DOE Bioenergy Technologies Office (BETO) 2023 Project Peer Review

Evaluation of Energycane for Bioenergy and Sustainable Agricultural Systems (EC-BioSALTS)

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Technology Area Session

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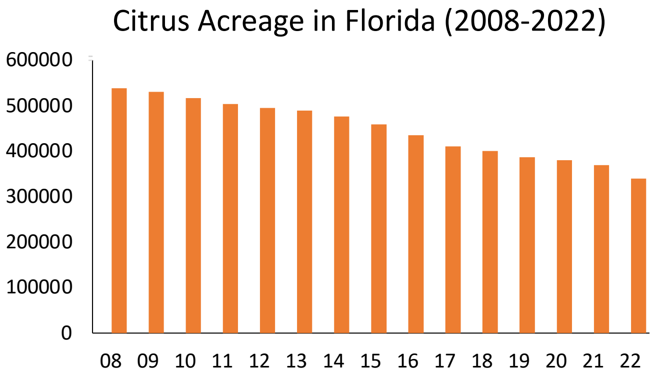
Project Overview

- Context and project history:
  - *Water quality problems from agricultural & urban activities in U.S. Southeast Coastal Plains*
  - *Organic soil loss in S. Florida & abandoned farmlands (200K acres) due to citrus greening*
  - *Demonstration of energycane for bioenergy and ecosystem services*

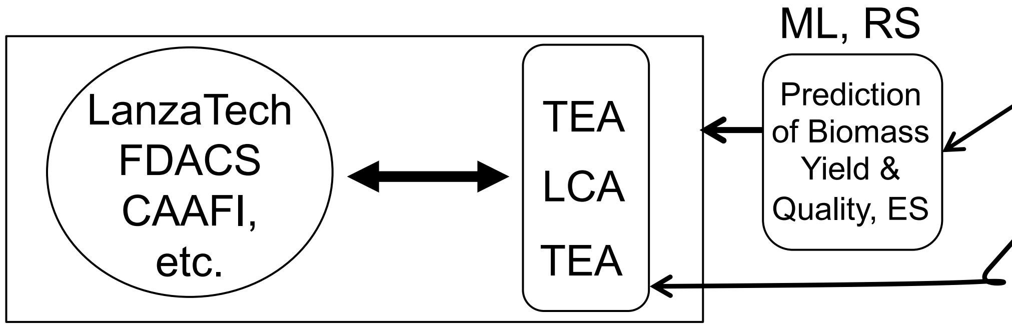


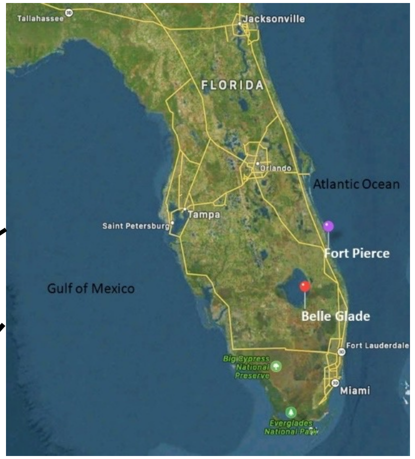
- High-level Project Goal:
  - *develop and evaluate an energycane (EC) feedstock production system on marginal and fallow croplands of the U.S. Southeast to support the emerging bioeconomy.*

- Utilize high-yielding bioenergy energycane (EC) cultivar

- Field-scale production system of EC
  - *Integrated Landscape Management Approach in Organic Soils*
  - *Monoculture on abandoned (fallow) farmlands on sandy soils*

- SAF EC feedstock cost-rate model from farmgate to biorefineries for the USSCP region





Project Overview

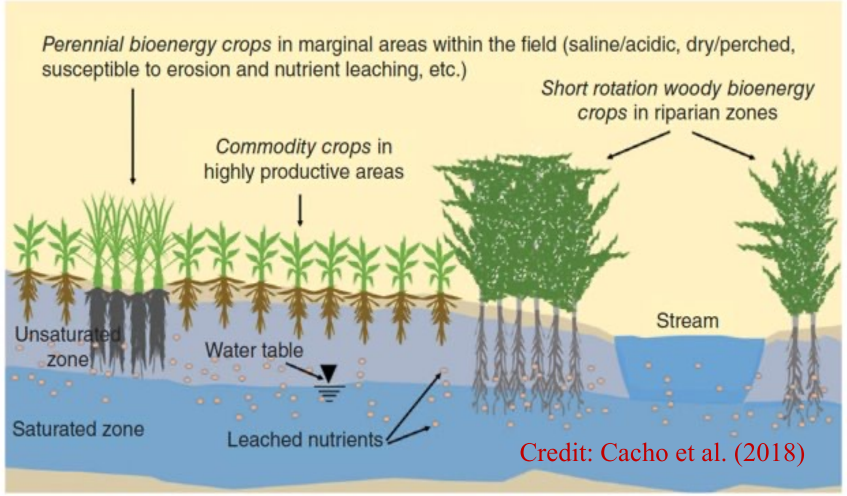
The overall goal of this project is to develop and evaluate an EC feedstock production system on marginal and fallow croplands of the U.S. Southeast to support the emerging bioeconomy.

Objectives

- To evaluate yield and quality of currently-available and advanced EC cultivar (University of Florida Canal Point UFCP 84-1047) for bioenergy at field-scale in marginal and fallow croplands
- To quantify ecosystem services (ES) of UFCP 84-1047 compared to sugarcane and sweet corn cropping systems on marginal and fallow croplands
- To test sensors to estimate EC canopy nutrients and biomass and ground-truth information management platforms
- To develop a machine learning (ML)-based model that can predict agronomic attributes (yield and feedstock chemical composition) of UFCP 84-1047 given a collection of environmental and crop management parameters
- To use field-scale data to generate baseline and enhanced (with estimated market values of ES) techno-economic analyses to quantify opportunities to meet the solicitation cost goal of <$3/gge with >4 ton/ac yield and a refinery delivery cost of < $84/ton.
- To quantify sustainability benefits such as greenhouse gas (GHG) emission reductions through life-cycle analysis (LCA) by evaluating the supply chain of the proposed system.

