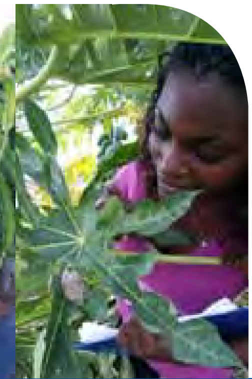
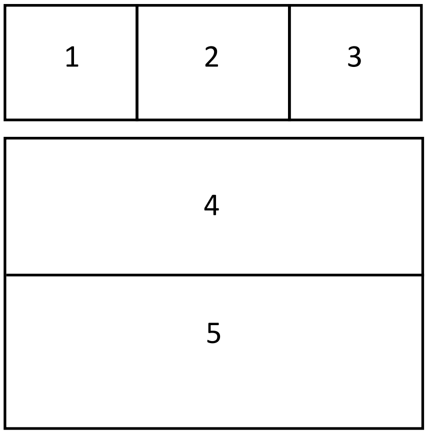


Agricultural Experiment Station

2016 ANNUAL REPORT

University of the Virgin Islands

On our cover...



1. Automated system to monitor soil moisture using capacitance sensors controlled by data loggers on okra production
2. Pitaya with flower buds about to open and also ripe fruit.
3. Imani Dailey collecting papaya data.
4. Horticulture and Aquaculture program team. From left to right: Luis Carino Jr., Abdel Rahman Ahmed Nassef, Micaiah Forde, Victor Almodovar, Rhuanito Ferrarezi (Faculty), Jayar Greenidge, Thomas Geiger, Donna Gonzales, Donald Bailey and Lorenzo Cannella (squatting).
5. St. Croix White and Dorper x St. Croix White ewe lambs returning to pasture.

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University of the Virgin Islands

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Agricultural Experiment Station

MESSAGE FROM THE DIRECTOR

We hope you enjoy reading the 2016 Annual Report that is just one of our publications to document the research activities of the faculty and staff of the Agricultural Experiment Station (AES) located on St. Croix on the Albert A. Sheen Campus of the University of the Virgin Islands. AES is one of the two Land Grant units that are part of the Research and Public Service component of UVI, the other being the Cooperative Extension Service.

While the University is going through some transitions that will impact the Land Grant programs, our scientists continue to conduct basic and applied research to meet the needs of the local agricultural community in the areas of agronomy, agroforestry, animal science, aquaculture, biotechnology and horticulture. Research is conducted on a variety of agriculture commodities that include sheep, beef cattle, vegetables, root crops, fish, trees and forages. To enhance our ability to meet the needs of our stakeholders we have increased the integration with our colleagues in the Cooperative Extension Service by developing joint appointments for positions that combine research and extension.

Because fresh water is a very limited commodity in the US Virgin Islands some of our new research initiatives involve evaluating the use of microprocessor technology to monitor and control irrigation for crops. We have also begun evaluating our overall water use and developing ways to collect and store more rain water for use by our plant and livestock research programs.

We continue our efforts to help train the next generation of scientists by mentoring students with support from USDA-NIFA funds for Resident Instruction in the Insular Areas. Because UVI has no academic program in agriculture AES has developed a program to provide opportunities for experiential learning and research training of UVI students. The student interns have become an integral part of the AES research activities as indicated by the number of research presentations they make at local, regional, national and international conferences.

Agricultural research generated by AES researchers continues to provide science based information to help our community move forward and make informed decisions about their food, nutrition and lifestyle in the US Virgin Islands.

Robert W. Godfrey, Ph.D.
Director & Professor of Animal Science

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Breeding for an Earlier Dark Open Sorrel

By Thomas W. Zimmerman and Carlos Montilla

UVI students Kenya Emanuel (left) and Tyrone Pascal (right) cleaning sorrel.

ABSTRACT

Sorrel, *Hibiscus sabdariffa*, has autogamous flowers that self-pollinate during the night prior to flower opening resulting in inbred varieties. Cross-pollination of inbred plants normally results in vigorous hybrids that out-perform both parents. Two varieties of red sorrel, 'TTB', a photoperiodic variety having a deep crimson open calyx and 'KDN', a day-neutral red calyx variety, were used as parents. The objective was to study two parental sorrel lines and reciprocal crosses for F_1 progeny and selected F_3 lines to evaluate plant vigor for production, floral initiation, fruit size and shape. Selected plants from the F_2 populations were used to obtain seed for the F_3 progeny. Plant vigor was determined by measuring plant height and number of branches at two-week intervals as well as recording when floral buds became visible. Although the F_1 population of 'TTB' x 'KDN' tended to be taller than the parents, it wasn't significant for plant height and branch development. However, the F_3 populations were significantly taller than the F_1 and parent varieties at 84 days. The TTB and F_1 'TTB'x'KDN' plants initiated flowers at the same time as 'TTB' which was four weeks later than 'KDN'. However, the F_3 line of 'KDN'x'TTB' initiated flowers at the same time as 'KDN' indicating a new earlier sorrel line. Hybrid vigor can be obtained from specific controlled crosses in sorrel. The day-neutral characteristic can be recovered in F_3 population where 'KDN' is the female parent.

INTRODUCTION

Sorrel (*Hibiscus sabdariffa* L.), also known as roselle, is an annual plant that is part of the Malvaceae family and is grown in tropical and subtropical regions for stem fibers, paper pulp, leaves, seeds and colorful edible succulent calyxes. Sorrel has autogamous flowers that self-pollinate prior to flower opening during the night, resulting in inbred varieties (Vaidya, 2000). Akpan (2000) reported an outcrossing rate of <1% in sorrel based on experiments conducted adjacent to breeding nurseries. Cross-pollination of inbred sorrel plants normally results in vigorous hybrids that out-perform both parents (Ibrahim and Hussein, 2006). The objective was to study reciprocal crosses in two parental sorrel varieties and the F_1 (first generation) and selected F_3 (third generation) progeny to evaluate their plant growth, floral initiation and fruit calyx characteristics.

MATERIALS AND METHODS

Seeds of two parental lines from the Caribbean sorrel, St. Kitts day-neutral 'KDN' and Trinidad black 'TTB', were used in reciprocal crosses to develop F_1 hybrids (Figure 1). 'TTB' is late-flowering with open dark crimson calyxes and 'KDN' is day-neutral with red calyxes. Controlled pollinations, between the two varieties, were used to develop the F_1 hybrids. Randomly selected plants of the first year F_1 hybrids 'KDN'x'TTB' and 'TTB'x'KDN' were used as the source of F_2 (second generation) seeds. The F_2 plants were grown and individual plants selected for early flowering and darkest calyx and served as a source of F_3 seeds which were bulked together. Seeds of the parents, F_1 and F_3 populations were planted in a greenhouse in mid-August and the seedlings transplanted to the field in early September. Sixty seedlings of each source were planted two feet apart within rows and five feet between rows in a randomized complete block design with 20 plants per replicated source. Drip irrigation was used to water and fertilize the plants. Chelated iron Fe-EDDHA was applied through the drip irrigation to overcome iron chlorosis induced by the high pH calcareous soil. The plants were maintained by regular hand-weeding of the field. Data was recorded at two-week intervals on sorrel plant height, number of branches and floral bud initiation. Calyxes were collected for fruit data on calyx length, epicalyx (spur-like structures at base of calyx) length and calyx width. Data was analyzed using ANOVA and mean separation using LSD test.

RESULTS AND DISCUSSION

The F_3 hybrids and F_1 'KDN'x'TTB' were significantly taller than the parents and F_1 'TTB'x'KDN' hybrid (Figure 2) by the 56th day and followed this trend through to the 84th day. This trend was also observed in the rate of branching. The F_1 'TTB'x'KDN' plants initiated flowers at the same time as 'TTB' which was four weeks later than 'KDN'. However, the F_3 line of 'KDN'x'TTB' initiated flowers at the same time as 'KDN' indicating a new day-neutral line (Figure 3).

The dark crimson color and open calyx of 'TTB' was lost in the F_1 but recovered in the F_3 generation (Figure 4). 'TTB' and F_1 'TTB'x'KDN' had significantly longer calyxes than the 'KDN' (Figure 5) while with the reciprocal cross both F_1 and F_3 calyxes were significantly longer than 'KDN' (Figure 6). This indicates that F_1 hybrid vigor is present and results in longer calyxes than were present in the largest parent and is significantly longer than the shorter 'KDN' parental line.

Hybrid vigor can be obtained from controlled crosses between 'TTB' and 'KDN' in the F_1 population for plant height and branching. Through

Figure 1. Calyx fruit characteristics of sorrel parents used in reciprocal crosses (KDN top, TTB bottom).

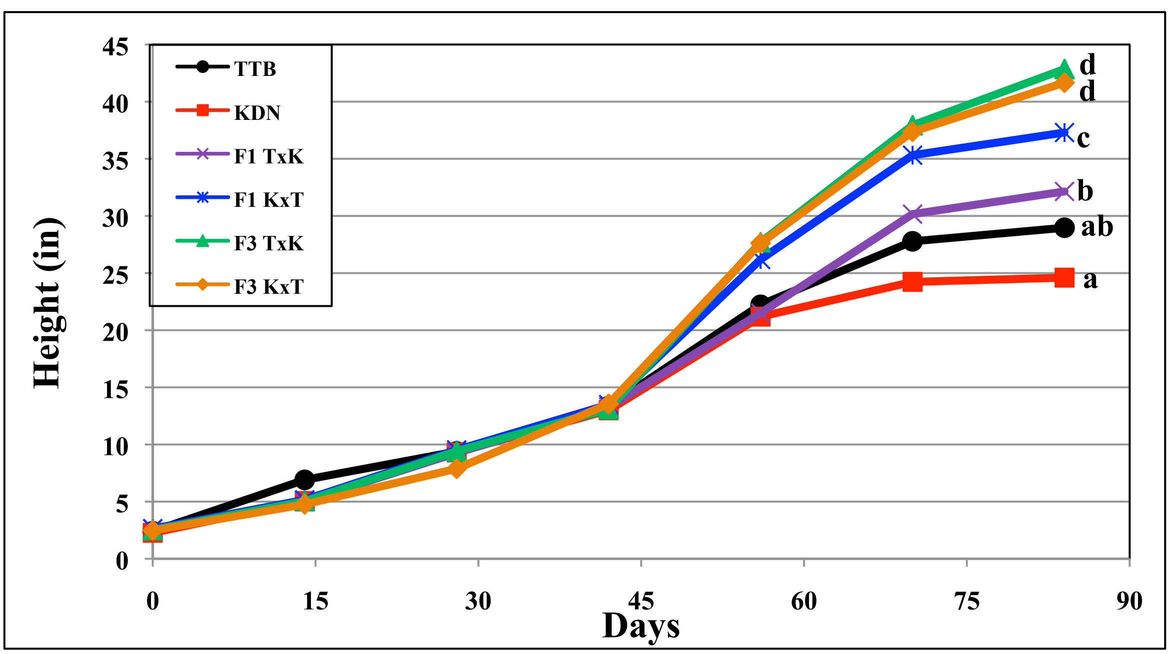

Figure 2. Average height after field planting for sorrel plants derived from parents, F1 and F2 populations. LSD (*P*=0.05) on day 84.over time.

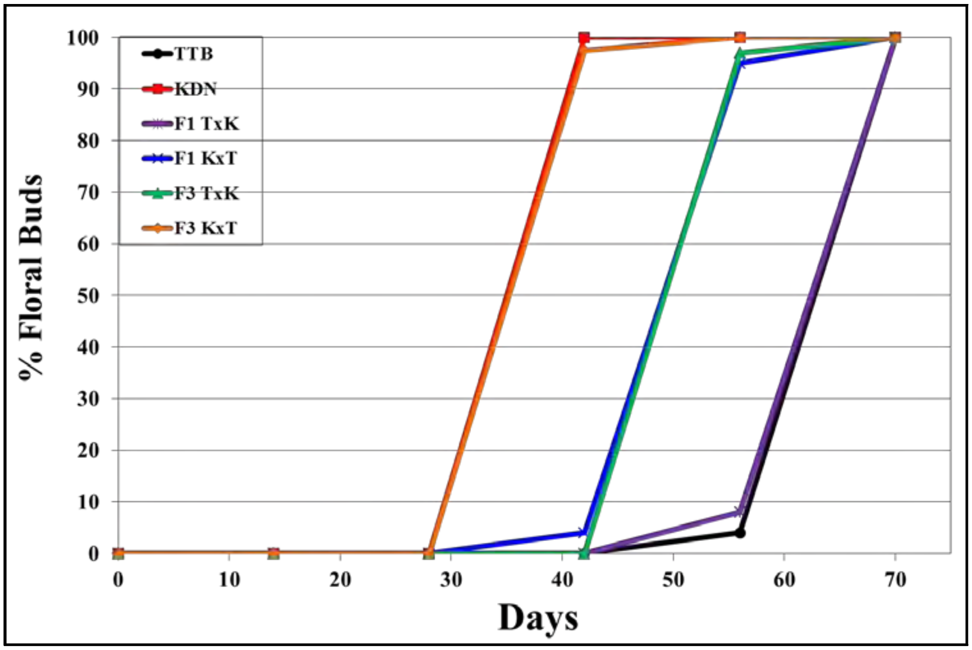

Figure 3. Days to visible appearance of developing floral buds for sorrel plants derived from parents F_1 and F_3 populations.

Figure 4. Fruit calyxes of parents (top) and two generations of TTB x KDN sorrel (bottom).

selection of the F2 population, F3 populations can be obtained that maintain the vigorous growth and branching characteristics found in the F1. The early-flowering characteristic of 'KDN' was recovered in a third generation from the 'KDN'x'TTB' hybrid. The day-neutral characteristic was recovered in the F3 population when 'KDN' was the female parent in the initial hybrid.

ACKNOWLEDGEMENTS

This research was funded through USDA-NIFA-Insular Tropical Grant funds (250439-6470-310) and USDA-NIFA-Hatch (201054-6470-310). The assistance from Henry Harris, James Gordon, Raheem Smart, Kenya Emanuel, Tyrone Pascal, Kalunda Cuffy, and Shamali Dennery for this research was gratefully appreciated.

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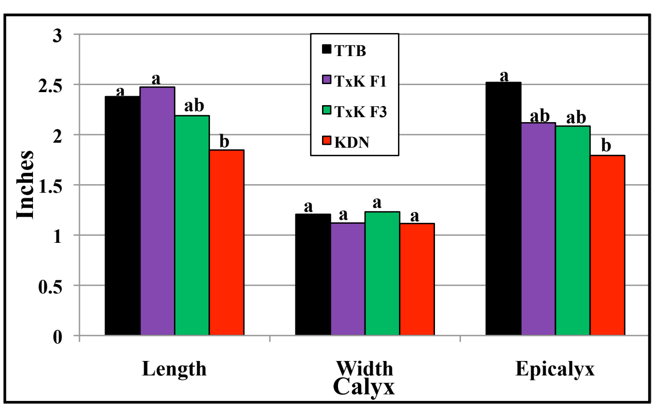

Figure 5. Size characteristics of parental, F1 and selected F3 sorrel calyxes from 'TTB'x'KDN' crosses (LSD *P*=0.05).

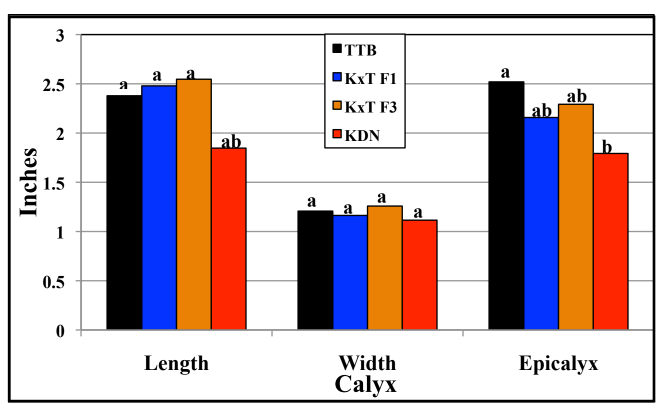

Figure 6. Size characteristics of parental, F1 and selected F3 sorrel calyxes from 'KDN'x 'TTB' crosses (LSD *P*=0.05).

Vahl's Boxwood, (*Buxus vahlii* Baill): A Federally Endangered Tree of St. Croix

By Michael Morgan and Thomas W. Zimmerman

Figure 1, above. Foliage of *B. vahlii*.
Figure 2, right. Flowers of *B. vahlii*. Note spike at tip of leaf.

ABSTRACT
Vahl's Boxwood is a federally endangered tree that occurs on four sites in St. Croix. It is related to the temperate ornamental bush Common Boxwood (*Buxus sempevirens*), which is trimmed to make elaborate hedges or topiaries.

