expands, we will revisit all the preliminary analyses listed above to improve the accuracy and insight. Ongoing collaboration between faculty at UVI and College of Charleston will begin to investigate the scale-invariance of Caribbean rainfall events as compared to similar continental studies.

Conclusions

The results presented above are only the beginning of an ongoing monitoring campaign made possible through WRRI funding. Preliminary results have already confirmed some anecdotal expectations; The most recent annual seasons on St Thomas have agreed on gross average with historical weather patterns, but have disagreed on the more precise timing of rainfall events (the past year has shown a wetter summer but drier hurricane season than usual). It is impossible to draw broad conclusions from such a short data collection timescale on questions of such long-term significance but the presence of the newly installed weather station network provides the infrastructure necessary to continue and expand these studies in coming years to build a more robust archive of weather pattern data more appropriate for answering the broader critical questions of how historical weather patterns may be changing in the current environment in the Caribbean.

Bibliography

Falkland, A. (2002). Tropical Island Hydrology and Water Resources Current Knowledge and Future Needs. Proceedings of the Second International Colloquium on Hydrology and Water Resources Management in the Humid Topics, 22-25 March 1999. J. S. Gladwell. Panama City, Panama, UNESCO-IHP. CATHLAC. : pp 237-298.

Urish, D. W. (2010). Island Groundwater: A Limited and Vulnerable Resource. World Environmental and Water Resources Congress. R. N. Palmer. Providence, R. I.: 795-805.

Jobsis, L., and Primack, A., 2013 Soil Erosion Characteristics on St. Thomas in *Proceedings of ECS Research Symposium 2013*

M.L. Larsen, A.S. Clark, M. Noffke, G. Saltzgaber, and A. Steele, Identifying the scaling properties of rainfall accumulation as measured by a rain gauge network, Atmospheric Research, 96, 149-158 (2010)

Ramsundar, A., and Morris, D., 2013 Rainfall Patterns on St. Thomas in *Proceedings of AGMUS Research Symposium 2013*

Ramsundar, A., and Morris, D., 2013 Rainfall Patterns on St. Thomas in *Proceedings of ECS Research Symposium 2013*

Simmons, K., and Morris, D., 2013 Rainfall on St. Thomas in *Proceedings of ECS Research Symposium 2013*

Stow, C.D., and Dirks, K.N., High-resolution studies of rainfall on Norfolk Island Part 1: The spatial variability of rainfall, Journal of Hydrology, 208, 163-186 (1998)

Active and Passive Irrigation as Means to Establish Trees on Arid and Semi-Arid Sites.

Basic Information

Title:	Active and Passive Irrigation as Means to Establish Trees on Arid and Semi-Arid Sites.
Project Number:	2014VI248B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	VI
Research Category:	Biological Sciences
Focus Category:	Conservation, Agriculture, Ecology
Descriptors:	None
Principal Investigators:	Michael Morgan, Thomas W. Zimmerman

Publication

1. There are no publications as yet resulting from this project.

ACTIVE AND PASSIVE IRRIGATION AS MEANS TO ESTABLISH TREES ON ARID AND SEMI-ARID SITES

Problem and Research Objectives

The original vegetation of the US Virgin Islands is classified as (sub) tropical dry forest (Holdridge, 1978). Tropical dry forests are subject to periods of drought and water stress that can last months or week. Drought and water stress van inhibit the establishment of new trees by killing seedlings and inhibiting growth of the surviving trees. Often times, supplementary water is needed to ensure that tree seedlings and newly planted saplings survive in the field.

We compared two water conservation systems for tree planting, one passive system and the other active, against a control. The passive system consists of a small basin dug out of the ground to collect rainwater, allowing it to soak into the earth before it runs off. The active system consists of a 2” diameter PVC pipe dug vertically into the ground to a depth of 16” (40 m). Supplementary water was periodically poured into the pipe to concentrate water around the root zone of the plant. The control treatment consists of trees planted in the conventional way. The tree species selected for the study are Mamey Apple (*Mammea americana*), Puerto Rican Hat Palm (*Sabal casaurium*), and Bay-rum (*Pimenta racemosa*).