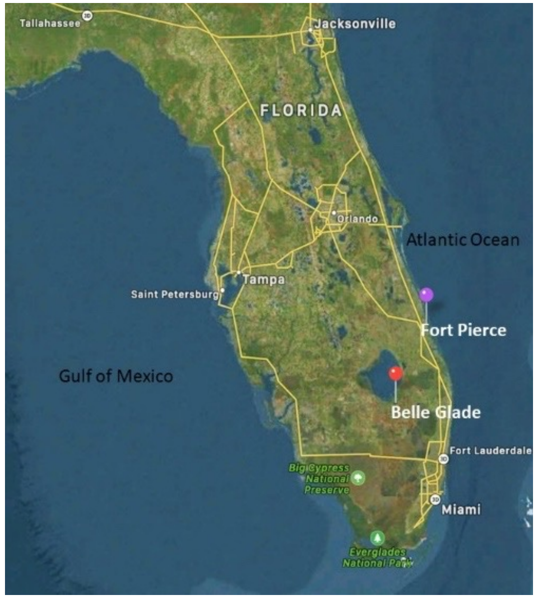
1-Approach

Experiment Site 1: UF-IFAS Everglades REC, Belle Glade, FL
Shallow soil depth, high pH, poor drainage with <1% slope are putting it in the category of marginal soils. Sugarcane is a major crop with sweet corn, rice and vegetables as rotation crops. Soil subsidence and nutrient runoff to the Florida Everglades are major concerns.



- ILM approach in which EC will be incorporated in conventional sugarcane and sweet corn cropping systems
- Total 48 plots (3 crops x 2 N treatments x 2 P treatments x 4 replications)

Experiment Site 2: UF-IFAS Indian River REC, Fort Pierce, FL: Sandy soils have very low OM, low water holding capacity, and poor nutrient status. Intensive water and nutrient management is critical for these marginal soils. Due to >40% decline in citrus acreage in this region over the past decade, there is a demand for alternate cropping systems for these marginal climatic and soil conditions.



- Two ac of EC will be incorporated as four half-acre strips (4 replications) in four ac of citrus fallow land.
- Total 16 EC plots (2 N treatments x 2 P treatments x 4 replications) and four fallow plots.

1-Approach

Biomass

- Biomass yield and composition
- Biomass storage

Ecosystem Services

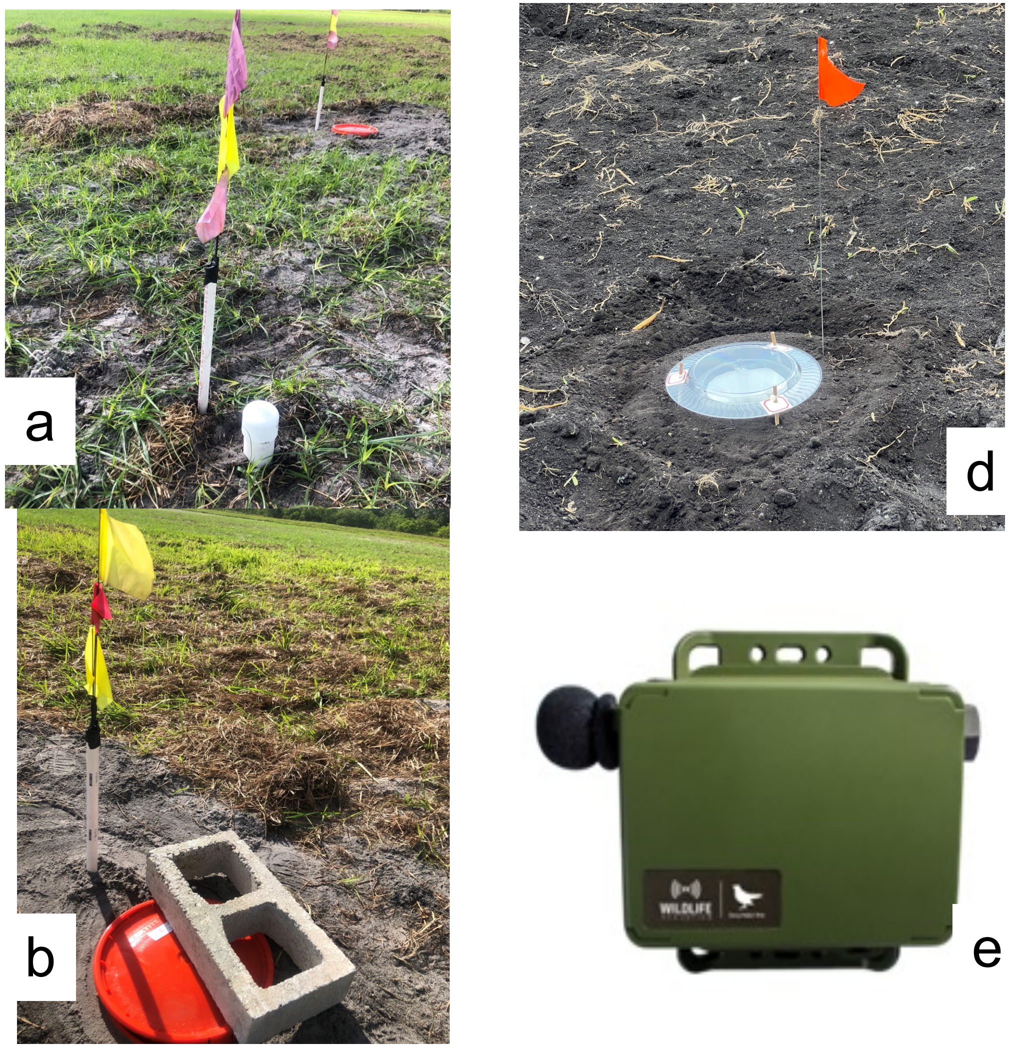
- Soil physical, chemical and biological properties
- Water quality
- Greenhouse gas emissions
- Biodiversity (soil invertebrates and avian population