INTRODUCTION

Vahl's Boxwood (*Buxus vahlii*) is an evergreen shrub, that is found only on four sites on the island of St. Croix in the US Virgin Islands and its distribution extends west to the Island of Puerto Rico with about six additional limited populations. It has been a federally endangered plant species since 1985 (USFWS, 1987). It is related to the temperate zone bush, *Buxus sempevirens*, which is a popular ornamental planted for hedges and sometimes trimmed into fanciful shapes called topiaries. It likes to grow on limestone-derived soils within tropical dry forest vegetation. Of the four sites on St. Croix, one population is within the Sandy Point National Wildlife Refuge; the other two populations are on the hills south and east of the town of Christiansted. A single individual is located in the former ALCOA site close to the airport. This species is threated by urban development resulting in habitat fragmentation and destruction, competition with exotic plant species such as Sansevieria (*Sansevieria* spp) and Coral Vine (*Antigonon letopus*), as well as devastating human-induced wild fires. Moreover, the species is threatened by its own reproductive biology, as it depends on mechanical dispersion of the seed by the splitting of

Figure 3. Close up of old flowers. Male flowers are at the base, female flower is at the top. Note the stigmas and ovary which develops into the seed capsule and are components of the female flower.

Figure 4. Developing seed capsules along a branch of *B. vahlii.*

the dry capsules and the seeds contained inside falling to the ground. This results in the seeds not traveling far from the parent plant.

DESCRIPTION

This small tree or bush does not get much taller than 12 feet (4 m).The leaves are dark green, leathery, and stiff (Figure 1). They are arranged oppositely on the branches. The mid vein of each leaf is sunken. There are two slight side veins that parallel the curve of the leaf edges. Each leaf has a little spine at the tip (Figure 2). Incidentally, the spines help distinguish *B. vahlii* from an unrelated but similar looking tree species that grows in association with *B. vahlii*, called stopper (*Eugenia foetida*, formerly *E. buxifolia*). The tree bark is gray and finely fissured.

The species is monecious, meaning the flowers are either male or female and both flower types are on the same plant. Flower cluster occurs at the base of leaves with three to four male flowers surrounding and below a single female flower. The flowers are greenish yellow with white stigmas and anthers (Figures 2 and 3). Bees and other insects pollinate the flowers. The fruit are woody green capsules about ¼” long (0.6 cm), with three “horns” on top (Figure 4). When mature, the seed capsules turn brown, then black and split open into three parts, ejecting the black seeds.

PROPAGATION

Since the seeds are contained in woody capsules that split and expel their seeds, it is best to collect seed capsules before they have ejected their seeds. If one sees open seed capsules or, better yet, seed capsules turning from green to brown, one should collect the woody capsules and put them in a sunny location to dry, placing the capsules on a wire screen small enough to support the capsules but big enough allow seeds to fall through into a container below. Seeds are

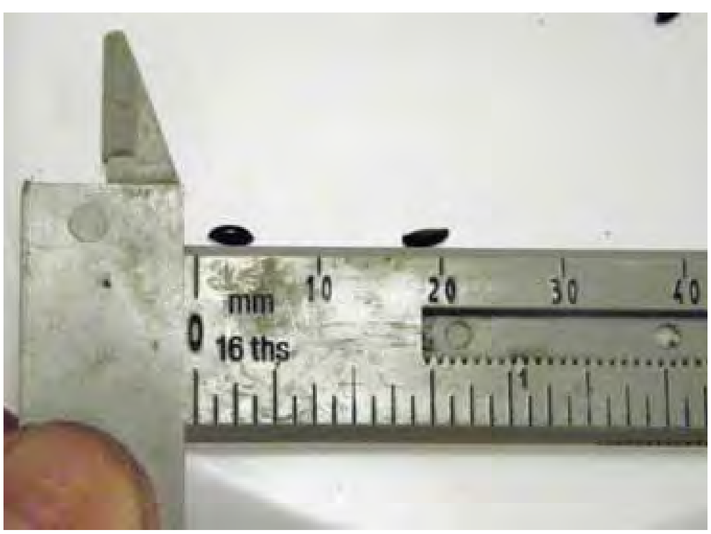

Figure 5. Size of *B. vahlii* seeds.

Figure 6. Two approximately 1.5 g (900 seeds) piles of seeds placed on CD case for scale.

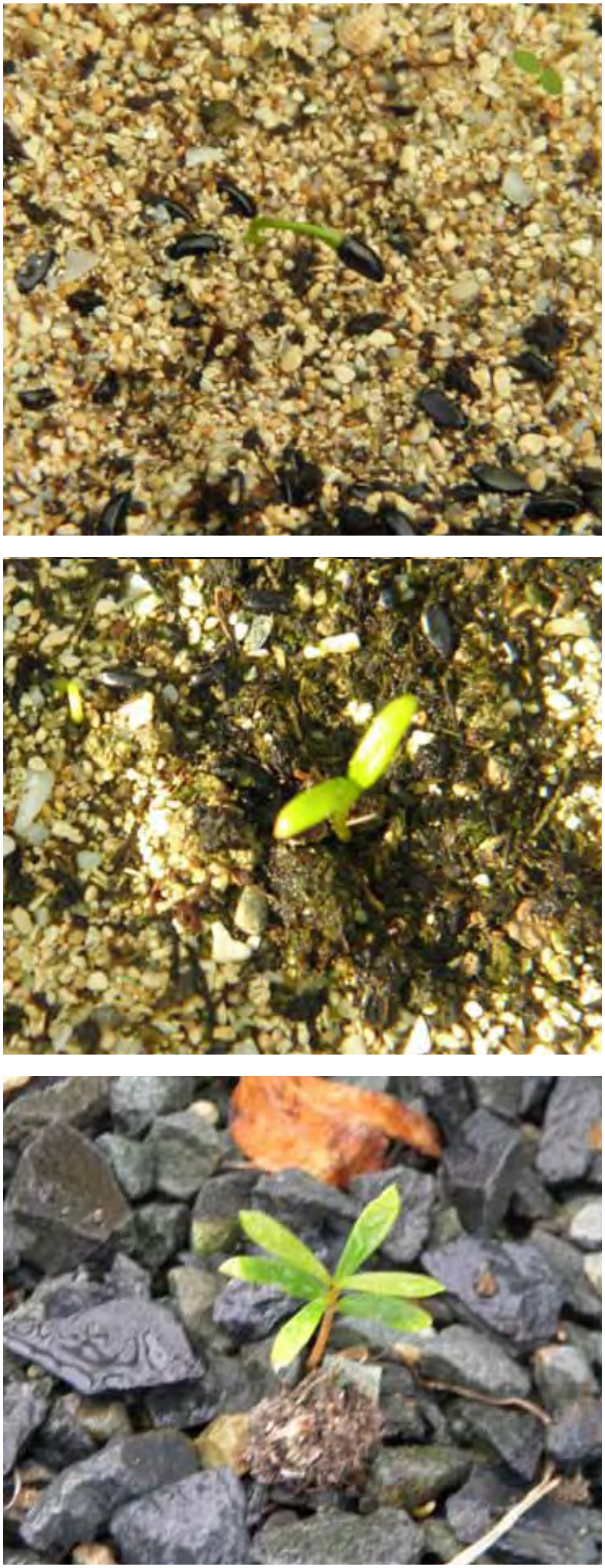

Figure 7. Progression from seed germination to seedling in 3 photos of *B. vahlii*.

extremely small (Figures 5 and 6). 100 seeds equal 0.146 grams; therefore a pound of seeds would have close to 310,700 seeds. Once dried, seeds can be stored in a cool, dry place and retain viability.

In many cases, it is recommended to wash seeds in a weak bleach and water solution to disinfect the seed surface of harmful seed-rotting fungus and bacteria, but since these seeds are so rare and small, one would be hesitant to do so for fear of damaging the seed. Sunlight is also an effective sterilizer, so we recommend exposing the seeds to direct sunlight.

The seeds of *B. vahlii* have a very low percentage of germination and take a very long time to germinate. For example in one germination trial that lasted some seven months, only three out 5,000 seeds germinated. Seeds appear to take a long time to germinate and do not germinate in a uniform way. Germination at 39, 60 and even 114 days after planting has been recorded. Random, lost and forgotten seeds will germinate years after planting too (Figure 7).

Vegetative propagation via the use of cuttings can work, but has only a 14% chance of putting out new leaves and roots. It appears that there is no difference whether hardwood or soft wood cuttings are used, or whether rooting hormone is used or not. Cuttings can stay alive and even put out new leaves, but they fizzle out and die if they don't initiate new roots. One must keep the cuttings moist for a month by using either a humidity tent or a mist bench. A humidity tent in this case is simply a transparent plastic bag over the cutting and the container it is planted in. The planting substrate in the soil needs to be periodically watered but the plastic bag recycles the water that either evaporates from the soil or is produced as a by-product of photosynthesis. The vapour condenses on the plastic as droplets of water and falls back into the planting substrate of the container. A mist bench periodically sprays the cuttings with mist several times throughout the day through the use of a timer and spray heads that produce a mist (Figure 8). We set our mist bench to spray twice a day for four minutes, at 4:00 pm and 4:00 am. Both mist benches and humidity tents give the same results.

LANDSCAPE USE

The dense dark green foliage of *B. vahlii* is attractive. It has the potential to make a good hedge and maybe topiary like its temperate zone relative, the Common Boxwood (*B. sempervirens*). However, experiments need to be performed upon the species to see how well it reacts to pruning. The species is slow-growing in terms of height and diameter. Plants grow less than 1 foot (30 cm) a year. Two trees planted at UVI that are approximately 3 years old are two feet

Figure 8. Mist bench with cuttings of *B. vahlii*.

(60 cm) high. However, fruiting and flowering begins in the second or third year of outplanting.

OTHER USES

Prior to the discovery of quinine in the Americas, leaves of the European Boxwood were used as a fever reducer. Perhaps the Tainos had a similar use for the leaves of *B. vahlii*. However, the rarity of this species precludes such a consumptive use. The Endangered Species Act forbids the destruction of these trees, and collection of botanical samples and seeds is regulated by permit. Perhaps, the most important use of the species is the provision of intangible environmental services such as biodiversity, conservation of soil, feeding pollinators, etc.

ACKNOWLEDGEMENTS

The following students assisted with seed collection and propagation of plants: Che Smith, Juliet Ruggiero, Kalunda Cuffy, Kenya Emanuel, Liam Marin and Tyrone Pascal. The environmental professionals Brian Daley, Claudia Lombard, David Hamada and Rudy O' Reilly helped with locating populations of this species on St. Croix.

FUNDING SOURCES

This research was funded by a grant from the McIntire-Stennis program and a grant from the US Fish and Wildlife Foundation

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Effects Of Agricultural Intensification On Soil Quality In Tropical Low-External-Input Organic Cropping Systems

By Stuart A. Weiss, Danielle D. Treadwell[1], Carlene A. Chase[1], and Rachel Ben-Avraham

Caledonia Valley experimental farm site with contoured fields and vegetable crop plots in the cool dry season at Ridge to Reef Farm, St. Croix, USVI (17º45'12.00" N 64º51'50"W, Elev-180 m).

SUMMARY

Tropical smallholder farmers typically farm under low-external-input (LEI) conditions due to limited access to off-farm resources on which conventional agriculture systems rely to optimize crop yields. Smallholder farmers in tropical environments are also challenged by difficult environmental conditions, low soil fertility, and high pest populations for which limited inputs and affordable services are available to address these constraints. Smallholder farmers may benefit from ecological management strategies that conserve and enhance soil fertility, reduce insect pests, and suppress weeds.

A two-year study was conducted on land converted from permanent pasture to vegetable production on a certified organic farm on St. Croix, US Virgin Islands. Experiments utilized monocultures and bicultures of legume (*Crotalaria juncea* L. and *Mucuna deeringiana* (Bort) Merr.) and grass (*Sorghum bicolor* (L.) Moench × S. *sudanense* (Piper) Stapf and *Pennisetum glaucum* L.) cover crops. The study compared seven cropping systems with two, one-year rotation sequences each consisting of a cover crop cycle followed by two vegetable crop cycles. The primary objective of the study was to compare the impacts of intensive, vegetable cropping systems on soil chemical parameters, key insect pests, and weed suppression.

This article focuses on the effects of agricultural intensification on primary macro soil nutrients and soil organic matter. This study was designed to test whether more complex cropping systems that utilize cover crops, bicultures, and intercropped vegetable production systems would maintain soil fertility more effectively than cropping systems without cover crops and monoculture vegetable crops.

Generally, vegetable crop productivity was high

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for tatsoi, tomato, and cucumber; and not affected by cropping systems. Cover crops produced large quantities of biomass that varied in total cover crop biomass and nutrient content. Systems with *Sorghum bicolor* × S. *sudanense* generated the greatest biomass. Weed biomass was substantial in weedy fallow control plots and recycled nutrients to the soil at similar levels as the cover crops evaluated. All cropping systems exhibited substantial declines in many soil nutrients and in soil organic matter. Overall, soil NO_3-N levels decreased by 68%, phosphorus decreased by 62%, potassium decreased by 56%, and soil organic matter decreased by 55% over the two-year study. Results suggest that the change in land use, cultural farm management practices, and agricultural intensification (system-wide increased soil tillage and vegetable crop removal) was the driving force of total farm system changes in soil fertility observed over the two-year cropping period. Although positive effects on pests and weeds were observed, modifications will be needed to reduce adverse effects on soil.

INTRODUCTION

Tropical Low-External-Input Agroecosystems

Tropical agriculture practices have been adopted largely from conventional farming methods developed in temperate climates with disregard for differing geographical, climatic, and ecological conditions (Altieri and Nicholls 2004). Conventional farming methods have been characterized by critics as contributing to soil degradation and low biological diversity, and as significant contributors to global pollution due to the heavy dependence on synthetic fertilizers, insecticides, and herbicides (Horrigan et al. 2002; Pimentel et al. 2005; Gomiero et al. 2011).

According to Sivakumar and Valentin (1997), the major causes of agricultural unsustainability in the humid tropics are low inherent soil fertility and the high erosivity of land from heavy rainfall. The failure to replenish soil organic matter (SOM) can lead to a dramatic reduction in soil biological activity, decreased soil aggregation, and increased soil compaction (Mortimore and Harris 2005). Through increased agricultural cultivation and intensification, SOM is reduced, leading to nutrient depletion and a reduction in farming system sustainability (Resck 2000, Saidou et al. 2003). Soil nutrient losses occur from erosion, leaching, volatilization and denitrification (Hartemink 2006; Cassman et al. 2002) and generally occur at a faster rate in tropical regions due to warm environmental conditions (Whitbread et al. 2004). This leads to soil nutrient deficiency, soil acidification, and agricultural unsustainability (Hartemink 2006).

Due to limited local inputs and the extremely high cost of imported inputs (synthetic fertilizers and pesticides), most tropical smallholder farmers rely upon locally sourced and on-farm derived inputs and are therefore classified as low-external-input (LEI) farmers. Low-external-input smallholder farmers have limited options available to correct such problems as soil infertility and pest incidence (Saidou et al. 2004; Palm et al. 2001; Harris 1999). Synthetic commercial fertilizers, bulk soil amendments, and synthetic pesticides are generally not economically feasible for LEI farmers and are often not available at all (Smithson and Giller 2002; Palm et al. 2001). Organic soil amendments that could be used to increase soil nitrogen (N), phosphorus (P), and potassium (K) levels, including bulk manures and animal by-products, are not generally available to LEI farmers (Smithson and Giller 2002; Snapp et al. 1998); thus, LEI farmers must seek alternative sources of nutrients (Saidou et al. 2004; Palm et al. 2001). Cover crop systems are one of the most promising technologies which farmers need to closely evaluate and adopt in order to conserve soil fertility and promote agricultural improvement (Snapp et al. 1998).

Role of Cover Crops in Agroecosystems

Planting cover crops (CC) and utilizing them as green manure can provide many benefits to cropping systems. Cover crops are crops planted during fallow periods in rotation with income-generating crops to provide a host of additional ecosystem services. In tropical regions that have an extended rain or monsoon season, CC play a critical role in soil conservation and in protecting tropical soils from nutrient loss (Altieri and Nichols 2004). When planted prior to the onset of intense rain events, CC can reduce nutrient leaching by sequestering soil nutrients in plant tissue (Wang et al. 2005b). In tropical environments soil loss due to high rainfall can lead to major reductions in soil quality and subsequent losses in crop productivity. Soil erosion can be nearly eliminated when approaching a near 100% soil cover level (Erenstein 2003; Moldenhauer et al. 1994) through proper CC management.

High biomass-producing CC can improve the physical structure of soil through the direct increase in SOM. Soil organic matter is a key component of soil quality and the contributions of SOM include: stabilization of soil aggregates and increased soil tilth, aeration, water-holding capacity, and buffering capacity. When planted during fallow periods between main crops, CC can improve soil physical, chemical, and biological properties and consequently lead to improved soil health and increased yields

Table 1. Experimental design structure depicting the 7 Cropping System x 2 crop Rotation, 14 experimental plot model with assigned crops for each of the 6 seasonal Cycles of the continuous two-year cropping study.