The benefit of this research will be the demonstration and confirmation of two low cost, effective ways to establish trees in areas that normally receive low levels of rainfall, such as the tropical dry forests of the US Virgin Islands, Puerto Rico, and Hawaii or the deserts of the American Southwest.

Methodology

Fifty six tree seedlings, approximately 12” (30 cm) tall, will be planted in one of the fields used by the UVI-AES for experiments. Three tree species native to the USVI, Mammey Apple (*Mammea americana*), Bay-Rum (*Pimenta racemosa*), and Puerto Rican Hat Palm (*Sabal casaurium*). Six trees of each species will be assigned to a treatment. The treatments are control, active irrigation, and passive irrigation. The control treatment consists of just planting a tree in the conventional manner: i.e. dig a hole, remove the planting container from the tree seedling, place seedling in the hole and back fill the hole with the soil previously excavated. The “active” treatment consists of planting a tree seedling and then burying vertically some 16” (40 cm) next to the tree, a PVC pipe with a 2” (5cm) diameter (Bainbridge; 2014, 2002). This pipe will serve as a means to concentrate supplementary water near the deeper roots of the tree seedlings. The “passive” treatment consists of planting trees in small 4” (10 cm) deep basins, approximately 20-30” (50-70 cm) square. Rain water is supposed to pool in the basin and soak into the ground.

Every two weeks, as per Bainbridge, 2002, each in the active irrigation treatment plant received one liter of water. The plants with deep irrigation pipes will have their water poured into the pipes. All plants received regular watering of 2l a week for the first four weeks of establishment and prior to the start of the experiment.

Of course, all plants received rainwater whenever it rained. Evapo-transpiration will be estimated weekly by filling a pre-existing evapo-transpiration pan with 10” (25 cm) of water and then measuring the change in water levels to the nearest millimeter.

We measured tree heights to the nearest centimeter and survival, during the 10 months of the study. Data was be analyzed a completely randomized design in order to determine if there is a statistical difference amongst treatments and species. Each species and its associated treatments will be considered a completely randomized block design.

Principal Findings and Significance

What we were hoping to find was that the trees planted in the deep pipe treatment, and basin treatment would grow better than the trees assigned to the control treatment. We thought that the trees assigned to the deep pipe treatment would grow the best; not only because they received rainwater, but they were receiving receive rainwater, but were actively being irrigated every two weeks with 2L of water being poured down the pipes. The next best results were to be had by the trees planted in basins, where rainwater and run off would pool. We called this the passive irrigation treatment because the trees were dependent on what rain fell from the sky. The trees assigned to the control treatment were expected to survive, but grow slower than those trees assigned to the previous two treatments.

What happened was the unexpected. Almost all the control trees survived, 17 out of 18 trees or 94%; 11 out of 18 trees in the basin treatment survived (72%), and only 7 of the 18 trees planted in the active irrigation/ deep pipe treatment survived (39%).

Two of the three studied species were trees; *Mammea americana* is considered a large tree that grows up to 65’ (20m) tall, and *Pimenta racemosa* a medium sized tree that grows up to 40‘ (12m) tall. The third species studied is the palm (*Sabal casaurium*) a palm species that grows to up to 33’(10m) tall. The species differ in drought tolerance, with *S. casaurium* being the most drought tolerant, followed by *P. racemosa*, with *M. americana* being adapted to more mesic sites like stream sides.

Most of the *M. americana* trees died in the deep pipe and basin plots (66%). However, almost all of the trees survived in the control plot (5 out 6 trees). All of the *P. racemosa* trees survived in the control plot, 5 out of 6 survived in the basin plot, and only 2 out of 6 survived in the deep pipe plot. Of the palm species, *S. casaurium*, results were similar to *P. racemosa:* 6 palms, 5 palms and 3 palms for control, basin, and pipe, respectively .Differences in height have more to do with species differences than with treatment. *P. racemosa* grows the fastest, followed by *M. americana*, and then *S. casaurium*.