Modelling

- Sensors to estimate EC biomass
- Sensors to estimate canopy nutrients
- ML based model to predict agronomic attributes
- TEA to quantify opportunities to meet the solicitation cost goal of <\$3/gge with >4ton/ac yield
- LCA framework in GREET
- Market Transformation Plan

1-Approach

- In both sites, the biomass yield potential, feedstock composition, and ES will be monitored and evaluated at high resolution to optimize EC feedstock production on fallow and marginal croplands.
- Analyses of the energy balance and economics associated with feedstock production management and logistics will be investigated to determine system sustainability and economic opportunities

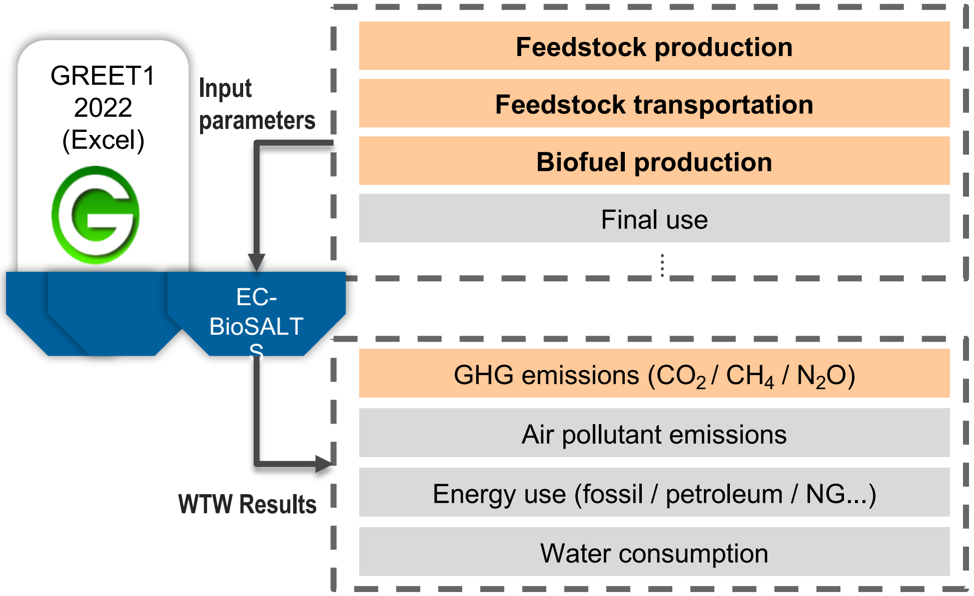


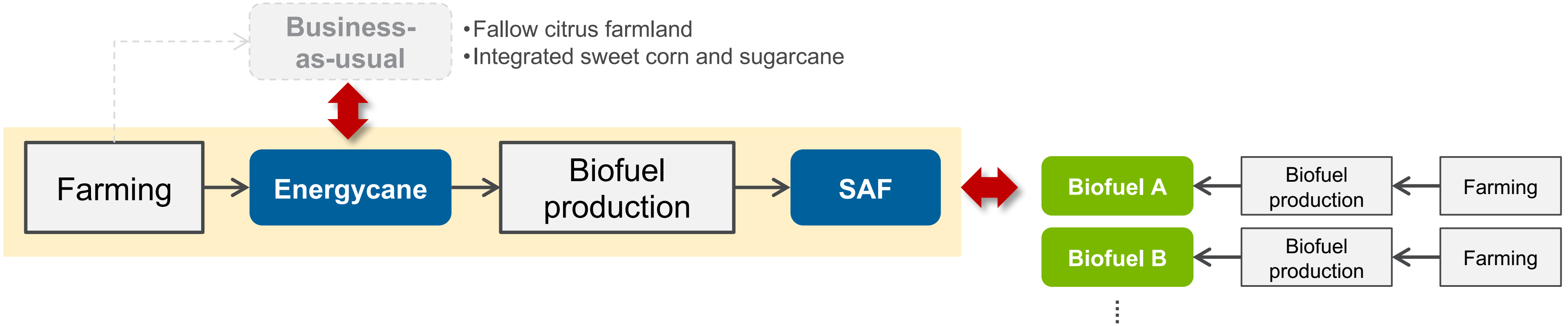
a) Soil health/ quality measurement b) Water quantity and quality measurement c) Pitfall trap d) Avian Monitoring Sensor

1-Approach: LCA of energycane and SAF

Life-cycle analysis (LCA) of energycane for bioenergy and sustainable agricultural systems using GREET

- Evaluate life-cycle greenhouse gas (GHG) emissions, water consumption, air emissions, and energy uses using the datasets collected through the project that are incorporated into the GREET model
- Estimate emission reductions by comparing the conventional farming with the bio-enhanced practices; energycane-derived SAF with other fuels.
- Generate a version of GREET that includes the energy cane to biofuel production pathway so that further emission reductions are considered





1-Approach

Potential Risks and Mitigation Strategies

- The risk associated with biomass production is failure in/poor stand establishment due to poor seedcane quality or environmental conditions such as prolonged drought, flooding, insect pests and diseases
- our access to additional seedcane source, irrigation and drainage equipment, and high resistance of UFCP 84-1047 to insect pests and diseases mitigate these risks.
- Wild animals, including hogs, can occasionally enter field research sites and mitigation through construction of electric fencing has proven to be effective.
- The primary technical risk associated with avian monitoring is the inability of the ML techniques to accurately identify birds in the monitoring videos and photos. However, ML models developed for the aforementioned DOE BETO project have already successfully demonstrated the ability to identify birds in recorded video; therefore, there is great promise that the ML technique will be applicable for this project.