		Year 1				Year 2		
		Cycle 1	Cycle 2	Cycle 3		Cycle 4	Cycle 5	Cycle 6
Cropping System	Crop Rotation	Rainy Season Cover Crop	Cool Dry Season Vegetable	Hot Dry Season Vegetable	Crop Rotation	Rainy Season Cover Crop	Cool Dry Season Vegetable	Hot Dry Season Vegetable
1	1	Fallow	Tatsoi	Sweet Corn	2	Fallow	Tomato	Cucumber
1	2	Fallow	Tomato	Cucumber	1	Fallow	Tatsoi	Sweet Corn
2	1	Sorghum Sudan	Tatsoi	Sweet Corn	2	Millet	Tomato	Cucumber
2	2	Sorghum Sudan	Tomato	Cucumber	1	Millet	Tatsoi	Sweet Corn
3	1	Millet	Tatsoi	Sweet Corn	2	Sorghum Sudan	Tomato	Cucumber
3	2	Millet	Tomato	Cucumber	1	Sorghum Sudan	Tatsoi	Sweet Corn
4	1	Velvet Bean	Tatsoi	Sweet Corn	2	Sunn Hemp	Tomato	Cucumber
4	2	Velvet Bean	Tomato	Cucumber	1	Sunn Hemp	Tatsoi	Sweet Corn
5	1	Sunn Hemp	Tatsoi	Sweet Corn	2	Velvet Bean	Tomato	Cucumber
5	2	Sunn Hemp	Tomato	Cucumber	1	Velvet Bean	Tatsoi	Sweet Corn
6	1	Sorghum Sudan & Velvet Bean	Tatsoi & Bean	Sweet Corn & Pea	2	Sunn Hemp & Millet	Tomato & Bean	Cucumber & Pea
6	2	Sorghum Sudan & Velvet Bean	Tomato & Bean	Cucumber & Pea	1	Sunn Hemp & Millet	Tatsoi & Bean	Sweet Corn & Pea
7	1	Sunn Hemp & Millet	Tatsoi & Bean	Sweet Corn & Pea	2	Sorghum Sudan & Velvet Bean	Tomato & Bean	Cucumber & Pea
7	2	Sunn Hemp & Millet	Tomato & Bean	Cucumber & Pea	1	Sorghum Sudan & Velvet Bean	Tatsoi & Bean	Sweet Corn & Pea

of principal crops (Fageria et al. 2005; Wang et al. 2005a). Generally, incorporation of CC residue is accomplished through conventional soil tillage practices using modern mechanical equipment. Conventional tillage practices have been exhaustively studied and the detrimental short- and long-term effects on soil health are well documented for agricultural commodities such as corn and soybean. In general, information is limited on the effects of CC in vegetable crop rotations and it is of interest to test the effects of agriculture intensification on a tropical organic farm with initially high soil quality.

In this study, CC served as the primary LEI soil amendment for intensively managed organic vegetable cropping systems. The objective of the study was to evaluate the effects of cropping systems varying in CC classification (grass or legume) and level of complexity (monoculture or biculture) on vegetable crop productivity, soil organic matter, and soil macro-nutrient levels.

MATERIALS AND METHODS

A continuous two-year on-farm cropping system field experiment was conducted from August 1, 2006 to August 20, 2008 at the Virgin Island Sustainable Farm Institute (VISFI) in St. Croix, U.S. Virgin Islands (USVI). All land in this project was certified organic according to the United States Department of Agriculture-National Organic Program (USDA-NOP). All inputs used in this experiment were in compliance with the USDA-NOP.

Experimental Design

Seven distinct cropping system treatments (Cropping Systems) and two different crop rotations (Rotation 1 and Rotation 2) were simultaneously studied over a two-year period consisting of six distinct crop cycles (Table 1). This resulted in seven Cropping Systems x two Rotations for a total of fourteen treatment combinations evaluated within cycles and over time across cycles. The yearly tropical crop sequence contains three distinct crop cycles, each between three to four months long. The three crop cycles within each year are categorized as the Rainy Season (RS), the Cool Dry Season (CD), and the Hot Dry Season (HD). Year 1 consisted of Cycles RS1, CD1, and HD1; and Year 2 consisted of Cycles RS2, CD2, and HD2, respectively). Year was used for descriptive purposes only and was not part of the statistical model during data analysis. The experimental design was a randomized complete block design with 14 treatment plots per block and 3 blocks, for a total of 42 experimental plots. Each treatment was locked into its assigned experimental plot location and monitored over the course of the two-year study.

Cover crops were planted prior to the onset of the rainy season (Cycles RS1 and RS2: September to December) to provide soil cover during extreme rainfall events with high potential for soil erosion, and when weeds, insect pests, and plant pathogens are problematic. Cool-season vegetable crops requiring milder growing conditions were chosen for the cool, dry season (Cycles CD1 and CD2: January to April), and heat-tolerant, hardier, vegetable crops were selected for the hot, dry season (Cycles HD1 and HD2: May to August).

Crop Species Evaluated

The CC cycle included a no cover crop system (Cropping System 1; weedy fallow; served as the control cropping system), two Poaceae CC in monoculture (grasses; Cropping Systems 2 and 3), two Fabaceae CC in monoculture (legumes; Cropping Systems 4 and 5), and two Poaceae+Fabaceae bicultures (Cropping Systems 6 and 7). CC species evaluated during Cycles RS1 and RS2 were: sorghum-sudangrass (*Sorghum bicolor* (L.) Moench × S. *sudanense* (Piper) Stapf cv. Mega Green) [SS]; pearl millet (*Pennisetum glaucum* L. cv. Brown-midrib [Cycle RS1] and cv. Mega Mill [Cycle RS4]) [PM]; sunn hemp (*Crotalaria juncea* L.) [SH]; and velvet bean (*Mucuna deeringiana* (Bort) Merr) [VB]. Plots with no CC were managed as weedy fallows [WF] and apart from having no CC they received the same management practices as the other Cropping System treatments. The PM cultivar was changed to cv. Mega Mill in Cycle RS2 due to photoperiod sensitivity of the Brown-midrib cultivar in lower latitudes that resulted in stunted growth and early seed head formation.

Vegetable crops selected are commonly grown on St. Croix and are in demand by local consumers. The vegetable crops grown during Cycles CD1 and CD2 were tomato (*Solanum lycopersicum* L. cv. Bush Early Girl, VFFNT Hybrid number 3231) and tatsoi (*Brassica rapa* L. cv. Narinosa). Vegetable crops evaluated during Cycles HD1 and HD2 included cucumber (*Cucumis sativus* L. cv. Eureka) and sweet corn (*Zea mays* L. cv. Hawaiian Supersweet #9A).

Cropping Systems 6 and 7 were developed to represent a higher crop biodiversity level that included the CC bicultures and vegetable crops intercropped with legumes. Legume intercropping is a standard organic management practice to improve soil health, increase biodiversity, and disrupt pest cycles. During Cycles CD1 and CD2, tomato and tatsoi in Cropping Systems 6 and 7 (paired with the CC bicultures) were intercropped with snap beans (*Phaseolus vugaris* L. cv. Provider). During Cycles HD1 and HD2, cucumber and corn in Cropping Systems 6 and 7 (paired with the CC bicultures) were intercropped with cowpea (*Vigna unguiculata* L. Walp. cv. Iron Clay).

Table 2. Comparison of total cover crop and total combined cover crop and weed biomass between CC Cycles RS1 and RS2.

Cycle [z]	Cover Crop Biomass	Cover Crop + Weed Biomass
RS1	6115	6548
RS2	8313	8695
p	0.0411	0.0059

[z] Rainy season year 1, rainy season year 2, respectively.

Cover Crop and Weed Data Collection

In Cycles RS1 and RS2, plant biomass was sampled to ground level in a 0.25-m^2 quadrat at three random points on a linear transect that bisected each plot. Samples were separated by CC species and weed species classes (dicots, monocots, or sedge). Plant samples were dried to constant weight and dry weights were used to determine total dry matter plant biomass (kg ha^{-1}). Analysis of dried plant samples were conducted to determine plant tissue nutrient concentration. Potentially available nutrients (PAN) are an estimation of total elemental N, P, and K contained in the total shoot biomass (CC or weed) produced in each Cropping System for both CC Cycles. Potentially available nutrients are calculated by multiplying plant shoot biomass times the plant tissue nutrient concentration.

Soil Data Collection

Soil samples were collected from each plot at the end of each of the six crop cycles directly following crop termination and prior to crop residue soil incorporation. Soil was collected from each plot using a 2.54-cm-diameter hand-held soil probe. Twelve soil cores were collected to a depth of 20 cm using a diagonal cross transect sampling pattern. Macronutrients analyzed are the primary plant nutrients N, P, and K. Nitrogen is reported as nitrate-nitrogen (NO_3-N) and P is reported as P1 weak (Bray).

Data Analysis

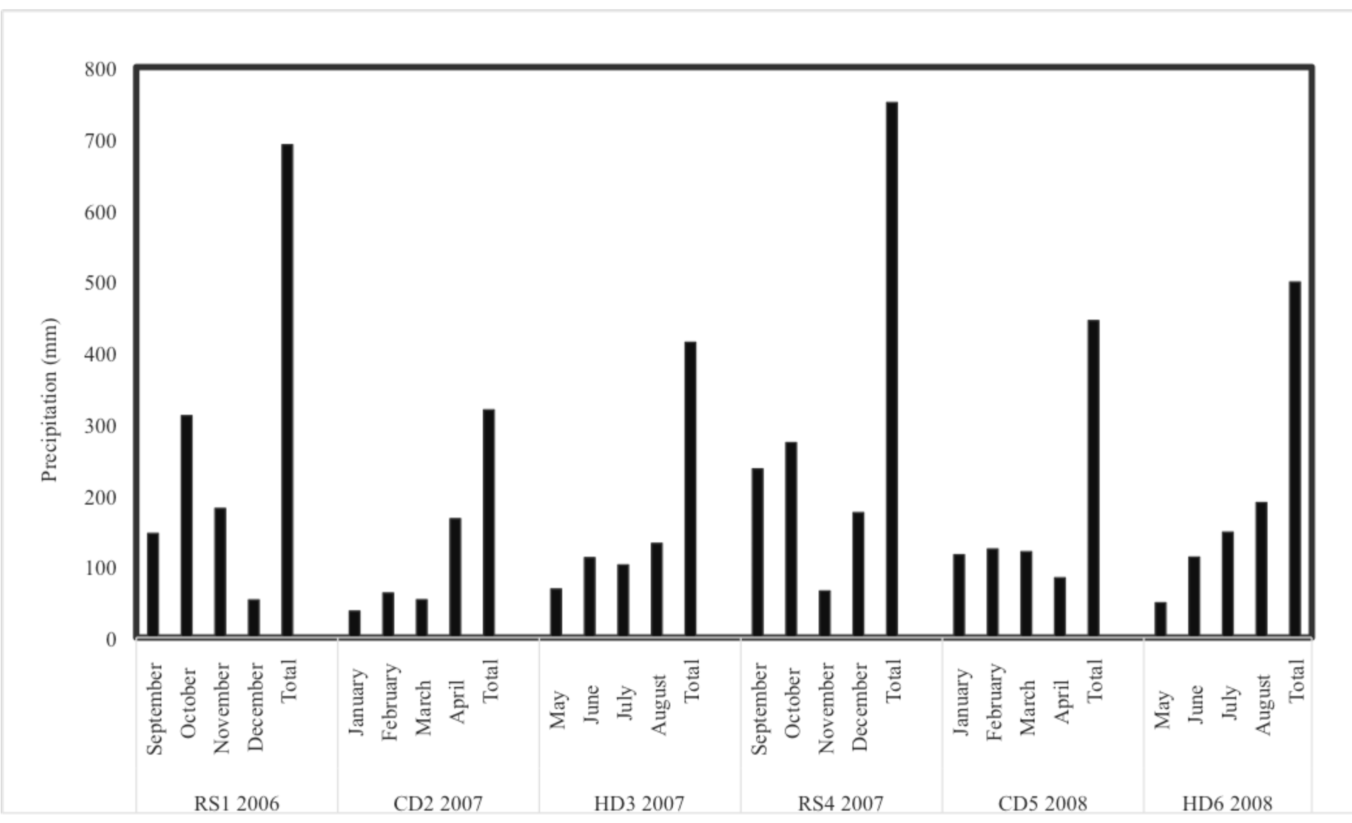
The data analyses for this study were generated using SAS/STAT software, Version 9.3 of the SAS System for Windows. Copyright © [2011] SAS Institute Inc. Data were analyzed using the generalized linear mixed model procedure (PROC GLIMMIX) and pairwise comparisons of least square means were conducted by invoking the DIFF option. The level of significance was five percent (0.05). The full statistical model used was for a split block in time and included Cropping System, Rotation, and Cycle as main effects along with two-way and three-way interactions. When interaction was significant a reduced model was used and was fit for a randomized complete block design.

RESULTS

Cover Crop and Weed Biomass

Analyses indicate significant interactions for Cropping System x Rotation x Cycle, Cropping System x Cycle, and Rotation x Cycle for CC biomass, weed biomass, and total PAN of the CC Cropping Systems. Therefore, results are presented by Cropping

Figure 1. Monthly and total precipitation (mm) by crop cycle during the study period.



Total = the sum of seasonal rainfall. RS1, CD1, HD1, RS2, CD2, and HD2 indicate: rainy season year 1, cool dry season year 1, hot dry season year 1, rainy season year 2, cool dry season year 2, and hot dry season year 2, respectively.

Table 3. Effect of Cropping System on cover crop, weed, and total biomass, and potentially available nutrients for elemental nitrogen (N), phosphorus (P), and potassium (K) from total shoot biomass to Cropping Systems in Cycles RS1 and RS2.

Cycle RS1					Potentially Available Nutrients		
Cropping System	Cover Crop	Cover Crop Dry Biomass kg ha^{-1}	Weed Dry Biomass kg ha^{-1}	Total Dry Biomass kg ha^{-1}	Nitrogen kg ha^{-1}	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}
1	Weedy Fallow	*No cover crop*	4,421 a	4,421 b	71 b	14 c	151 abc
2	Sorghum Sudan	9,354 b [z]	<1 b	9,354 a	126 ab	29 ab	178 a
3	Pearl Millet	4,091 c	<1 b	4,091 b	72 b	15 ab	95 bc
4	Velvet Bean	96 d	4,727 a	4,823 b	115 ab	14 c	169 ab
5	Sunn Hemp	5,487 c	<1 b	5,487 b	97 b	12 c	70 bc
6	Sorghum Sudan + Velvet Bean	12,623 a	<1 b	12,623 a	175 a	29 ab	214 a
7	Pearl Millet + Sunn Hemp	5,038 c	<1 b	5,038 b	99 b	14 c	87 bc

[z] Least square means in columns followed by the same letter are not significantly different as determined by the DIFF option of the LSMEANS statement, $\alpha = 0.05$.

Table 3. Continued

Cycle RS2					Potentially Available Nutrients		
Cropping System	Cover Crop	Cover Crop Dry Biomass kg ha^{-1}	Weed Dry Biomass kg ha^{-1}	Total Dry Biomass kg ha^{-1}	Nitrogen kg ha^{-1}	Phosphorus kg ha^{-1}	Potassium kg ha^{-1}
1	Weedy Fallow	*No cover crop*	5,378 a	5,378 e	124	14 c	228 ab
2	Pearl Millet	9,543 b [z]	37 b	9,580b c	134	23 ab	238 a
3	Sorghum Sudan	12,195 a	6 b	12,201 a	162	24 a	237 a
4	Sunn Hemp	8,525 b	112 b	8,637 c	176	23 ab	144 b
5	Velvet Bean	195 c	5,457 a	5,652 de	160	16 bc	150 b
6	Pearl Millet + Sunn Hemp	7,862 b	2 b	7,864 cd	159	21 abc	152 ab
7	Sorghum Sudan + Velvet Bean	11,555 a	<1 b	11,555 ab	159	24 a	164 ab

[z] Least square means in columns followed by the same letter are not significantly different as determined by the DIFF option of the LSMEANS statement, $\alpha = 0.05$.

System for each CC Cycle. Cover crop biomass and combined CC and weed biomass differed between Cycle RS1 and Cycle RS2 (Table 2). Differences in CC biomass between years could have been influenced by different rainfall patterns and by total rainfall recorded during Cycles RS1 and RS2. Greater total rainfall was recorded in Cycle RS2 compared to Cycle RS1 (Figure 1).

Velvet bean had poor germination in both CC Cycles with less than 5% germination rates that resulted in failed VB establishment in all plots containing VB. In both CC Cycles, weed biomass of the WF Cropping System and of the failed VB monoculture Cropping System were not different totaling 4,421 and 4,727 kg ha^{-1} in Cycle RS1, respectively, and 5,378 and 5,457 kg ha^{-1} in Cycle RS2, respectively (Table 3). Due to the substantial quantity of weed biomass in the WF and monoculture VB Cropping Systems, these treatments were considered as a similar weedy cover crop.