Conclusions

We had hoped to replicate the success of D. A. Bainbridge and his use of deep pipe irrigation to establish trees in the Mojave Desert, in the less arid environment of the US VI. What we suspect caused our poor results was species selection, and the occurrence of a severe drought in the first two months of the experiment. Also, Dr. Bainbridge, used a deep rooted tree species adapted to extreme drought (*Prosopsis glandulosa)*, and we used species adapted to the moister environment of the USVI.

References

Bainbridge, D. A. (2002). "Alternative irrigation Systems for Arid Land Restoration." Ecological Restoration **20**(1): 23-30.

Bainbridge, D. A (2014)" Innoculation Response by Irrigation System Type for Desert Tree Establishment". Tree Planters Notes **57** (2) : 44-52

Daley, B. F. a. Z., T.W (2009). "Germinating five forest tree species native to the Virgin Islands." Tree Planters' Notes **53**(1): 10-15.

Gibney, E., R. O'Reilly and B. Devine (2000). The USVI Vegetation Classification System. USVI Data Atlas.

Holdridge, L. R. (1978). Ecología Basada en Zonas de Vida. San José, Costa Rica, Instituto Interamericano de Ciencias Agrícolas.

Lamprecht, H. (1990). Silvicultura en los Trópicos. Eschborn, Germany, GTZ -Deutsche Gesellschaft fur Tecnische Zusammenarbeit.

O'Donnell, J. a. O. R., R. G. (1997). Propagating native tree species by cuttings. U. o. t. V. Islands, The University of the Virgin Islands, The Virgin Islands Dept of Agriculture and USDA Forest Service.**:** 2.

Rocheleau, D. F. W., and A. Field-Juma (1988). Agroforestry in Dryland Africa. Nairobi, Kenya, ICRAF (International Counceil for Research in Agro-Forestry.

Weber, F. R., and C. Stoney (1986). Reforestation in Arid Lands. United States, Volunteers in Technical Assistance (VITA).

Quantification and Molecular Typing of Escherichia coli from watersheds above Brewers Bay and UVI, St. Thomas

Basic Information

Title:	Quantification and Molecular Typing of Escherichia coli from watersheds above Brewers Bay and UVI, St. Thomas
Project Number:	2014VI249B
Start Date:	3/1/2014
End Date:	2/28/2015
Funding Source:	104B
Congressional District:	
Research Category:	Biological Sciences
Focus Category:	Floods, Water Supply, Water Quality
Descriptors:	None
Principal Investigators:	Jennilee Robinson, Jennilee Robinson

Publication

1. There are no publications as yet resulting from this project.

QUANTIFICATION AND MOLECULAR TYPING OF *ESCHERICHIA COLI* FROM WATERSHEDS ABOVE BREWERS BAY AND UVI, ST. THOMAS

Problem and Research Objectives

Escherichia coli is the name given to a group of bacteria that is predominately found in the intestines of humans and animals. Most *E. coli* strains are harmless, but some may cause severe illness such as *E. coli* O157:H7. This strain has been implicated in outbreaks of hemorrhagic colitis and hemolytic uremic syndrome. Other pathogenic strains cause a broad range of diseases from localized diarrhea and urinary tract infections to severe systemic illnesses including septic shock and neonatal meningitis (Orskov and Orskov, 1992). Diseases that are associated with water systems are the leading cause of morbidity and mortality around the world, with an estimated 1.8 million lives lost per year to diarrhea alone (Ishii and Sadowsky, 2008). Accordingly, it is important to monitor the levels of fecal contamination for the prevention of disease outbreaks. The presence of cultivatable *E. coli* in water is an indicator of fecal contamination, and has been used historically to assess water quality and safety (U.S. Environmental Protection Agency 1986).