1-Approach

- Go/No-Go decision points
- #1: Quantity and quality of EC propagated to use as seedcane (M12) -*Completed*
- #2: Demonstrate biomass growth, nutrient uptake, water quality, carbon footprints and biodiversity (M24)
- #3: Demonstrate the use of sensors in assessing water stress, biomass and canopy nutrients (M24)
- #4: Demonstrate availability of large volume, high quality data generated from the field sites and other sources for ML and successful demonstration of Go/No go decision point number 1 for ES valuation. (M24)

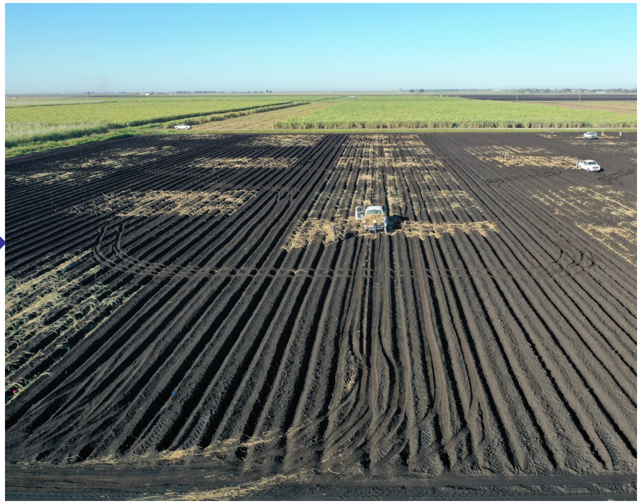
Currently, we are in M18 of this project. The project was awarded in FY20 but there was a long negotiation period that delayed the actual start date of this project.

Communication:
Monthly meetings with the project team and biannual meetings with the advisory committee

2-Progress and Outcomes

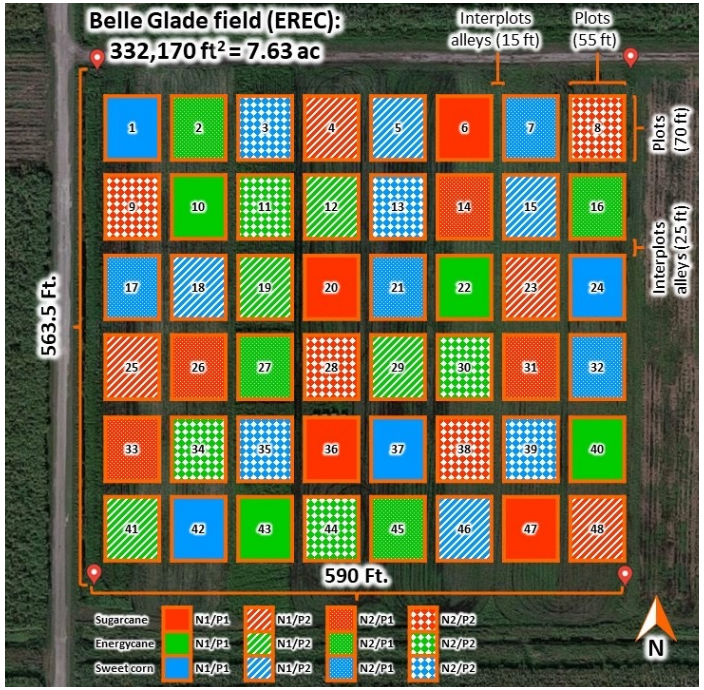
Objective 1. Energycane billet propagation