Cycle RS1 Biomass and Potentially Available Nutrients

Cropping System 6 in Cycle RS1 (SS+VB) produced the greatest biomass at 12,623 kg ha^{-1} of all Cropping Systems (98.5% SS; 1.5% VB; Table 3). The legume SH in Cropping System 5, amassed 5,487 kg ha^{-1} of shoot biomass. Cropping System 1 (WF) and Cropping System 4 (VB) weed biomass totaled 4,421 and 4,727 kg ha^{-1}, respectively (Table 3). Weed biomass at this level of growth was similar to cover crop biomass production in Cropping Systems 3 (PM), 5 (SH), and 7 (PM+SH), but lower than Cropping Systems containing SS. Complete weed suppression was obtained within Cropping Systems 2, 3, 5, 6, and 7 (Table 3) due to effective CC establishment.

Potentially available nutrients (from total shoot biomass) by Cropping System for N, P, and K as influenced by CC and weed biomass is presented

Table 4. Marketable fresh produce and total fresh produce for tomato, cucumber, corn (kg ha^{-1}), and tatsoi (heads ha^{-1}).

Crop	Cycle [y]	Marketable Fresh Produce	Total Fresh Produce
Tomato	CD1	35,170	59,670
	CD2	36,931	53,454
	p	0.6857	0.2081
Tatsoi [z]	CD1	25,679	26,179
	CD2	39,554	40,036
	p	< 0.0001	< 0.0001
Cucumber	HD1	21,942	23,622
	HD2	14,234	15,115
	p	0.309	0.3129
Corn	HD1	3,563	5,638
	HD2	2,445	3,084
	p	0.2603	0.0457

[z] Mean tatsoi fresh marketable head weight is 0.33 kg.
[y] Cool dry season year 1, hot dry season year 1, cool dry season year 2, hot dry season year 2, respectively.

Table 5. Effect of Cycle on soil macronutrient concentration and soil organic matter.

Cycle [z]	Nitrate Nitrogen (mg kg^{-1})	Phosphorus P1 Weak (mg kg^{-1})	Potassium (mg kg^{-1})	Soil Organic Matter (%)
RS1	86 a [y]	19 a	107 a	4.7 b
CD1	60 b	14 b	107 a	5.6 a
HD1	37 c	13 bc	45 c	3.7 c
RS2	32 c	12 bc	74 b	3.5 cd
CD2	36 c	8 cd	62 bc	2.9 de
HD2	28 c	7 d	47 c	2.5 e
p	< 0.0001	0.002	< 0.0001	< 0.0001

[z] Rainy season year 1, cool dry season year 1, hot dry season year 1, rainy season year 2, cool dry season year 2, hot dry season year 2, respectively.

in Table 3. Potentially available nitrogen (N-PAN) was greatest in Cropping System 6 (SS+VB) at 175 kg ha^{-1} due to high SS biomass accumulation. Similarly, potentially available phosphorus (P-PAN) and potentially available potassium (K-PAN) was also high from SS in Cropping Systems 2 and 6. Dicot weeds dominated Cropping Systems 1 (WF) and 4 (VB) and were particularly efficient at scavenging N, P, and K (data not shown). Cropping System 4 resulted in a N-PAN of 115 kg ha^{-1}, which was similar to SS in Cropping Systems 2 and 6. In Cropping Systems 1 and 4, K-PAN from weed biomass contained 151 and 169 kg ha^{-1}, respectively, and did not differ from Systems 2 and 6.

Cycle RS2 Biomass and Potentially Available Nutrients

Similar to Cycle RS1, Cycle RS2 Cropping Systems with SS generated more CC biomass than all other Cropping Systems. Weed biomass in all CC Cropping Systems (2, 3, 4, 6, and 7) where cover crops fully established had comparably low to no measurable weed biomass present (Table 3). This was in stark contrast to Cropping System 1 (WF) and 5 (VB) that produced 5,378 and 5,457 kg ha^{-1} (respectively) of total weed biomass. Overall, cover crops and weeds contributed to a return of N-PAN, P-PAN, and K-PAN to each cropping system (Table 3).

Vegetable Crop Yield

For all vegetable yields, no interactions were present between Cropping System and Cycle and no significant differences were detected in response to Cropping System treatment. However, yields were significantly different between Cycles CD1 and CD2 for marketable and total tatsoi yields (Table 4). Cycle CD1 yielded 36,931 kg ha^{-1} marketable tomato fruit and was comparable to marketable tomato yields of 35,170 kg ha^{-1} in Cycle CD2 (Table 4). Marketable corn yield was not different between Cycle HD1 and HD2. Marketable cucumber yield in Cycle HD1 measured 21,942 kg ha^{-1} and was similar to Cycle HD2 with 14,234 kg ha^{-1} (Table 4).

Macronutrients

No significant interactions were detected for soil macronutrient analysis when the full statistical model was fit. Cycle had a significant effect on NO_3-N, P, and K (Table 5). Soil NO_3-N concentration at the start of the experiment measured 86 mg kg^{-1} at CC termination in Cycle RS1. Post vegetable crop production in Cycle CD1, NO_3-N significantly decreased to 60 mg kg^{-1} and then significantly decreased again to 38 mg kg^{-1} at the end of vegetable production in Cycle HD1. Cycle RS2, CD2, and HD2 NO_3-N levels were 32, 36, and 28 mg kg^{-1}, respectively, and did not differ statistically from NO_3-N in Cycle HD1. Overall, NO_3-N levels decreased by 68% over the six-cycle study (Table 5).

The labile soil P fraction was greatest in Cycle RS1 and significantly greater than P levels of all other subsequent Cycles at 19 mg kg^{-1} (Table 5). Soil P decreased over the course of the two-year study. In Cycle CD1, P was 14 mg kg^{-1}, was similar to Cycles HD1 and RS2 at 13 and 12 mg kg^{-1}, respectively and at the end of Cycle HD6 were 7 mg kg^{-1}. Plant available soil P decreased by 62% from Cycle RS1 to Cycle HD2.

Potassium levels differed by Cycle (Table 5). The greatest decrease in K levels occurred between Cycles CD1 and HD1 where K decreased from 107 mg kg^{-1} to 45 mg kg^{-1}. At the end of the final vegetable crop cycle (HD2), soil K measured 47 mg kg^{-1} and represented a 56% decline in soil K from the start of the experiment.

Soil Organic Matter

Soil organic matter was not influenced by either Cropping System or Rotation main effects and no interactions were detected in the full model analysis. However, Cycle did significantly influence SOM levels, and changes in SOM occurred throughout the duration of the study in response to Cycle. At the onset of the study, SOM was 4.7% (RS1) prior to the incorporation of the CC (Table 5). After vegetable crop production in the cool dry season, SOM increased to 5.6%, and was greater than SOM in all other Cycles. Subsequently, SOM declined in Cycles HD1, RS2, CD2, and HD2 with respective levels of 3.7%, 3.5%, 2.9%, and 2.5%. Overall, experiment-wide SOM declined by 55% in less than two years of continuous cropping.

DISCUSSION

This study provided a unique opportunity to monitor the conversion of a highly fertile, lightly wooded permanent grassland to vegetable crop production using intensive organic crop management practices. Changes in land use and agricultural intensification affected aspects of the agroecosystem across all Cropping System treatments with notable changes in soil fertility occurring over time across Cycles irrespective of CC inputs or differences in vegetable crop yields. Drinkwater and Snapp (2007) detail the fundamental concept of how historic agricultural intensification can positively increase agroecosystem productivity at the unintended expense of negative environmental consequences that include soil and water degradation and the transformation of biogeochemical cycles. Individual treatment effects of Cropping System and Crop Rotation had no significant effect on soil NO_3-N, P, K, and organic matter. Substantial quantities of CC biomass were generated and incorporated into the soil strata with dry matter levels peaking at 12,623 kg ha^{-1} and potential nutrient contribution from the CC dry matter reaching 176 kg ha^{-1} of NO_3-N, 29 kg ha^{-1} of P, and 238 kg ha^{-1} of K. However, it appears that CC biomass returning large quantities of PAN to the cropping systems did not improve nor maintain soil NO_3-N, P, K, or organic matter levels measured at the beginning of this study. The results suggest that the change in land use, cultural farm management practices, and agricultural intensification (system-wide increased soil tillage and vegetable crop removal) was the driving force of total farm system changes in soil quality observed over the continuous two-year cropping systems study.

Agricultural intensification cannot be linked to one single management practice, but to the cumulative farming practices of the entire agroecosystem. When simplified, this includes the physical inputs for crop production (water, seed, fertilizer, etc.); the associated management practices used to produce the outputs (e.g. soil tillage and pest control); and the resulting output of vegetable crops removed from the agroecosystem. Agricultural intensification through land use conversion by clearing native savannah and forest in Brazil for commercial grain and soybean, utilizing conventional full tillage, has resulted in the loss of up to 30% to 50% of the initial soil organic matter (Resck et al. 2000). The resulting soil degradation from these production practices results in the rapid decline of crop yields over time despite the implementation of crop rotations and the increased use of chemical inputs (Séguy et al. 1996; Scopel et al. 2013). To mitigate the negative effects of agricultural intensification, Scopel et al. (2013) recommends the implementation of conservation agricultural principles, particularly in tropical zones where CC residues decompose rapidly.

CONCLUSION

It is theorized that the driving force behind the rapid mineral nutrient and SOM declines is the combined effect of tropical environmental conditions coupled with the intensive full tillage soil disturbance practices utilized for crop residue incorporation at the end of each cycle and seed-bed preparation prior to each crop cycle. A possible solution to help reduce soil quality decline could be to change farm management practices by moving away from conventional full tillage practices and adopting conservation tillage practices (Scopel et al. 2013). The application of an additional organic soil amendment could provide improved soil fertility and potentially compensate for declining soil nutrient pools and SOM loss when combined with the use of CC rotations and conservation tillage practices. It can be concluded that the use of CC as the primary cropping system input in diversified crop rotations did not maintain soil NO_3-N, P, K, and organic matter at the level initially observed in this study and that intensive organic tropical cropping system sustainability is influenced by cultural cropping system management practices.

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Detail, Caledonia Valley experimental farm site.

Evaluating the Impact of Breed, Pregnancy and Hair Coat on Body Temperature and Sweating Rate of Hair Sheep Ewes in the Tropics

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The sweating rate monitor (aka Bovine Evapometer) being used over the shaved area of a Dorper x St. Croix White ewe.

SUMMARY

The objective of this study was to evaluate the effect of pregnancy and breed on body temperature and sweating rate of hair sheep. St. Croix White (STX; n = 9) and Dorper x STX (DRPX; n = 9) ewes (3.6 y of age) were evaluated at 126 d of gestation and at 46 d postpartum. Data loggers recorded vaginal temperature (VT) at 10-min intervals for 96 h. Rectal temperature (RT) was measured using a digital veterinary thermometer and respiration rate (RR) was measured as breaths per minute (bpm). Sweating rate (SR) was calculated from measured air properties passing over a shaved (300 cm^2) and unshaved area of the ewes' body using a portable calorimeter. Ewes were evaluated over 4 d, during gestation and postpartum, in the shade and sun and in the morning (AM; 0900 to 1200 h) and afternoon (PM; 1300 to 1600 h) after a 20 min acclimation to each condition on each day. Data were analyzed using GLM procedures of SAS with breed, pregnancy status, sun exposure and time of day as main effects. Mean temperature, relative humidity, temperature-humidity index, wind speed and solar radiation on the days of data collection were 28.2 °C, 82.8 %, 80.3, 4.2 km/h and 237.5 W/m^2, respectively. There was no difference ($P > 0.10$)) in RT, RR and SR between DRPX and STX ewes. Pregnant ewes had lower RT ($P < 0.007$) and SR ($P < 0.0001$) and higher RR ($P <$

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0.007) than open ewes. During the PM RR, RT (P < 0.05) and SR P < 0.006) were higher than in the AM. In the sun RR P < 0.001) and SR (P < 0.0001) were higher than in the shade, but there was no difference (P > 0.10)) in RT. There was no difference in SR (P > 0.10) between the shaved and unshaved area of the ewe. The DRPX ewes had higher (P < 0.0001) VT than STX ewes. Pregnant ewes had higher (P < 0.001) VT than open ewes during the night time and lower VT during the daytime than open ewes (P < 0.0001). Pregnant ewes had a smaller range of VT over time than open ewes did (P < 0.009) but there was no breed difference (P > 0.10). The elevated RR of pregnant ewes may have contributed to the lower RT when compared to open ewes. Pregnant ewes had a more even body temperature throughout the day which may be a protective mechanism for the developing fetus. The body temperature and sweating rates of the two breed types indicates that they are both adapted to the tropical climate.

INTRODUCTION

Heat stress is a common problem in ruminant production throughout the tropics. St. Croix White hair sheep are well adapted to the hot, humid climate found in the U.S. Virgin Islands but other breeds of sheep such as the Dorper, which was initially selected for arid areas (Baker et al., 1999), may not be as suited to the humid tropics.

Body temperature and respiration rate are indicators of excessive heat load in animals. When sheep were housed at either 24 ºC or 36 ºC there was an increase in rectal temperature of 0.8 ºC with a concomitant increase in respiration rate from 76.2 bpm to 156 bpm as well (Llamas-Llamas and Combs, 1990). Respiration rate increases during periods of heat stress to enhance cooling by evaporative cooling from the membranes of the oral cavity and increased air movement through the respiratory system which dissipates heat as well. Mader et al. (2002) reported that bunching occurs when cattle are heat stressed and can lead to decreased air flow around the animals which increases the heat load. Respiration rate increases during periods of heat stress to enhance cooling by evaporative cooling from the membranes of the oral cavity and increased air movement through the respiratory system which dissipates heat as well.

Even when parameters such as rectal temperature and respiration rate are used as measures of the impact of elevated environmental temperature on animal well-being, our knowledge of what occurs at the skin surface, under the hair coat, remains incomplete. Because livestock (cattle and sheep) in the tropics tend to have short hair coats, skin surface thermal properties may play a more important role. Assessing sweating rate of tropically adapted breeds of sheep can lead to the development of more efficient strategies to employ in tropical environments to alleviate heat stress. The objective of this study was to compare body temperature and sweating rate between pregnant and non-pregnant St. Croix White and Dorper x St. Croix White hair sheep ewes in a tropical environment.

MATERIALS AND METHODS

St. Croix White (STX; n = 9) and Dorper x STX (DRPX; n = 9) ewes (3.6 y of age) were evaluated at 126 d of gestation (pregnant; June) and again at 46 d postpartum (open; August). Ewes were evaluated over 4 d, during gestation and postpartum, in the shade (SHADE) or sun (SUN) and in the morning (AM; 0900 to 1200 h) or afternoon (PM; 1300 to 1600 h). Over the 4-d period each ewe was evaluated in the sun or shade and in the AM or PM. On the first day of each 4-d evaluation period temperature data loggers (Stowaway Tidbit, Onset Computer Corp, Bourne, MA USA) were placed in the vagina of each ewe to record vaginal temperature (VT) at 10-min intervals for 96 h.

On each day of evaluation, ewes were allowed to acclimate in the shade or sun for 20 min prior to collecting any measurements in the AM and PM. Ewes were placed on a shearing stand to immobilize them for RT and RR collection in the sun or shade. Rectal temperature (RT) was measured using a digital veterinary thermometer (GLA M700, GLA Agricultural Electronics, San Luis Obispo, CA;

Shaved area on a St. Croix White ewe where the sweating rate was measured.

accuracy ± 0.1°C) and respiration rate (RR) was measured by holding a hand in front of the muzzle and counting breaths for 15 s and adjusting to breaths per minute (bpm).

On the first day of evaluation each ewe had an area (300 cm^2) shaved over the left flank using an electric clipper and a #40 blade (SHAVED). Sweating rate (SR) was measured over the SHAVED and a corresponding unshaved area on the right flank (UNSHAVED) using a Bovine Evaporation Meter (BEM; Gebremedhin et al., 2009) that measured air properties passing over the areas of the ewes' body. The equipment consists of a portable calorimeter that has been modified to directly and accurately measure evaporation (= sweating) rate from the sample area. The BEM allows measurement of sweating rate ($g \cdot m^2 \cdot h^{-1}$) from 76 x 102 mm area of body surface. Air velocity over the sample area was set at 1.0 m/s. A transparent film above the sample area allows unimpeded exposure to solar radiation.

Ambient conditions during each data collection period were monitored using a weather station located at the UVI Sheep Research Facility (Vantage Pro2, Davis Instruments Corp., Hayward, California, USA). The station measured temperature, relative humidity, wind speed and solar radiation (average and maximum). Temperature-humidity index (THI) was calculated using the formula THI = (0.8 x T) + ((RH/100) x (T - 14.4)) + 46.4, where T = temperature, °C and RH = relative humidity (NOAA, 1976). The environmental conditions during each period and time of day within each period are shown in Table 1.

Rectal temperature, RR and SR were analyzed using GLM procedures of SAS with breed (STX and DRPX), pregnancy status (pregnant and open), time of day (AM and PM) and location (sun and shade) as main effects. Mean separation was conducted using the PDIFF option. There were no significant interactions among breed, pregnancy status, time of day, location and hair coat for RR, RT and SR so only means for main effects are reported. Serial vaginal temperature samples were analyzed using repeated measures with breed, pregnancy status, time of day and the appropriate interactions in the model. The magnitude of change in VT during a day (0000 h to 2400 h) was calculated as the difference between the highest and the lowest VT within each day. Breed, day and pregnancy status were used in the model to analyze magnitude of change in VT over the 4-d sampling period. All results are presented as least square means ± SEM.