Brewer's Bay is located on the southwest shore of St. Thomas in the U.S. Virgin Islands. The goal of this project is to determine the amount and type of fecal contaminants, particularly *E. coli* in the watersheds above Brewer's Bay. The west-facing bay includes a sandy beach that attracts visitors year-round. The bay is surrounded by steeply elevated and mostly uninhabited land to the north, an airport runway on the south side, and the St. Thomas campus of the University of the Virgin Islands (UVI) to the east. Further east of the campus, industrial and residential land use increases. St. Thomas is an island where most households rely on private septic tanks with drainage fields. In addition, livestock can contribute to contamination. These contaminants can be spread during rain events in watersheds, flowing from a source to a sink such as the bay. We hypothesized that water collected from watersheds with increased development will have higher levels of fecal coliform bacteria, specifically *Escherichia coli*. Moreover, *E. coli* isolates from sewage-polluted water will encode genetic factors involved in antibiotic resistance and ability to cause disease.

Our objectives were to select sampling sites in guts, characterize the watersheds following into them, and to collect and analyze water when rainfall accumulated as run-off. We selected eight sites surrounding the bay and began to monitor them for run-off. Unfortunately, low rainfall has mostly prevented water from collecting and flowing in the guts during the study period. Therefore, we have been granted a one year no-cost extension to continue our work. However, some samples have been collected and were useful to develop our methodology as described below.

Methodology

Site Selection

Sites for sample collection in guts were selected based on several criteria including accessibility, size and location. The study area has several different watersheds that eventually flow to either the north side of the beach or along the airport runway to the south. The mountainside northwest of the bay is very steep and almost completely undeveloped except for a few houses at the very top of the ridge. The first of sites affecting the north side of the beach (N1) is located uphill in a large gut at the Reinhold Center for the Arts on the northwest corner of the St. Thomas UVI campus. The next site (N2) is located nearer the beach along culverts draining both the road leading to Reichhold and the main road. From the east, this main road travels through campus, bordered on the south by the airport, turns north when it reaches the bay to run just behind Brewer's Beach, and continues west along the north border of the bay. Finally, a gut that flows from these areas onto the beach is the downstream site (N3) on the north end of the study area.

The southern end of the bay is influenced by watersheds above and on the UVI campus to the northeast and by developed land and roadways to the east. The mountain ridge that is uphill of the bay to the north continues behind the UVI campus. Water from watersheds in these areas flows downhill towards the bay in a southwest direction. The land flattens to the south nearer the aforementioned main road, where water is directed in made-made gutters into a collection area along the airport runway. This water flows into a small lagoon at the southern edge of the bay next to the marine science building.

There are five sites from the watersheds that drain into the southern edge of the bay. The first of the sampling sites (S1) heading east from the bay and across the campus is located on a gut that flows a road at the northern border of the campus. There is still little development on the mountainside above this gut. Also, this gut flows from a watershed separate from N1, N2 and N3. Next, a gut located at the east border of the campus (S2) collects a slightly more developed watershed. Moving east, a flat area of land hosts a residential community bordered by the north mountain ridge. Two sites in this community were selected. The first (S3) is in a gut flowing through the center of the community one block downhill from a residence with livestock, mostly goats. The second site (S4) is at the southeast border of the community and the main road. This site is in a large man-made gutter that collects the flow including water from the previous site (S3), as well as from the eastern side of the community and mountain above and directs it under the road into the airport. Land development becomes more industrial and slopes uphill to the east of the residential community. The final site (S5) is located along the road where guts and flat lands drain into an earthen culvert at the eastern border of the airport. Beyond these sites, hills create new watersheds that direct the flow from the northern mountain ridge east into Crown Bay.

There is increased land development spanning the sampling sites. The least developed land lies to the west closest the bay (sites N1, N2 and N3). Development to the east increases following the road though campus and along the airport. Therefore, S1 is the least developed and S5 is located in the most developed area.

Water Collection

Water samples were collected from sites when rainwater was flowing in the guts. Water, ~500 ml, was collected using aseptic technique into 1 l plastic bottles. Bottles were returned to the lab and refrigerated. All samples were processed within 72 hours of collection.