Successful seed cane propagation –*Outcome required for #1 Go/no-go decision*

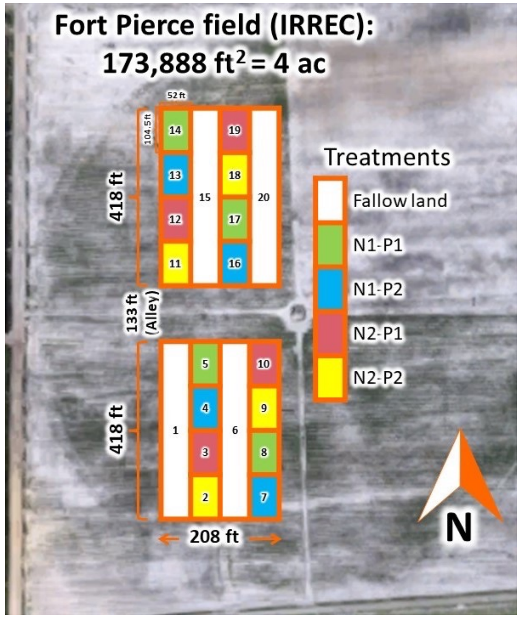


Planting Field trials

Plot size is $\geq$ 400 m^2

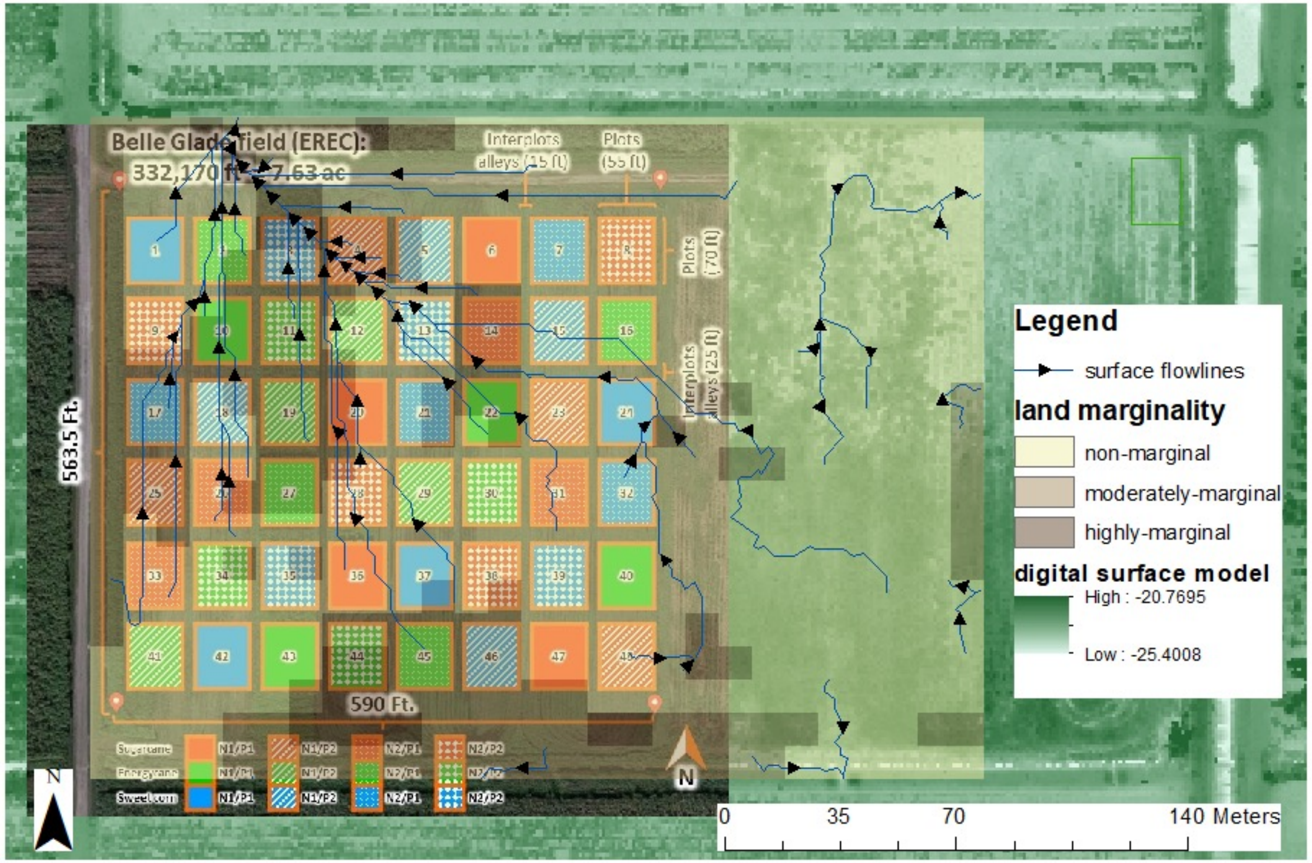


Lay-outs



2- Progress and Outcomes (EREC Study Site Characterization)

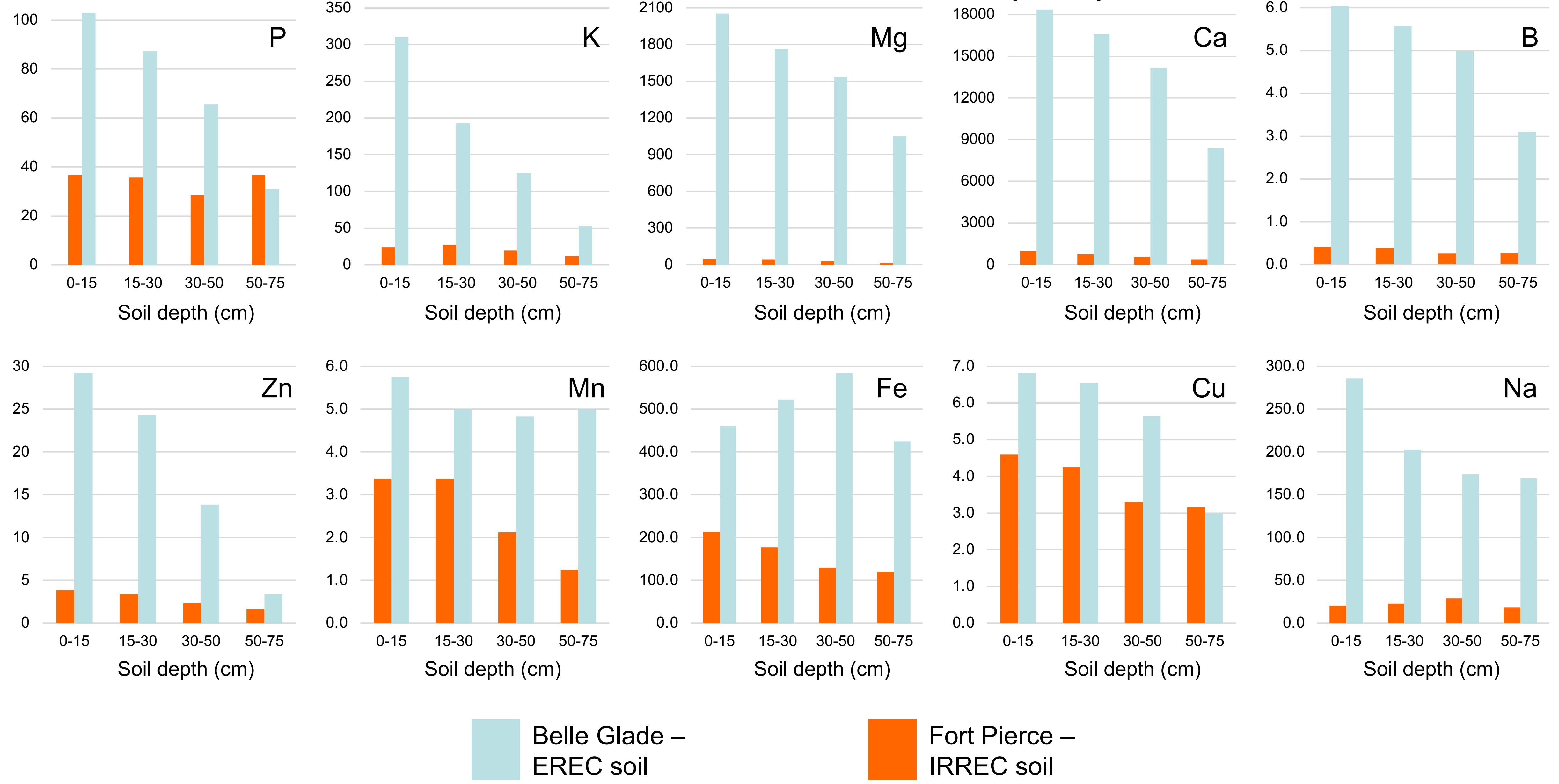
- Completed Integrated Landscape Management Analysis of the Everglades Research and Education Center Study Site