RESULTS

There was no difference (P > 0.10) in RT, RR or SR between STX and DRPX ewes (Table 2).

Table 1. Environmental conditions during data collection.

Pregnant (June)	Mean[a]	Range[a]	AM[b]	PM[b]
Temperature, °C	27.9	25 - 31	29.5	29.7
Relative Humidity, %	83.5	67 - 93	78.2	77.1
Temperature Humidity Index	79.9	76 - 84	81.8	81.9
Wind speed, km/h	4.4	0 - 11	6.5	6.3
Average solar radiation, W/m^2	198.1	0 - 1080	496.7	456.6
Maximum solar radiation, W/m^2	237.6	0 - 1136	607.8	535.1
Non-pregnant (August)				
Temperature, °C	28.5	25 - 32	30.6	31.5
Relative Humidity, %	82.1	67 - 95	75.5	72.5
Temperature Humidity Index	80.6	76 - 85	83.1	83.9
Wind speed, km/h	3.9	0 - 13	6.7	8.7
Solar radiation, W/m^2	273.9	0 – 1104	671.8	826.6
Maximum solar radiation, W/m^2	315.6	0 - 1176	800.6	908.7

[a] Mean and range of values for the entire 4-d measurement period within each time period (pregnant and non-pregnant)
[b] Mean values on each day of measurement between 0900 and 1200 h (AM) and 1210 to 1600 h (PM)

Table 2. Rectal temperature, respiration rate and sweating rate of St. Croix White and Dorper x St. Croix White ewes by breed, pregnancy status, time of day and location.[a]

	Rectal temperature, ^0C	Respiration rate, bpm	Sweating rate, $g•m^{-2}•h^{-1}$
St. Croix White	38.7 ± 0.2	72.8 ± 2.2	81.1 ± 3.1
Dorper x St. Croix White	38.9 ± 0.2	77.6 ± 2.2	77.5 ± 3.1
Pregnant	38.5 ± 0.2[b]	79.5 ± 2.2[b]	70.2 ± 3.1[d]
Postpartum	39.1 ± 0.2[c]	72.1 ± 2.2[c]	88.3 ± 3.1[e]
AM	38.3 ± 0.2[f]	72.1 ± 2.2[f]	73.1 ± 3.1[h]
PM	39.2 ± 0.2[g]	78.3 ± 2.2[g]	85.5 ± 3.1[i]
Sun	38.6 ± 0.2	88.1 ± 2.2[d]	91.2 ± 3.1[d]
Shade	38.9 ± 0.2	62.3 ± 2.2[e]	67.3 ± 3.1[e]

[a] Ewes were evaluated at 126 d of gestation (June) and again at 46 d postpartum (August) in the morning (AM; 0900 to 1200 h) or afternoon (PM; 1300 to 1600 h) and in the sun or shade after 20 min acclimation period.
[b,c] Means within a column and section with different superscripts are different ($P < 0.0007$).
[d,e] Means within a column and section with different superscripts are different ($P < 0.0001$).
[f,g] Means within a column and section with different superscripts are different ($P < 0.05$).
[h,i] Means within a column and section with different superscripts are different ($P < 0.006$).

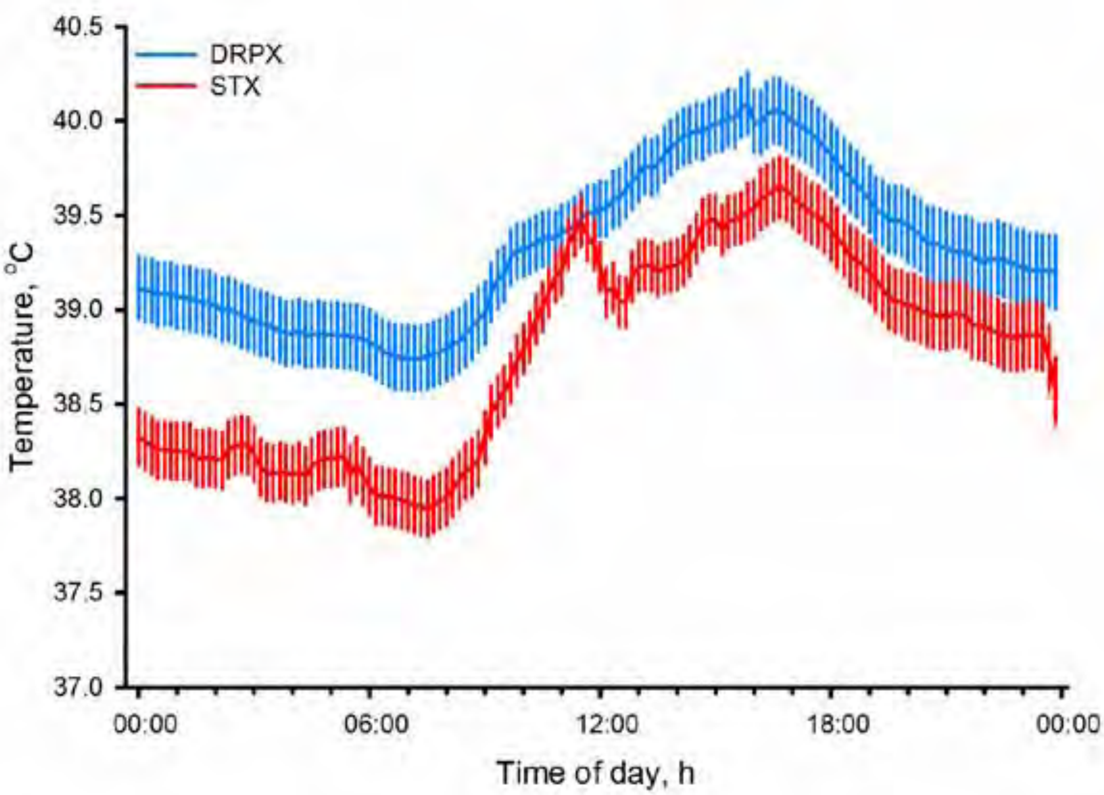

Figure 1. Daily profile of vaginal temperature of St. Croix White (STX) and Dorper x St. Croix White (DRPX) ewes averaged over a 96-h period. The vaginal temperature of DRPX ewes was higher than that of STX ewes (P < 0.0001).

Pregnant ewes had lower RT ($P < 0.0007$), higher RR ($P < 0.0007$) and lower SR ($P < 0.0001$) than open ewes. In the morning RT, RR ($P < 0.05$) and SR ($P < 0.006$) were lower than in the afternoon. There was no difference ($P > 0.10$) in RT between ewes evaluated in the sun and shade, but RR and SR were higher in the sun than in the shade ($P < 0.0001$). There was no difference ($P > 0.10$) in SR measured over the shaved or unshaved areas on the ewes (80.1 ± 3.1 vs. 78.4 ± 3.1 $g•m^{-2}•h^{-1}$, respectively).

Vaginal temperature was higher ($P < 0.0001$) in DRPX ewes compared to STX ewes (Figure 1). Pregnant ewes had higher ($P < 0.0001$) VT than open ewes from midnight to 1030 h (Figure 2). Between 1030 h and 1820 h VT was lower in pregnant ewes ($P < 0.0001$), except for a temporary dip in VT of open ewes between 1220 and 1250 h. From 1820 to 2400 h there was no difference ($P > 0.10$) in VT between pregnant and open ewes (Figure 2).

Open STX ewes had the lowest VT from midnight to 1010 h and open DRPX ewes had the highest VT from 1210 h to 1820 h ($P < 0.001$, Figure 3). Open ewes had a greater ($P < 0.009$) magnitude of change in VT during the day than pregnant ewes (2.5 ± 0.4 vs. 1.1 ± 0.4 °C, respectively) but there was no difference ($P > 0.10$) between STX and DRPX ewes and the breed x pregnancy status interaction was not significant ($P > 0.10$).

DISCUSSION

The higher body temperature of DRPX ewes compared to STX ewes, measured as VT in this study, is in agreement with previous work in our lab where we reported that DRPX ewes had higher VT than STX ewes (Godfrey et al., 2013). Because the Dorper breed was developed in a hot, arid climate (Baker et al., 1999) it may not have the tolerance for the hot, humid climate of the Caribbean that the St. Croix White breed does.

The pregnant ewes had higher RR than the open ewes and this may have contributed to their ability to maintain a lower RT. This is not apparent when comparing ewes evaluated in the morning and afternoon. The ewes evaluated in the afternoon had greater RR but also had higher RT indicating that they were not able to use respiration to regulate body temperature. Both sheep and cattle have been shown to increase RR in response to elevated ambient temperatures as a method to keep core body temperature from rising (Llamas-Llamas and Combs, 1990; Mader et al., 2002). The environmental conditions at each time of day may have played a role in the changes in RT and RR even though temperature was less than 1 °C higher in the PM than

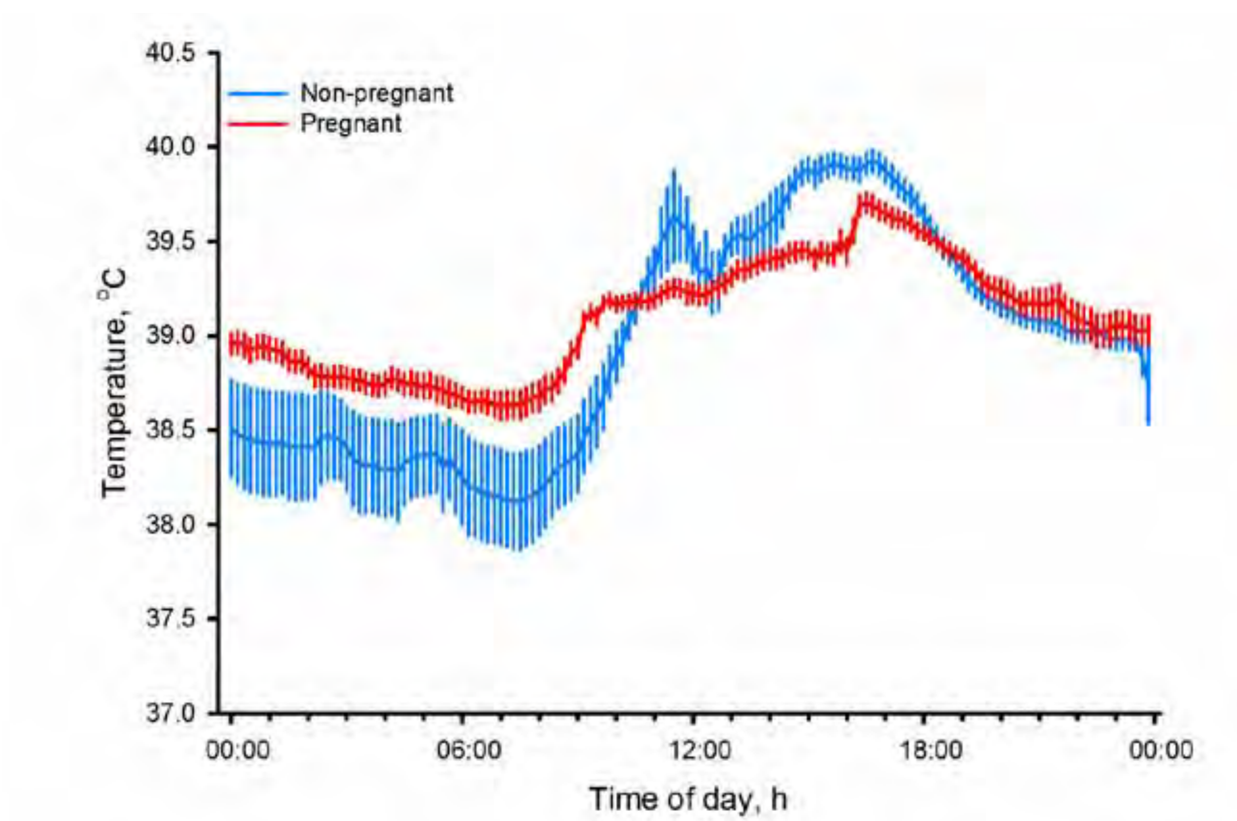

Figure 2. Daily profile of vaginal temperature of pregnant and non-pregnant ewes averaged over a 96-h period. The time of day x pregnancy status interaction was significant ($P < 0.0001$).

in the AM across both time periods (Table 1). Even THI was less than one unit higher in the PM than in the AM. The elevated RT during the afternoon does agree with the VT profiles shown in Figures 1 and 2 and our previous work (Godfrey et al., 2013) where the VT begins increasing by 0900 h each day regardless of breed or pregnancy status.

The lower SR of pregnant ewes compared to open ewes seems to indicate that RR may be more important for regulating body temperature than SR in sheep, even though SR increased in the afternoon. Collier et al. (2009) reported that evaporative heat loss is the primary route of heat dissipation for cattle exposed to thermal environments above their thermoneutral zone. Cattle are panting animals and do lose some latent heat by this route but skin surface evaporation of sweat is the primary means of latent heat loss during heat stress (Collier and Beede, 1985). This may be different in sheep, especially in wool breeds, where the fleece provides significant boundary layer between the skin and the ambient air.

Hair coat of animals plays a critical role in heat and moisture transfer from the skin surface (Jiang et al., 2005, Gebremedhin et al., 1984). The hair coat, which traps air to provide insulation in cold weather, becomes an obstruction for evaporative cooling by reducing the velocity and moisture gradient through the fur layer in hot and humid conditions. The hair sheep breed used in the present study did not have any difference in SR between the shaved and unshaved areas indicating that the short hair coat found on these animals may not play a significant role in limiting or enhancing evaporative heat loss.

In support of the need for thermal control during pregnancy, studies in dairy cattle have shown that heat stress can reduce fertility and embryonic survival (Dunlap and Vincent, 1971; Putney et al., 1988a; Ealy et al., 1993). In cattle the deleterious effects of maternal heat stress decline as pregnancy proceeds (Ealy et al., 1993) which may reflect acquisition of thermal resistance by the embryo as it progresses to blastocyst stage (Edwards and Hansen, 1997). The lower RT and change in VT, and higher RR, of the pregnant ewes may be part of a mechanism to help protect the developing fetus from elevated temperatures during the final trimester of pregnancy, even though the fetus is fairly well developed at this point. The lower magnitude of change in VT in pregnant ewes is in contrast to this preliminary results from our laboratory (Godfrey et al., 2012a) showing that there was no difference in magnitude of change in VT between pregnant and open Senepol cattle (1.20 ± 0.08 vs. 1.22 ± 0.08 °C, respectively).

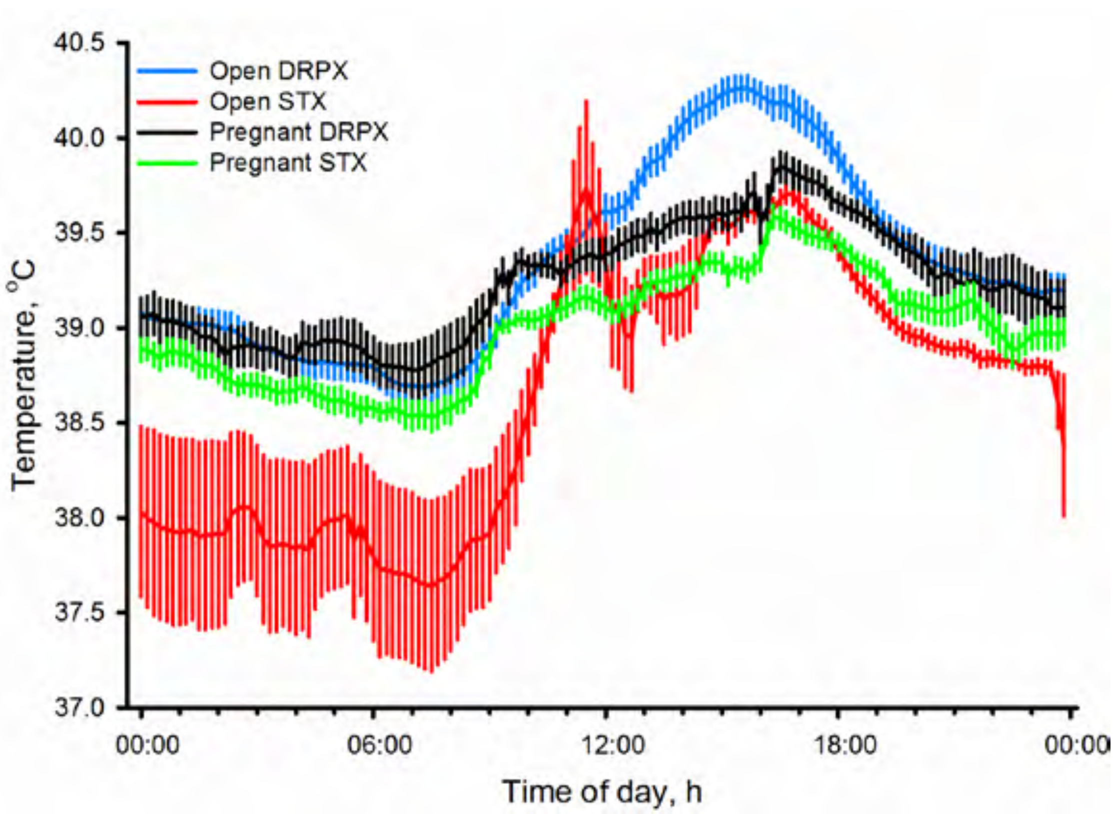

Figure 3. Daily profile of vaginal temperature of pregnant and non-pregnant St. Croix White (STX) and Dorper x St. Croix White (DRPX) ewes pooled over a 96-h period. Both breed and pregnancy status were significant (P < 0.001).