Membrane Filtration for Live E. coli Enumeration

Water was filtered through sterile 0.45 um cellulose ester membranes (Millipore, Bedford, MA). For enumeration of individual colonies of bacteria, water was filtered directly in volumes of 100 ml, 10 ml and also diluted 10-fold in 50ml volumes of distilled H_2O to 10^{-1}, 10^{-2}, 10^{-3}, and 10^{-4}. These six membranes were each placed on an individual plate containing modified mTEC agar and grown 2 hours at 35.5 degrees Celsius followed by 22 hr at 44 degrees Celsius following EPA Method 1603 (EPA 2002).

Membrane Filtration for DNA

Two water samples diluted10-fold in 50 ml of distilled H_2O were filtered through sterile 0.45 um cellulose ester membranes (Millipore, Bedford, MA). Filters were frozen at -80 degrees Celsius. DNA was extracted from the filter using the MP Biomedicals FastDNA Spin Kit For Soil (Solon, OH). Frozen filters were broken up into small fragments with a metal spatula. The lysing matrix, sodium phosphate buffer and MT buffer from the kit were added to the fragmented filter in the 2.0 ml cryotube. The cells were lysed using a vortex for 10 min at the highest setting, and DNA was extracted from the lysate following the kit protocol. DNA was eluted in a volume of 150 ul and stored frozen at -20 degrees Celsius.

Principal Findings and Significance

Water accumulated following rain to be collected from most sites only once during the study period in the first week of November. Otherwise, samples were able to be collected following lighter rainfall from the large cement-bottomed culvert site S4. *Escherichia coli* were enumerated from ten samples collected during the single heavy rain. Bacteria ranged from 6.69 x 10^2 to 8.67 x 10^5 CFU/100 ml of water. While statistical comparisons are not possible on this small data set, sites S1-S5 had on average more bacteria than sites N1-N3. This pattern supports our hypothesis that there will be increased contamination in the watersheds of areas with greater development.

Conclusions

To continue, additional samples will be collected with heavier rainfall. Also, DNA extracts will be screened by quantitative PCR for the presence of fecal contamination and *E. coli*. We have assays for novel human fecal indicators, gut microbiota unique to humans of the Lachnospirales and Bacteroidetes groups. In addition, we have an assay for ruminant-specific Bacteroidetes to distinguish fecal contamination from livestock. We also have assays for different groupings of *E. coli* to distinguish pathogenic from non-pathogenic strains.

References

Ishii, S., Sadowsky, M.J., 2008. Escherichia coli in the environment: Implications for water quality and human health. Microbes and Environments. 23(2): 101-108.

Orskov, F., and I. Orskov. 1992. *Escherichia coli* serotyping and disease in man and animals. Can. J. Microbiol. 38: 699–704.

U.S. Environmental Protection Agency. 1986. Ambient Water Quality Criteria for Bacteria – 1986. EPA 440⁄5-84⁄002. Washington, DC: Criteria and Standards Division, U.S. Environmental Protection Agency.

U.S. Environmental Protection Agency. 2002. Method 1603: *Escherichia coli* (*E. coli*) in Water by Membrane Filtration using Modified Membrane-Thermotolerant *Escherichia coli* Agar (Modified mTEC). Publication EPA-821-R-02-023. Washington, D.C: US EPA Office of Water, Office of Science and Technology.

Information Transfer Program Introduction

No VI-WRRI projects were supported through the Information Transfer Program during the 2013-2014 program year. However, all projects conducted through the VI-WRRI are required to include elements of information dissemination and training in their activities. This was done and is evident through the many public presentations that were made and the numerous students, both graduate and undergraduate, that participated in the research projects.

USGS Summer Intern Program

None.

Student Support					
Category	**Section 104 Base Grant**	**Section 104 NCGP Award**	**NIWR-USGS Internship**	**Supplemental Awards**	**Total**
Undergraduate	17	0	0	0	17
Masters	3	0	0	0	3
Ph.D.	0	0	0	0	0
Post-Doc.	0	0	0	0	0
Total	20	0	0	0	20

Notable Awards and Achievements