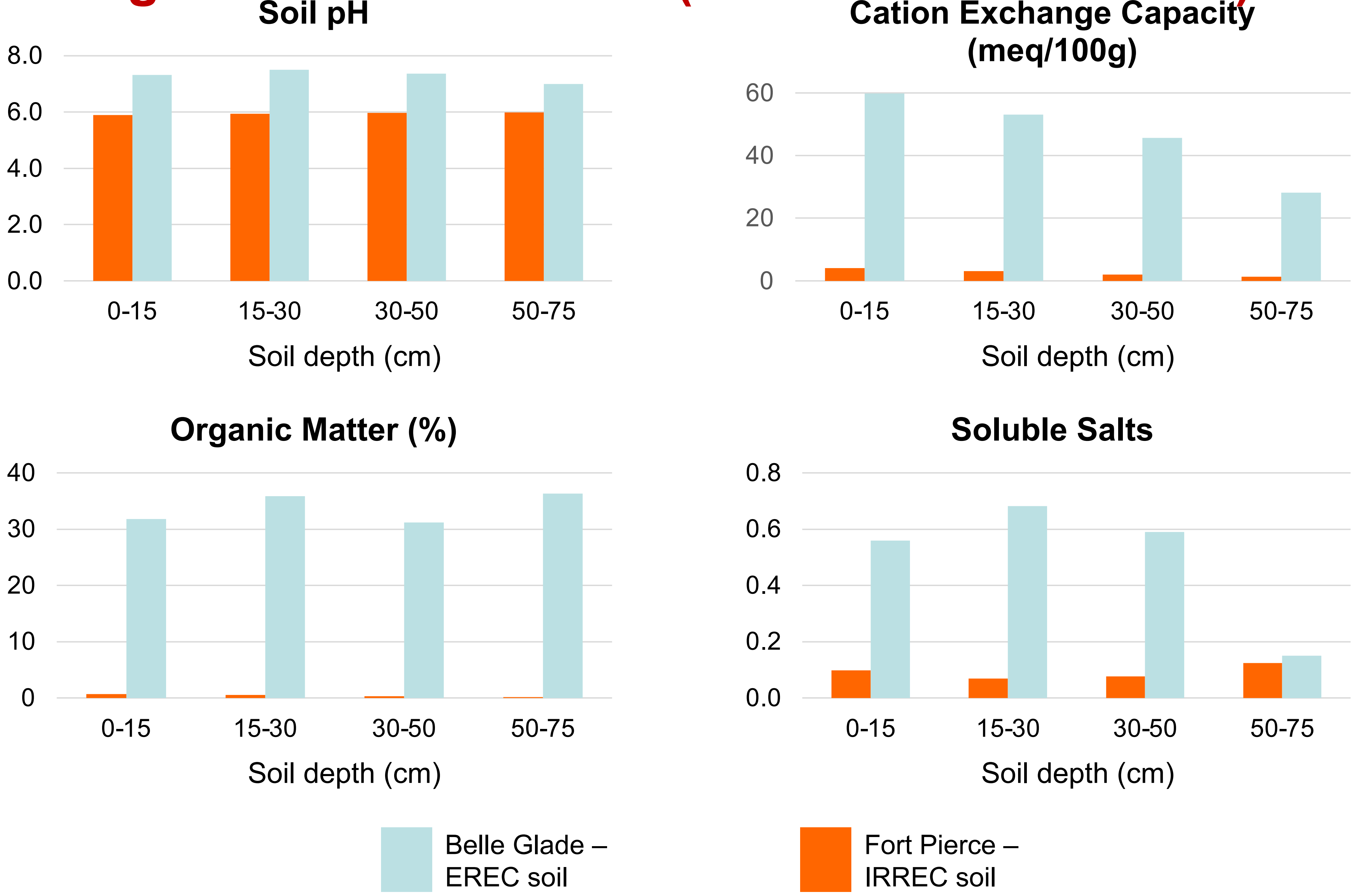
Schematic of experimental plots informed by land marginality map

2- Progress and Outcomes (Baseline data- Soil properties)

Available Nutrients (lbs/a)



2- Progress and Outcomes (Baseline Data – cont.)



2- Progress and Outcomes (Baseline Data – cont.)