IMPLICATIONS

The elevated RR of pregnant ewes may have contributed to the lower RT but did not decrease VT when compared to open ewes. Pregnant ewes had a more even body temperature throughout the day. This may be a protective mechanism to keep the developing fetus from being exposed to large temperature swings during gestation. Further work needs to be done to evaluate ewe body temperature at earlier stages of gestation.

ACKNOWLEDGEMENTS

Supported by USDA-NIFA Special Research Projects TSTAR Grant # 2008-34135-19505.

Undergraduate students Serena Joseph and Lucas LaPlace were supported by USDA-NIFA grant Award No. 2012-38416-19977. This project was a contribution to the USDA-NIFA Multistate Project W-2173 (Impacts of Stress Factors on Performance, Health, and Well-Being of Farm Animals).

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Valuation of Vegetable Crops Produced in the UVI Commercial Aquaponic System

By Donald Bailey and Rhuanito Soranz Ferrarezi

Basil (*Ocimum basilicum*) is one of the vegetable crops grown in the UVI-AES Commercial Aquaponic System.

SUMMARY

The UVI Commercial Aquaponic System is designed to produce fish and vegetables in a recirculating aquaculture system. The integration of these systems intensifies production in a small land area, conserves water, reduces waste discharged into the environment, and recovers nutrients from fish production into valuable vegetable crops. A standard protocol has been developed for the production of tilapia which yields 5 MT per annum. The production of many vegetable crops has also been studied but, because of specific growth patterns and differences of marketable product, no single protocol can be promoted. Each crop yields different value per unit area and this must be considered when selecting varieties to produce to provide the highest returns to the farmer. Variables impacting the value of a crop are density (plants/m2), yield (unit or kg), production period (weeks) and unit value ($). Combining these variables to one unit, $/m2/week, provides a common point for comparison among crops. Farmers can focus production efforts on the most valuable crops or continue to produce a variety of crops meeting market demand with the knowledge that each does not contribute equally to profitability.

INTRODUCTION

Aquaponics is a food production technology that combines aquaculture and hydroponics in an integrated system. The integration is symbiotic in that processes in each component add advantages to the other. Fish, which are daily fed a protein-rich diet, generate waste which flows to the hydroponic component. The hydroponic component has an environment suitable for bacteria to convert the waste into compounds required for plant growth. The primary waste product of fish metabolism is ammonia which is excreted by the fish and dissolved in the water. Nitrifying bacteria convert the ammonia to nitrite and then nitrate, which the vegetable crops use for growth. Solid fish waste, eliminated after digestion, contains many of the other macro- and micro-nutrients required by the plants. The hydroponic component serves the purpose of providing an area for nitrification and uptake of nutrients by the plants. This improves water quality for the returning water to the fish component. The integration of the aquaculture and hydroponic components reduces water discharge into the environment.

Aquaponic farmers can produce a great variety of vegetable crops in their systems to meet customer needs and preferences. The UVI Commercial Aquaponic System has been in operation since 1993. Design modifications happened in 1999 and 2003 to improve the system performance. The system has been used to determine the best crops and varieties that could be grown commercially. Lettuce (*Lactuca sativa*) was continuously produced in the system for three years, growing a number of types and different cultural conditions (Rakocy et al., 1997). Basil (*Ocimum basilicum*) was produced using batch and staggered cropping systems (Rakocy et al., 2004b). Several okra (*Abelmoschus esculentuswas*) varieties were produced over a 3-month period in batch culture (Rakocy et al., 2004a). Economic studies of lettuce and basil production have also been made (Bailey et al., 1997; Rakocy et al., 2004b). In general, leafy vegetables grow well with the abundant nitrogen in the system, have a short production period, and are in high demand. Fruiting crops have longer production periods and produce less marketable yield but their value is often higher than the value of leafy produce.

Existing economic analysis of commercial aquaponic farms is limited. Several studies develop hypothetical farms based on research data. Chaves (1999) incorporated hydroponic tomato (*Solanum lycopersicum*) production in an aquaponic system. Bailey (1997) analyzed three farm sizes growing lettuce. These studies evaluated farm profitability by considering all farm revenues and subtracting all variable and fixed costs to determine a return. There is a growing number of case studies using farm data, including the University of Hawai'i (Tokunaga, 2013) and University of Kentucky (Heidemann, 2015a; 2015b). These studies use standard accounting techniques, the Modified Internal Rate of Return (MIRR) and Cost of Goods Sold (COGS), to analyze farm profitability. The Hawai'i case studies included two farms growing only lettuce and one farm with mixed produce. The University of Kentucky studies do not mention the product grown.

A method of valuing each crop for comparison was used to quantify the contribution to revenues that each crop can make to the enterprise. This paper provides a method to evaluate different plant production procedures which vary by plant spacing, yield, and time to harvest.

MATERIALS AND METHODS

The UVI Commercial Aquaponics System used consisted of three main components: fish rearing, solids removal and hydroponic vegetable production troughs (Table 1) (Rakocy et al., 2004a). The hydroponic troughs were 30 × 1.2 × 0.3 m with a volume of 11.3 m^3 and a surface area of 214 m^2 for vegetable production. The flow rate of water through the troughs is 125 L/min for a retention time of 3 hours. Fish waste products were the source of nutrients for plant growth. The fish (tilapia, *Oreochromis niloticus*) were fed three times daily *ad libitum* for 30 minutes with a complete, floating pelleted diet with 32% protein (PMI Aquamax, Gray Summit, MO). The system pH was maintained around 7.0 with the addition of either calcium hydroxide or potassium hydroxide on alternating days. Chelated iron (11% FeDTPA; BR Global LLC, Rocky Mount, NC) was added every three weeks with a quantity equal to 2 mg L^{-1} Fe. Total dissolved solids

Table 1. UVI Commercial Aquaponic system components, area and volume summary (Rakocy et al., 2004a).

System tanks	Quantity	Volume (m^3)
Fish rearing tanks	4	7.8
Cylindro-conical clarifiers	2	3.8
Filter tanks	4	0.7
Degassing tank	1	0.7
Hydroponic tanks	6	11.3
Sump	1	0.6
Base addition tank	1	0.2
Total plant growing area	214 m^2	
Total water volume	110 m^3	
Land area	0.05 ha	

ranged 62-779 mg L^{-1}.

Vegetable crops were grown on Styrofoam rafts floating on the surface of the hydroponic troughs. The rafts are 2.4 × 1.2 × 3.9 cm, an area of 2.97 m^2. Rafts were prepared for planting by painting with white non-toxic roof paint (Cool-Cote 22-DW-9, BLP Mobile Paints, Mobile, AL) and drilled with holes 4.8 cm diameter. Holes in the rafts were drilled at different spacing for the various plant requirements. Planting density ranged from 0.67 to 30 plants per meter square depending on the crop and mature plant size (Table 2). Net pots, 5 × 5 cm, were inserted into each hole to hold the rooted seedling.

Seedlings were produced in an open-ended, covered greenhouse. Seedling flats, 25.4 × 50.8 cm with 98 cells, 2.54 × 2.54 × 2.54 cm, were filled with ProMix® potting mix (Premier Tech Horticulture, Riviere-du-loupe, Quebec, Canada), a mixture of 79-87% peat moss, 10-14% perlite and 3-7% vermiculite. Depending on the seeds' requirement, they were surface-seeded with a vacuum seeder (Seed E-Z Seeder, Inc. Baraboo, WI) or manually drill-seeded into 1.5 cm deep holes made in the ProMix® media. The seedling flats were watered to begin the germination process and then covered for 2-3 days until cotyledons emerged. The flats were then uncovered and the seedlings allowed to develop over a 2- to 3-week period. The seedlings were watered twice daily and fertilized once weekly with Peters Professional Plant Starter 4-45-15 (Everris International B.V., Waardenburg, The Netherlands).

Seedlings were ready to transplant when 1-2 sets of true leaves had developed and the roots had grown to encircle the media. They were transplanted into clean rafts in the aquaponic system. Pest management required spraying once weekly with *Bacillus thuringiensis* subsp. kurstaki strain ABTS-351, fermentation solids, spores, and insecticidal toxins (Dipel® DF; Valent Biosciences, Libertyville, IL) on all crops to control caterpillars and with potassium salts of fatty acids (M-Pede®; Dow AgroSciences, Indianapolis, IN) insecticidal soap to control aphids and white fly on crops susceptible to infestations of those pests. Plants grew in the system for the required period to come to maturity.

Okra was planted for one trial in fall 2002 (Rakocy, 2004a). Three varieties were planted at two densities. The varieties were 'Annie Oakley', 'North-South' and 'Clemson Spineless'. The two densities were 2.8 and 4.0 plants/m2. Two-week old seedlings were transplanted on Oct 1, 2002 and the first harvest was made 33 days later. Pods were harvested three times each week for 49 days for a total of 22 harvests. The most productive variety and density was 'North-South' planted at 4.0 plants/m2 which yielded 3.04 kg/m2 over the harvest period.

Basil 'Genovese' was produced in staggered production for a 12-week trial. Transplants were placed in one-quarter of the system for 4 weeks. After 28 days the first crop was harvested by the "cut and

Table 2. Crops grown in UVI Commercial Aquaponic System, planting density, product harvested, number of harvests and weeks to maturity (post-transplant) (Rakocy et al., 1997).

Crop	Variety	Type	Density (plants/m^2)	Product	Number of harvests	Weeks in cultivation
Lettuce	Parris Island	Romaine	16	Head	112	4
	Sierra	Leaf	20	Head	112	4
	Boston	Bibb	30	Head	12	3
Chinese cabbage	New Nabai	Pak choi	30	Leaf	5	3
Kale	Black Magic		30	Leaf	6	3
Collards	Vates		30	Leaf	5	3
Swiss chard	Discovery		30	Leaf		3
Basil	Genovese	Sweet basil	16	Leaf and stem	8	4
Sorrel	TTB		4	Fruit – calyx	1	14
Cantaloupe	Jaipur		0.67	Fruit	1	13
Cucumber	Calypso	Pickling	8	Fruit	5	6
Okra	North South		4	Fruit	22	7
Summer squash	Profit	Green zucchini	2.7	Fruit	5	9

come again" method which allows for regrowth of the 15 cm of plant remaining after harvest. Each planting was harvested twice for a total of eight harvests. Yield was 1.2 kg/m^2 in the first harvest and 2.4 kg/m^2 in the second.

Plants yield different mass quantities depending on the part of the plant harvested: whole plant, leaves, or fruit. Lettuce and pak choi (*Brassica rapa* subsp. chinensis) were harvested by removing the plant and cutting the roots from the stem. The plant is trimmed of old, discolored or insect-damaged leaves, then packaged for market. Other leafy plants were harvested by the "cut and come again" method which leaves 15 cm of plant stem to regrow or removes mature leaves and retains the young leaves to continued growth. Kale (*Brassica oleracea*), collards (*Brassica oleracea*), Swiss chard (*Beta vulgaris*), and basil were harvested by this method. Okra, cucumber (*Cucumis sativus*), and zucchini (*Cucurbita pepo* var. cylindrica) yield fruits that are harvested frequently during production. Melon (*Cucumis melo*) and sorrel (*Hibiscus sabdariffa*) yield fruits to harvest at the end of a long growing period. Crops were harvested at maturity (Figure 1).

Fresh fruits and vegetables are shipped in commonly used containers designated by volume or product count and expected weight of the container (Table 3) (US Dept. of Agriculture [USDA] Agriculture Marketing Service [AMS], 2015). Typical shipping containers include carton, ½ carton, carton with 24 units, 35.2 L (1 bushel) basket, 17.6 L (1/2 bushel) carton and 38.8 L (1-1/9 bushel) carton. Produce prices were obtained from USDA AMS (2016). Weekly prices were obtained from the Miami Terminal Custom Report for the period May 1, 2015 – April 30, 2016

Figure 1. Crops harvested at the UVI Commercial Aquaponic System: romaine lettuce (A), leaf lettuce (B), okra (C), cucumber (D), squash (E), sorrel (F), cantaloupe (G), basil (H), and pak choi (I).

Table 3. USDA Miami Terminal package size, weight, low and high price and unit value for crops evaluated in the UVI Commercial Aquaponics System. (USDA AMS, 2015)

Variety	Package Size	USDA package weight	Price		Unit value ($)
			Low ($)	High ($)	
Lettuce Romaine	Cartons 24's[1]	18.1 kg (40 lb)/carton 24's	21	24	0.87-0.92/ea.[2]
Lettuce Green leaf	Cartons 24's	9.1 kg (20 lb)/carton 24's	18	20	0.75-0.83/ea.
Lettuce Boston	Cartons 24's	9.1 kg (20 lb)/carton 24's	18	22	0.75-0.92/ea.
Pak Choi	Carton	13.6 kg (30 lb)/carton	20	22	1.47-1.62/kg
Kale	Cartons bunches 24's	11.3 kg (25 lb)/bushel	13	14	0.54-0.58/bunch 1.15-1.24/kg
Collards	Cartons bunched 24's	11.3 kg (25 lb)/bushel	18	16	0.66-0.75/bunch 1.42-1.59/kg
Swiss Chard	Cartons bunched 12's	11.3 kg (25 lb)/bushel	24	28	2.00-2.33/bunch 2.12-2.47/kg
Basil	1-lb film bag	0.453 kg (1 lb)/bag	4	5	4.00-5.00/bag 8.80-11.03/kg
Cantaloupe	½ carton 9's	18.1 kg (40 lb)/ ½ carton	12.5	14	1.39-1.55/ea. 0.69-0.77/kg
Pickling Cucumber	1 1/9 bushel box	24.9 kg (55 lb)/39.1 L	30	32	1.20-1.28/kg
Okra	1/2 bushel	6.8 kg (15 lb)/17.6 L	14	12	$1.76-2.05/kg
Zucchini	1/2 bushel	9.5 kg (21 lb)/ 17.6 L	7	10	0.73-1.05/kg

[1] Cartons with 24 units. [2] ea. = each.

Table 4. Expected value of three lettuce types produced at different densities and growth periods. The value can change over time, and should be carefully evaluated before been used as an investment reference.

Type ('Variety')	Density (plants/ m^2)	Weeks in cultivation	Season	Expected value		
				($/head)	($/$m^2$)	($/$m^2$/week)
Romaine ('Parris Island')	16	4	All Seasons	0.87-0.92	13.92-14.72	3.48-3.68
Leaf ('Sierra')	20	4	All Seasons	0.75-0.83	15.00-16.60	3.75-4.15
Bibb ('Boston')	30	3	All Seasons	0.75-0.92	22.5-27.6	7.50-9.20

(Table 3). The most frequently occurring low price and high price were sorted from each product's weekly prices as representative of the price most likely to be received by a farmer. St. Croix farm price is used as the price for sorrel value since this product is not included in the USDA market prices because of its low volume of sales.

Production data, product value, and time to harvest were summarized and calculations made to determine crop value on a weekly basis. The crops are grouped by product type (leaf or fruit) and for leaf product by product harvested (whole head or leaves only). Expected value, $/m2/week, was calculated by formulas 1 and 2.

$$\text{Value}(\$/m^2) = \text{Value } (\$/kg) * \text{Yield } (kg/m^2) \quad (1)$$

$$\text{Expected Value } (\$/m^2/week) = \text{Value } (\$/m^2) \div \text{Weeks in cultivation} \quad (2)$$

where Value ($/kg) is the crop value of weekly low and high prices, Yield (kg/m^2) is the biomass harvested for the crop during research trials in the UVI Commercial Aquaponic System, and Weeks in cultivation is the time period between transplanting seedlings and harvest of the plant or removal of the plant after multiple harvests of its fruit.

RESULTS AND DISCUSSION

Production yield, time to harvest and value from romaine, leaf and bibb lettuce are listed in Table 4. Each crop was planted at different densities because the final size, and expected yield, of each plant is different. The densities are 16, 20 and 30 plants per square meter. Bibb lettuce requires three weeks of grow-out to market size while romaine and leaf lettuce require four weeks. Each type has a different value per head; $0.75-0.92 for bibb, $0.75-0.83 for leaf and $0.87-0.92 for romaine (Table 4). A farmer assessing value on the individual price per head would select romaine lettuce to produce, given that it has the highest value, followed by bibb and then leaf. Calculated on value per square meter, the farmer would select bibb with the highest density and value followed by leaf and romaine lettuce (Table 4). The final step is to include value per square meter per week. In this case, bibb lettuce has the higher value compared to leaf and romaine because of its higher value per area and its shorter growing period (Table 4). A farmer would choose to grow bibb lettuce with its returns of $7.50-9.20 per square meter per week. The higher planting density and the shorter production period overcomes the low individual value of the bibb lettuce.

Other leafy greens with different densities, growth periods and values are presented on Table 5. Whole heads of pak choi are harvested while the others—kale, collards, Swiss chard and basil—have only their mature leaves harvested or are harvested by "cut and come again." Time to harvest is three or four weeks. Basil, a culinary herb, stands out with the highest value per kilogram, $8.80-11.03 (Table 5). It has, however a low planting density and a 4-week growth period. This reduces the value per square meter per week and its value, $3.96-4.96, is more comparable to pak choi, $3.92-4.32/m2/week. The three other crops range from $0.23-1.19/m2/week (Table 5).

Fruiting crops are also evaluated by their density,

Table 5. Expected value of leafy crop yield produced at different densities and growth periods. The value can change over time, and should be carefully evaluated before been used as an investment reference.

Crop	Density (plants/ m^2)	Growth Period (weeks)	Season	Yield (kg/m^2)	Expected value ($/kg)	($/$m^2$)	($/$m^2$/week)
Pak choi	30	3	Winter	8	1.47-1.62	11.76-12.96	3.92-4.32
Kale	30	3	Winter	0.89	1.15-1.24	1.02-1.10	0.34-0.37
Collards	30	3	Winter	0.45	1.59-1.42	0.64-0.71	0.21-0.23
Swiss chard	30	3	Winter	1.44	2.12-2.47	3.05-3.56	1.02-1.19
Basil	16	4	Spring Summer	1.8	8.80-11.03	15.84-19.85	3.96-4.96

Table 6. Expected value of fruit yield produced at different densities and growth periods. The value can change over time, and should be carefully evaluated before been used as an investment reference.

Crop	Density (plants/m^2)	Growth Period (weeks)	Season	Yield (kg/m^2)	Expected value ($/kg)	($/$m^2$)	($/$m^2$/week)
Sorrel	4	14	Fall	3.0	8.82	26.46	1.89
Cantaloupe	0.67	13	Fall	2.7	0.69-0.77	1.86-2.08	0.14-0.16
Cucumber	8	6	Summer	6.2	1.20-1.28	7.44-7.94	1.24-1.32
Okra	4	10	Fall	3.04	1.76-2.05	5.35-6.23	0.53-0.62
Zucchini	2.7	9	Fall Spring	7.6	0.73-1.05	5.55-8.00	0.62-0.89

growth period, yield and value (Table 6). Sorrel and cantaloupe are planted in the system for long growth periods and harvested at the end of that time. Okra, cucumber and zucchini have shorter growth periods and harvests are made several times each week summarized in a total yield. Sorrel has the highest value per area per week (Table 6). The value per kilogram is the local St. Croix, USVI price at farm stands during the harvest season, December–January. The expected value of $1.89/m2/week is the highest value for a fruiting crop. Cucumber has high yield, moderate growth period and low value and expected value of $1.24-1.32/m^2/week (Table 6). Cantaloupe has low value, low yield and a long cultivation period. Its expected value is the lowest of fruiting crops, $0.14-0.16/m2/week.

Expected values are based on Miami terminal prices reported by USDA AMS (2015). Other terminals have different prices and farmers should use reports from their nearest market for crop valuation. Seasonal availably of locally grown products also affects wholesale prices. Even if a farmer is selling direct to customers an understanding of wholesale prices is needed to assess competition.

Understanding product values helps a farmer select crops that give the highest returns to the enterprise. Because of different production densities and time to harvest, a common factor of yield per area over time gives a common frame to compare. Market demand for specific products and the desirability of a product mix being available from the farmer to the consumer also plays a role in crop selection.

CONCLUSIONS

A method of valuing each crop was provided to assist growers quantify the contribution that each crop can make to the business revenue. Historical data provided yield from different varieties, seasons, plant spacing, yield and time to harvest, indicating an expected value ($/m^2/week) to allow proper marketing planning. Bibb lettuce has shown a higher expected value, followed by basil, pak choi, leaf and romaine lettuce. However, the crop value can change over time, and should be carefully evaluated before being used as an investment reference.

ACKNOWLEDGEMENTS

We thank Donna Gonzales and Luis Carino Jr. (Horticulture and Aquaculture program) for their technical assistance. Funding for this research was provided by USDA-NIFA-Hatch Funds.

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Alternative Sources of Food for Aquaponics in the U.S. Virgin Islands: A Case Study with Black Soldier Flies

By Lorenzo Cannella, Abdel Rahman Ahmed Nassef, Donald Bailey and Rhuanito S. Ferrarezi

Overview of black soldier fly growing unit. Left: Abdel Rahman Ahmed Nassef, Right: Lorenzo Cannella.

SUMMARY

The reduction of anthropogenic impact on nature is important to maintain the sustainability of food and animal production. Different techniques in aquaculture have emerged in the past years to support sustainable food production such as recirculating aquaculture systems (RAS). An aquaponics system is designed to produce fish and vegetables. Fish, which are daily fed a protein-rich diet, generate waste which flows to the hydroponic benches. The hydroponic component has an environment suitable for bacteria to convert the waste into compounds required for plant growth. Fish feed represents the unsustainable and expensive component of the system, since it relies on fishmeal with high protein content. For this reason, the Horticulture and Aquaculture program of the University of the Virgin Islands (UVI) started growing black soldier flies (*Hermetia illucens*) (BSF) in order to evaluate the use of alternative sources of food to feed the tilapia (*Oreochromis niloticus*) in the UVI Commercial Aquaponics System (CAS). The project consists basically in the design, assembling, and operation of a unit to produce the BSF larvae. The growing unit was designed from different sources available online, focusing primarily on having all the growing stages being performed at the same structure. We started with an initial population of 5,000 larvae. In the beginning the BSF production presented several issues related to the identification of the proper food source and the amount of food that should be provided. The system was improved to increase the number of larvae being produced. During 90 days we were able to produce 2,080 larvae, generating 318.5 g of BSF in 22.794 kg of compost and 4 m3 total available space. The production of the larvae is possible but the economy of scale to generate enough larvae to supplement the tilapia feed needs to be determined.

INTRODUCTION

The number of commercial aquaculture operations has increased in the last year due to the growth of the fish demand and the reduction in fresh and saltwater fish availability due to overfishing (Msangi et al., 2013). This has increased the amount of fish feed needed to maintain the industry and raised concerns about sustainability. The "Fish to 2030" report from FAO indicates that 62% of fish production will be supplied from aquaculture farms by 2030 (Msangi et al., 2013), increasing the need of alternative sources of food for RAS.

Fishmeal is the most important source of protein in the feed fish. Its production is not sustainable due to the reliability in corn, soybean, poultry, pork and wild-caught fish (Naylor et al., 2000). In addition, the price of feed has increased from US$493 (US dollars per metric ton) in 2000 to US$1,424.61 in April 2016 (Indexmundi, 2016). The feed price increased by 288% due to the increasing cost of feed ingredients (fishmeal, fish oil, and grains) and transportation costs.

The high price of feed and the cost of transportation represents a major issue especially for remote locations such as Caribbean islands. In the U.S. Virgin Islands all the fish feed is imported with a high shipping cost. To import fish feed to St. Croix (Aquamax Pound Fish 4000, Purina, Shoreview, MN) feed costs are $1.01/kg and shipping charges are $0.38/kg (ocean freight, bunker surcharge, low sulfur fuel surcharge, and U.S. terminal surcharge). Over 30% of the operating budget is attributed to feed costs. The CAS requires 7,524 kg of feed annually, an average of 20.5 kg/day. Replacing the feed required by a locally produced resource would reduce the quantity of feed needed, potentially reducing the system footprint. That is the primary reason why our local stakeholders cannot compete with the products produced in the mainland U.S., reducing the expansion of commercial aquaponics production in the island. Furthermore, high electricity and supply costs make the profit margins very tight (when positive). New technologies seeking less expensive and more sustainable alternative sources of fish feed are necessary (St-Hilaire et al., 2007; Bondari and Sheppard, 1987). Different studies have shown that BSF can be used as a substitute for fish feed (Bondari and Sheppard, 1981).

Black soldier flies (*Stratiomyidae* family) are decomposers, breaking down organic matter. Black soldier flies feed on scrap food or any kind of protein or organic waste. However, they prefer proteins over vegetables. Black soldier flies are not considered disease vectors for animals, plants and humans. Actually BSF are commonly used to reduce regular fly (*Musca domestica*) population (Sheppard, 1983). The life cycle of BSFs starts with eggs, larvae, pre-pupa and finally adult. The cycle is approximately 45 days long (Figure 1).

Black soldier flies are a great source of protein for fish and animal production. In the pre-pupal stage, the flies are composed of 42% protein and 35% fat, including essential amino and fatty acids and are 44% dry matter (Hale, 1973). The harvested pre-pupae are used in tilapia aquaculture and also in animal feed (such as poultry and pork) (Yu et al.,2009; St-Hilaire et al., 2007). Results have shown BSF are useful to prevent the spread of disease like Salmonella and *Escherichia Coli* (Erickson et al., 2004).

Black soldier flies can reduce from 65% to 79% of the given waste (Diener et al., 2011). This value depends on the amount of feed provided (740 g/m^2/day) and the presence of drainage system. The BSF ability to reduce waste is negatively influenced by larval mortality and lack of eggs due to elevated zinc concentration in the waste and limited access to food (Diener et al., 2011). Pre-pupa production can reach up to 252 g/m^2/day (wet weight), with a growing rate of 4 kg/m^2, generating 145 g/m2/day (dry weight) (Diener et al., 2011).

Black soldier flies have been successfully used on rainbow trout (*Oncorhynchus mykiss*) and catfish (*Siluriformes* spp.) diet. Fish feed formulated with 25% of BSF pre-pupa (15% protein derived from BSF pre-pupa) showed no significant difference of feed conversion rate and no significant difference

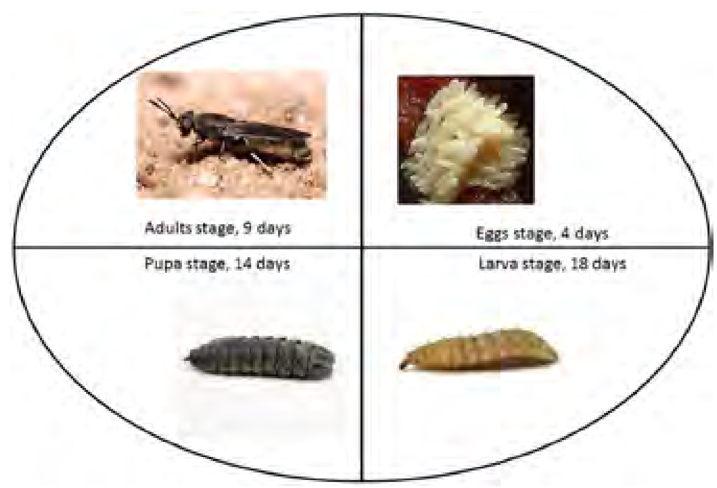

Figure 1. Black soldier fly (*Hermetia illucens*) life cycle (45 days total). They spend two stages of their life in the growing media as eggs (4 days) and larva stage (18 days). Only when they are transforming from pre-pupa (14 days) to adults (9 days) do they move away from the media to find a dry place to complete the metamorphosis (source eggs stage: www.justbajan.com, source larva stage: www.junglebobsreptileworld.com, source pre-pupa stage: www.projectnoah.org, source adult stage: www.aqua-ponics.wikia.com).

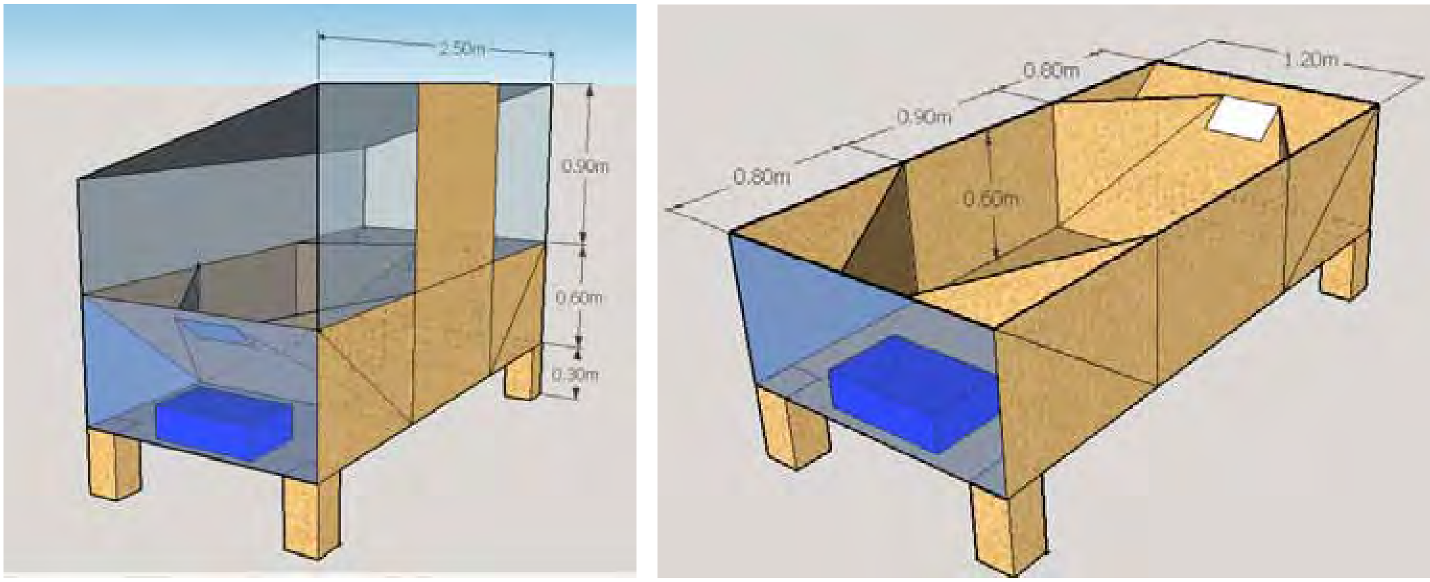

Figure 2. The black soldier fly growing unit schematics. The unit is covered with plastic nets on both sides to increase the air recirculation and has a central door to facilitate the daily operations.

in total weight gain compared to regular feed based on 40% protein (67% fish source, 33% plant source) (St-Hilaire et al., 2007). This has caused a reduction of 38% in oil fish component, the unsustainable component of fish feed, but at the same time a decrease of oil fish component due to a decrease of omega 3 fatty acids in fish muscle (St-Hilaire et al., 2007). The replacement of 10% fishmeal by 10% BSF larvae did not reduce the growth rate of catfish cultivated in culture tanks (Bondari and Sheppard, 1987). Black soldier flies have a chitin shell, which is indigestible to vertebrate animals and can clog filters and pumps. When BSF are dried and mixed with other ingredients its use is similar to the commercial feed (St-Hilaire et al., 2007; Bondari and Sheppard, 1987). Feeding the fish with 100% larvae did not provide sufficient dry matter or protein intake for good growth (St-Hilaire et al., 2007). Positive results have been collected when fish food was substituted with BSF pre-pupae as 25% and 50% replacement for the fish meal component of the control diet (St-Hilaire et al., 2007). Furthermore, Stamer et al. (2014) have indicated that substituting 50% of rainbow trout fishmeal with BSF decreased the feed conversion ratio and protein retention ratio, resulting in increased body weight gain. Based on Stamer et al. (2014) and St-Hilaire et al. (2007), the percentage of BSF pre-pupa in the fish feed should between 25% and 50% (and never exceed 50%) of the total commercial feed amount or other component, to stimulate a significant gain of weight.

The goal of this project is to provide guidelines related to designing and assembling a BSF growing unit and produce enough BSF pre-pupa to supply the daily requirements of fish feed. Then we would feed the fish in the CAS with BSF in order to be more sustainable and reduce the costs of fish feed.

MATERIAL AND METHODS

The project started by adapting project designs available for hobbyists to one that can have the possibility to produce all BSF phases (larvae, pre-pupa and adult stage). Our setup also provides space for reproduction, keeping the flies inside the growing unit.

Black soldier fly growing unit

The BSF growing unit has a dimension of 2.5 × 1.8 × 1.2 m (Figure 2). The system was assembled using two 2.5 × 0.6 m and two 1.2 × 0.6 m plywood sheets. Plywood was also used to assemble two sliding doors for the larvae collection compartment and the 2.5 × 1.2 m roof. The dimensions of the growing unit were 0.9 × 1.2 × 0.6 m, with a volume of 0.648 m^3. The BSF growing unit was surrounded by a 1 × 5 m plastic screen (2 × 2 mm mesh) to cover the sides, keep the flies inside and allow air movement. In the front there was a 0.9 × 0.9 m door made with plywood to allow feeding activities inside the growing unit (Figure 2). The project design was created using Google SketchUp 2016 (Google, Mountain View, CA).