Baseline data-Soil Biological Properties

Location	Total Bacteria (Units/g)	Total Actinomycetes (Units/g)	Fungi-bacteria ratio	Total #species	Fungal Phyla (%)		Bacteria Phyla (%)	
					Ascomycota	Basidiomycota	Actinobacteria	Proteobacteria
IRREC	10^9	10^7	292	525	77	17	31	26
EREC	10^8	10^6	772	501	86	9	28	26

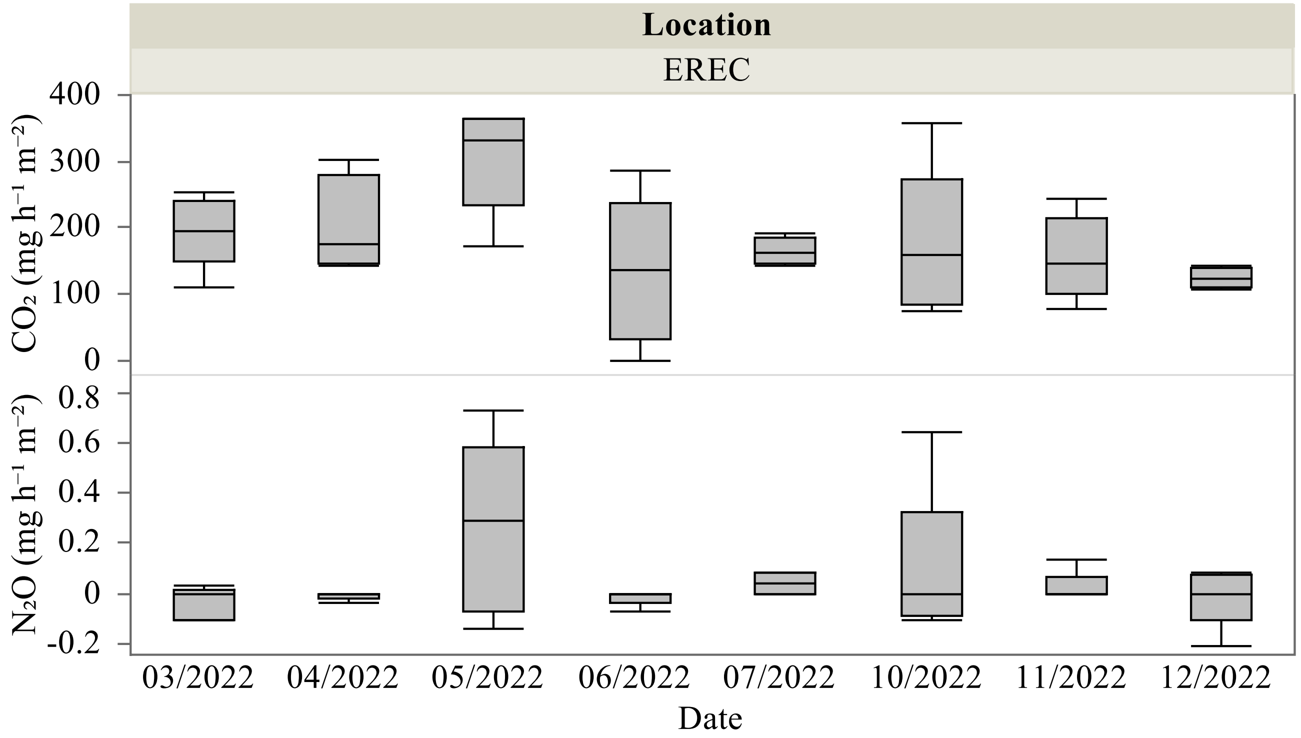
Baseline data - soil invertebrates

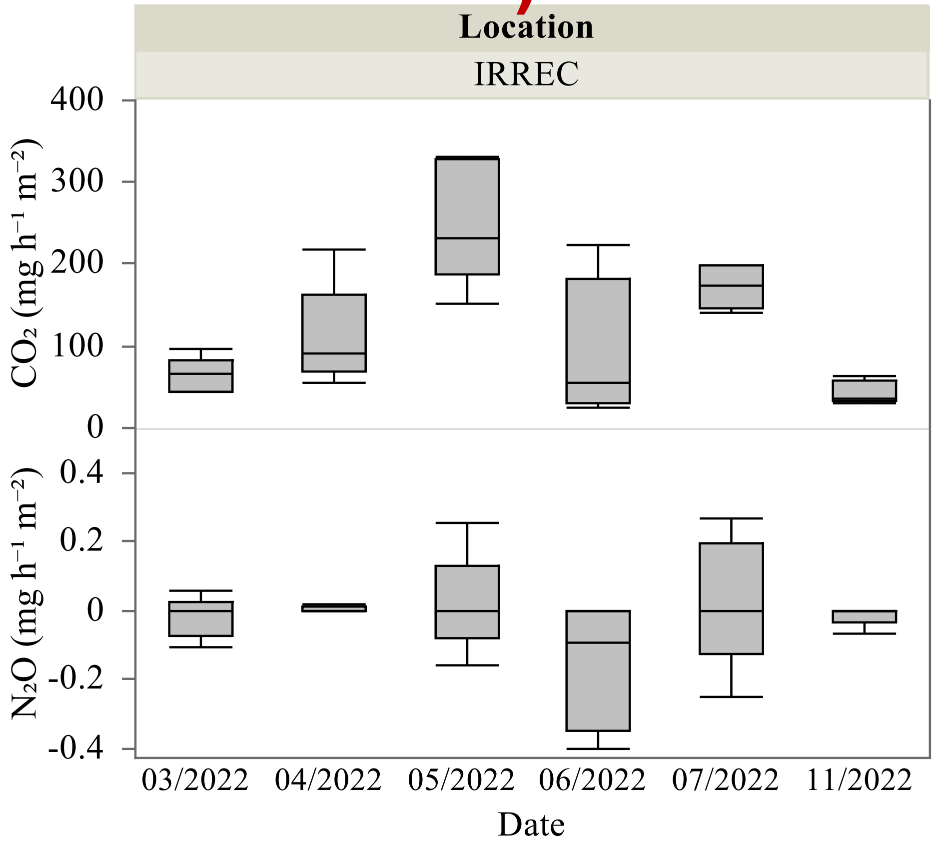
Site	Sample	Fire ants	Earwigs	Ground beetles	Rove beetles	Wolf spiders	Other spiders
EREC	1	2	6	3	8	0	2
EREC	2	1	7	0	4	0	0
EREC	3	0	14	1	3	0	0
EREC	4	3	9	2	3	0	3
EREC	5	1	2	0	0	0	0
IRREC	1	22	2	0	0	0	2
IRREC	2	25	8	0	0	0	5
IRREC	3	17	3	0	0	1	3
IRREC	4	35	4	0	0	1	0
IRREC	5	22	3	0	0	0	1

- Fungi-bacteria ratio was higher at EREC than IRREC
- Among soil invertebrates, IRREC had higher fire ant population while EREC had higher rove beetles

2- Progress and Outcomes (Baseline Data – cont.)