Inside the growing unit there are two ramps with a hole on the top to help the BSF larvae move from the growing media to a 26-L tray (Sterilite, Fitchburg, MA) installed in both sides (Figure 2). During the pre-pupa stage, larvae start migrating from the food area to the 26-L trays. The larvae start a metamorphosis phase, where they stop eating and empty their

Table 1. Different diet composition during the trial.

Day	Vegetable waste	Fish	Cafeteria waste	Water added (L)	Frequency per week
3 to 15	✓			3	2
16 to 28	✓	✓	✓	3	2
29 to 71		✓		7	2

stomach. For this reason, the BSF move into a new area without food and water. Our growing unit design is adequate to maximize the BSF migration and simplify the harvest by having the larvae BSF fall into the 26-L trays.

To facilitate the reproduction of BSF adults, we attached a piece of corrugated cardboard (25 × 25 cm) on the wall of the growing unit. The BSF spawn the eggs in the cardboard and the larvae fall down directly onto the compost after hatching. Our BSF growing unit has a cost of approximately $250.

The larvae were obtained from a commercial supplier available at Amazon.com (Alfredo Llecha, GA) and delivered in a small container with coffee grounds to keep the larvae alive. The trial started on March 1st, 2016 (day 1), and 5,000 first and second instar larvae was added on March 8th, 2016 (day 8). The BSF growing unit media was composed of 60% woodchips (B&T Shavings, Jasper, AL) and 40% peat moss (Lambert Peat Moss Inc., Riviere-Ouelle, Quebec, Canada), creating a moistened environment with the addition of 7 L/day of water.

Feed

We provided a diet using only vegetable waste (lettuce, squash) every 5 days in the beginning of the trial. After two weeks, we started adding fish to the diet (tilapia, 1.5 to 2 kg), cafeteria scrap (pasta, rice, meat, and salad), and water with the same frequency. However, that approach resulted in the attraction of other flies because the BSF were not eating all the organic material available. On day 16 we started feeding the BSF only with 1.5 to 2 kg of tilapia and on day 29 we started applying 7 L of water twice per week (Table 1). During the development of the trial we added ground coffee in the media.

Procedures

Both sides of the growing unit were checked daily and the BSF pre-pupae were collected. If another type of fly was found inside the system, it was manually removed. The pre-pupae collected were counted and weighed and returned to a 3.78-L bucket (Sterilite, Fitchburg, MA) inside the growing unit to allow metamorphosis into the adult phase and generation of more flies. We also added 7 L of water daily to maintain the media moisturized by using a 3.78-L sprayer (Root-Lowell manufacturing Co., Lowell, MI). We added 1.5 to 2 kg of tilapia carcass every 3 days to feed the BSF. We recorded the amount and weight of larvae, water, feed and coffee during the trial.

Temperature monitoring

An automated system was used to monitor environmental conditions inside the growing unit from day 77. We used a low-cost open-source microcontroller (Arduino Mega 2560 R3; Arduino, Ivrea, Italy) connected to a compost temperature sensor (DS18S20; Adafruit, New York, NY) and an air temperature and relative humidity sensor (AM2302; Adafruit, New York, NY). The assembling instructions and basic programming are available in Ferrarezi et al. (2015). The system was monitoring the data every 15 minutes and recording the data automatically using Wi-Fi in a Google Sheets spreadsheet (Google, Mountain View, CA).

RESULTS AND DISCUSSION

From day 1, the BSF were fed with vegetable waste (lettuce and squash leaves) and 2-3 L of water were sprayed twice a week. From day 16, we started adding a source of protein (1.5 to 2 kg of tilapia) to supplement the diet because the larvae were not eating the vegetables. Tilapia was added twice a week. From day 23, we started adding cafeteria scraps (mix of pasta, rice, meat and salad) with the same frequency. The change in diet resulted in maintenance of larvae production.

The first pre-pupa collection was on day 21. In the next weeks the BSF pre-pupa number collected were irregular, ranging from 5 to 1,120 (Figure 3). During this period, BSF continued to be fed with the same amount of fish and cafeteria food.

The uneaten feed was attractive for other types of flies, especially maggots (order Diptera, in particular larvae of Brachyceran flies, such as houseflies, cheese flies, and blowflies). From day 25 to 29, the trial recorded a high amount of maggots and larvae. On day 29, we collected 95 g of maggots. That was a high amount when compared with 160 g of BSF pre-pupa collected at the same day. The pre-pupa collected presented the highest value reported in

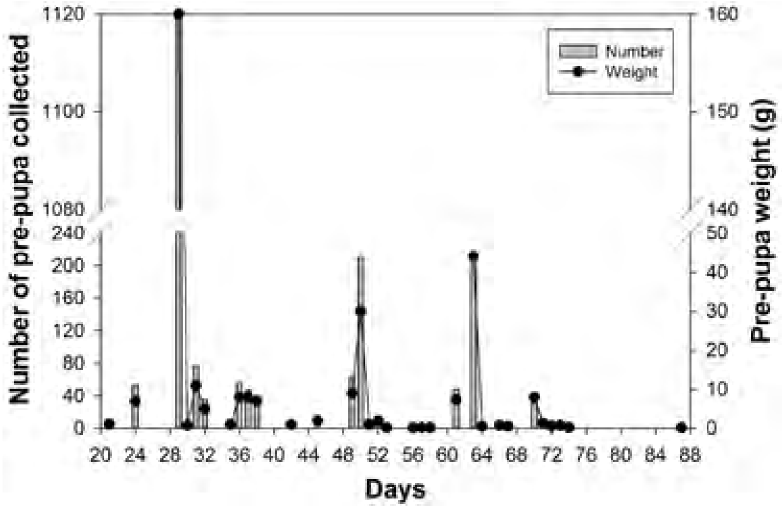

Figure 3. Number and weight of pre-pupa collected overtime. The large amount of pre-pupa collected on day 29 was due to the initial larvae added to the system. The peaks of pre-pupa collection are related to the larvae cycle.

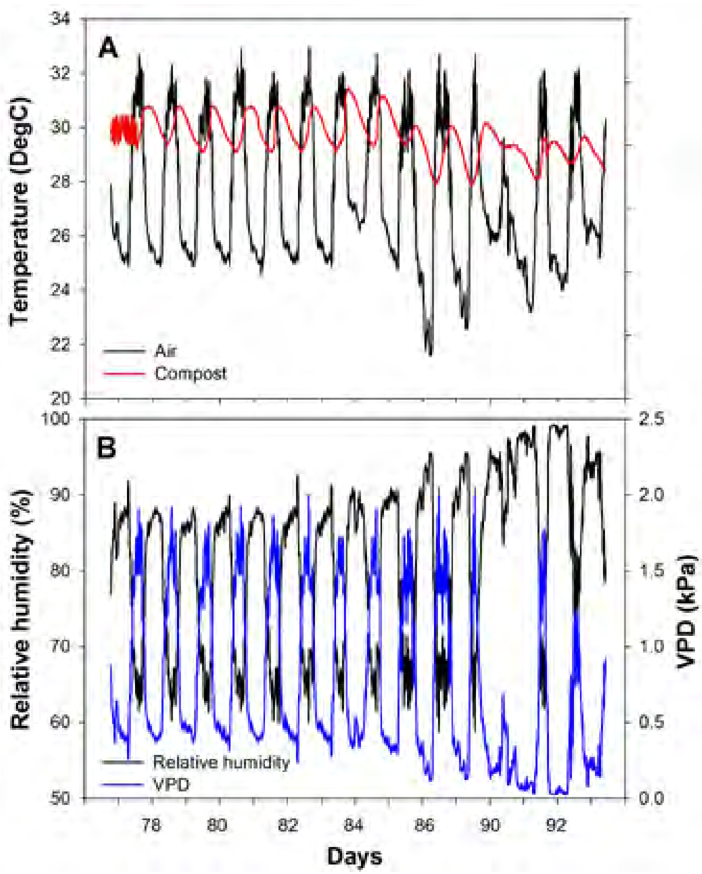

Figure 4. The air and compost temperature (A) and relative humidity and vapor pressure deficit (VPD) (B) over time.

the trial. The maggots have a shorter life cycle than BSF and colonized all the growing unit. We had to reduce the food source from cafeteria scraps and vegetables to only fish, and added more media (wood chips) to the growing unit. The number of maggots started to decrease, and by the end of the month, the maggots disappeared. We noticed the increase in BSF population efficiently reduced the regular fly population and consequently the number of maggots as indicated by Sheppard (1983). The peak in the amount of pre-pupa collected on day 29 could also be caused by the large number of larvae used to start the trial. On days 50 and 63 there are two peaks of pre-pupa production. Those values indicate the start of a new life cycle in the growing unit. It will be interesting checking this type of recurrence to be sure if the system is self-sustainable. In gaining knowledge through experience and by providing the right amount of feed and water based on the BSF needs, the growing unit started generating new larvae.

Temperature monitoring

The air temperature inside the growing unit presented a minimum of 21.6°C and maximum of 32.94°C following the day and night temperature variation. The same trend can be seen for the compost temperature with minimum of 28.75°C and maximum of 31.81°C (Figure 4A). The humidity sensor has recorded minimum value of 58.8% and maximum value of 99.% (Figure 4B). Calculated vapor pressure deficit (VPD) ranged from 0.03 to 2.04 kPa (Figure 4B).

Practical recommendations

For system assembling, we recommend the use of plywood sheets. All the materials should be secured to avoid open spaces, reducing the entrance of other insects or animals inside. It is recommended painting the outside of the growing unit using white paint to reduce the growing unit temperature. Drill a few small holes (2 × 2 mm) on the unit bottom to avoid water accumulation.

Related to the BSF growing unit management, feed the BSF *at libitum*, adding small amounts of feed. If the BSF are eating all the food in less than 1 h provide more in the next meal. Make sure the BSF growing unit is completely sealed, with no openings to other flies or animals — especially lizards that can eat all the BSF larvae. After the pre-pupa reach the adult stage, throw away the larva skin from the bucket inside the growing unit since they can attract ants and other insects. Moisten the media in the growing unit regularly (twice a week).

CONCLUSIONS

During 90 days we were able to produce 2,080 larvae, generating 318.5 g of BSF from 22.794 kg of compost and 4 m^3 total available space. This amount of larvae produced was not economical. Approximately 5 kg/day of larvae is needed to supplement 10% of the feed requirements of the CAS. The production of the larvae is possible but the economy of scale to generate enough larvae to supplement the tilapia feed needs to be determined.

ACKNOWLEDGEMENTS

We thank Amro Mustafa, Donna Gonzales, Luis Carino Jr., and Micaiah Forde (Horticulture and Aquaculture program) for their technical assistance. Funding for this research was provided by USDA-NIFA-Hatch Funds.

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CURRENT PROJECTS

CAPACITY FUND PROJECTS

Agronomy

USDA-NIFA HATCH Project, 2014-2019, Evaluation of integrated tropical cover crop systems

Animal Science

USDA-NIFA Hatch Project, 2012-2017, Evaluation of weaning age on parasite burdens of hair sheep lambs in an accelerated lambing system in the tropics

USDA-NIFA Hatch Project, 2012-2017, Evaluation of Senepol heifer productivity in the U.S. Virgin Islands

USDA-NIFA Hatch Multistate Project (W-2173), 2011-2016, Impacts of stress factors on performance, health, and well-being of farm animals

USDA-NIFA Hatch Multistate Project (S-1064), 2014-2019, Genetic improvement of adaptation and reproduction to enhance sustainability of cow-calf production in the Southern United States

Biotechnology & Agroforestry

USDA-NIFA Hatch, 2011- 2016, Breeding and selection for early bearing large fruited papaya

USDA-NIFA Hatch Multistate Project (S-9), 2013-2018, Plant genetic resources conservation

USDA-NIFA McIntire-Stennis, 2016-2021, Establishing Trees Using Active and Passive Irrigation on Arid Lands

Horticulture & Aquaculture

USDA-NIFA Hatch Project, 2011-2016, Variety trials and improving tropical vegetable production in the U.S. Virgin Islands

USDA-NIFA Hatch Project, 2011-2016, Development of aquaponic technology for the production of tilapia and hydroponic crops

USDA-NIFA Hatch Multistate Project (W-3128), 2015-2019, Scaling microirrigation technologies to address the global water challenge

GRANTS AND CONTRACTS

Experiment Station Grants

USDA-NIFA Resident Instruction in the Insular Areas, 2015-2017, Enhancing undergraduate students' education through experiential learning in agriculture research

Agronomy

USDA-NRCS, 2014-2016, Tropical cover crops and multipurpose nitrogen fixing trees to reduce soil erosion, increase soil quality and provide ecosystem services in Caribbean agroecosystems (Collaboration with **Horticulture** & **Aquaculture**)

Animal Science

USDA-NIFA Resident Instruction in the Insular Areas, 2015-2017, Evaluation of the relationship between body temperature and grazing behavior in livestock in the tropics

Biotechnology & Agroforestry

USDA-NIFA Specialty Crop Grant, 2011-2016, Muscadine grape utilizing cisgenetic modification technology

U.S. Fish & Wildlife Service, 2014- 2016, Federally endangered *Buxus vahlii* and *Catesbaea melanocarpa*

Ventria BioScience, 2015-2016, Sorghum x Sudan cover for rice production

USDA-VI Dept. of Agriculture -Specialty Crop Block Grant, 2015-2017, On-Farm sweetpotato weed control

USDA-VI Dept. of Agriculture -Specialty Crop Block Grant, 2015-2017, Trellis systems for sustainable Pitaya production

Students collecting sweating rate data on sheep.

PUBLICATIONS

AGRONOMY

Journal Articles

Weiss S.A., R.W. Godfrey, R. Ben-Avraham and R.C. Ketring. 2015. Performance and carcass characteristics of hair sheep lambs finished on tropical pasture or rangeland and supplemented with maize. Livestock Research for Rural Development. Volume 27, Article #228. Available at: http://www.lrrd.org/lrrd27/11/weis27228.htm

Abstracts

Weiss, S., R.S. Ferrarezi, D.D. Treadwell, K.P. Beamer and T.S. Geiger. Mulching strategies using conservation tillage for weed management in tropical organic hot pepper cropping systems. ASHS 2016 Annual Conference, August 8-11. Atlanta, Georgia.

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Beamer, K.P., S. Weiss and T. Geiger. 2016. Harvest timing and inorganic-nitrogen alternatives impact on lignocellulosic characteristics and yield under an intensified climate. UVI Research Day 2016 Proceedings. 5:2.

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Invited Presentations

Managing reproduction in hair sheep. 9th Annual Small Ruminant Conference, Alabama A&M University, Orange Beach, AL, August 26-27, 2016.

Gastrointestinal parasite resilience of hair sheep breeds. 9th Annual Small Ruminant Conference, Alabama A&M University, Orange Beach, AL, August 26-27, 2016.

UVI Symposia

Godfrey, R., A. Nero, G. Roberts and S. Lakos. 2016. Evaluation of the relationship between body temperature and grazing behavior in hair sheep in the tropics. UVI Research Day 2016 Proceedings. 5:5.

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Journal Articles

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Bailey, D., S. Balkaran, J. Bernier and R.S. Ferrarezi. 2016. Assessment of basil varieties for production in the UVI Commercial Aquaponic System. ASHS 2016 Annual Conference, August 8-11. Atlanta, Georgia.

Invited Presentations

Arduino: building and programming simple measurement and control systems ASHS 2016 Conference, CE WG workshop

UVI Symposia

Mustafa, A., D. Bailey and R.S. Ferrarezi. 2016. Aquaponic waste as nutrient source for duckweed production used for fish feed. UVI Research Day Proceedings. 5:7.

Greenidge, J., J. Atemazem, T.C. Geigerand R.S. Ferrarezi. 2016. Evaluating microirrigation performance on okra cultivation in the U.S. Virgin Islands. UVI Research Day Proceedings. 5:6.

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Geiger, T.C., K. Cuffy and R.S. Ferrarezi. 2016. Greenhouse production of slicing cucumbers in the U.S. Virgin Islands. UVI Research Day Proceedings. 5:5.

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Bailey, D., S. Balkaran, J. Bernier and R.S. Ferrarezi. 2016. Assessment of basil varieties for production in the UVI Commercial Aquaponic System. UVI Research Day Proceedings. 5:2.

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Geiger, T.C., K.P. Beamer, S.A. Weiss and R.S. Ferrarezi. 2015. Preliminary Evaluation of Sugar Snap and Snow Pea Varieties for Production in the U.S. Virgin Islands. UVI-AES Annual Report pp. 23-27.

Nutrient film technique (NFT) hydroponics system with chives, parsley, celery and lettuce used in comparison to the UVI Commercial Aquaponics System.

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