Greenhouse Gas Emissions





- Measured GHG fluxes during the baseline period match previous reports on agricultural lands on both organic and mineral soils.
- **Organic soils:**
  - CO_2 Flux : 400 - 1300 mg m^{-2} h^{-1}
  - N_2O Flux : 0.036 mg m^{-2} h^{-1}
- **Mineral soils:**
  - CO_2 Flux : 72 - 612 mg m^{-2} h^{-1}
  - N_2O Flux : 0.006 - 0.05 mg m^{-2} h^{-1}

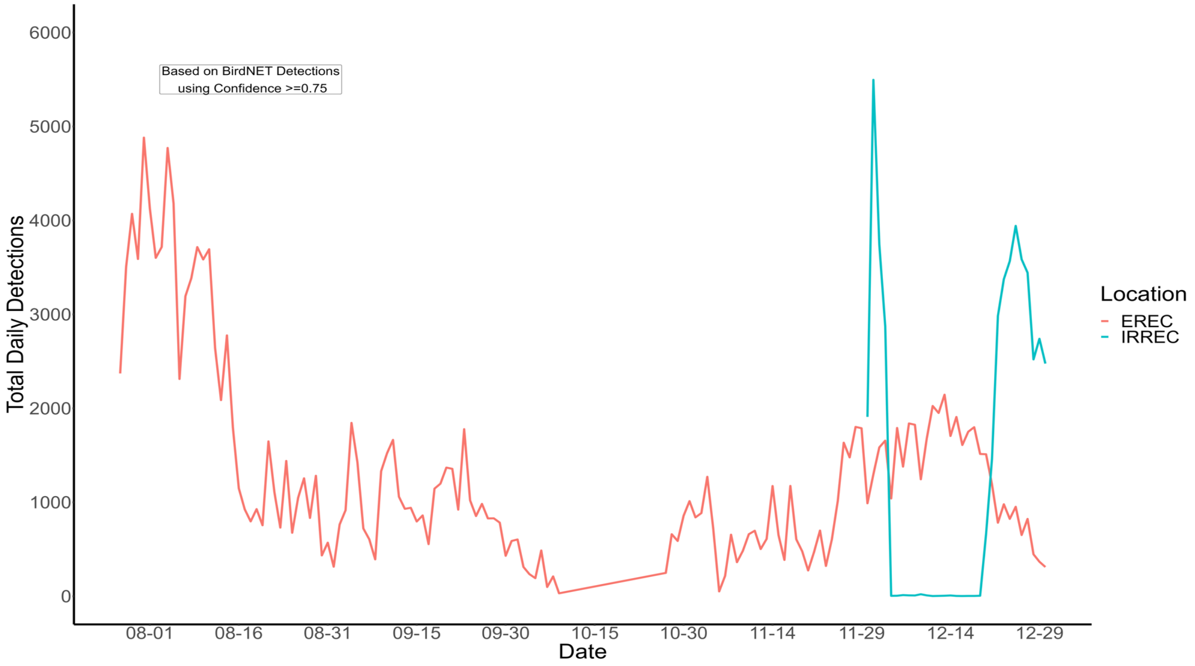
Examples

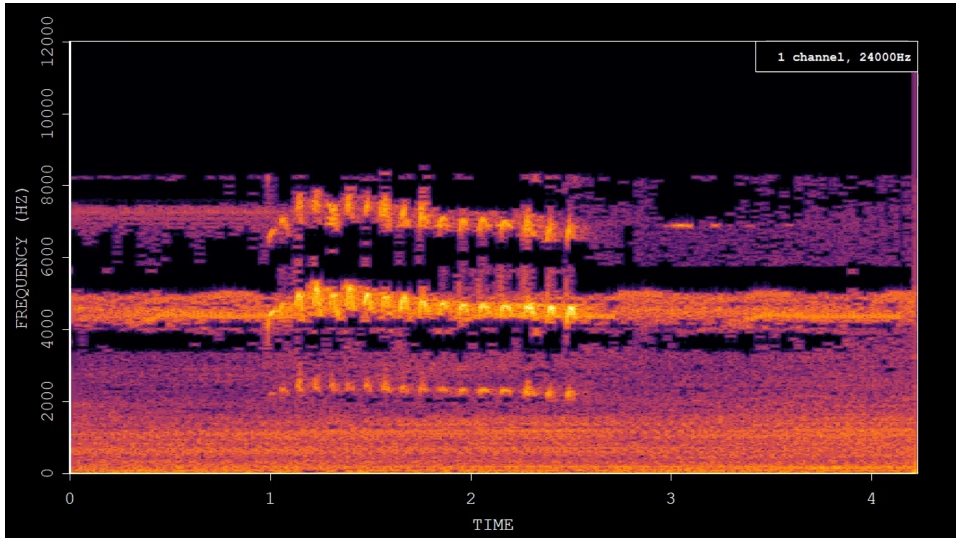
2- Progress and Outcomes (Avian and Wildlife Assessment)

- Over 9K recordings (>800 GB) and 50K images (500 GB) since deployment
- >100 bird species detected
- Cameras recorded the presence of several bird and wildlife species

Site	Number of Recorders	Year	Detections Per Month*	Most Detected Species
EREC	4	2021	36,856	(1) Common Nighthawk, (2) Killdeer, (3) Common Yellowthroat
IRREC	4	2021	47,986	(1) Killdeer, (2) Boat-tailed Grackle, (3) American Kestrel

* These numbers are the sum of repeated detections. These numbers do not represent the total number of individuals as individuals may be detected more than once.



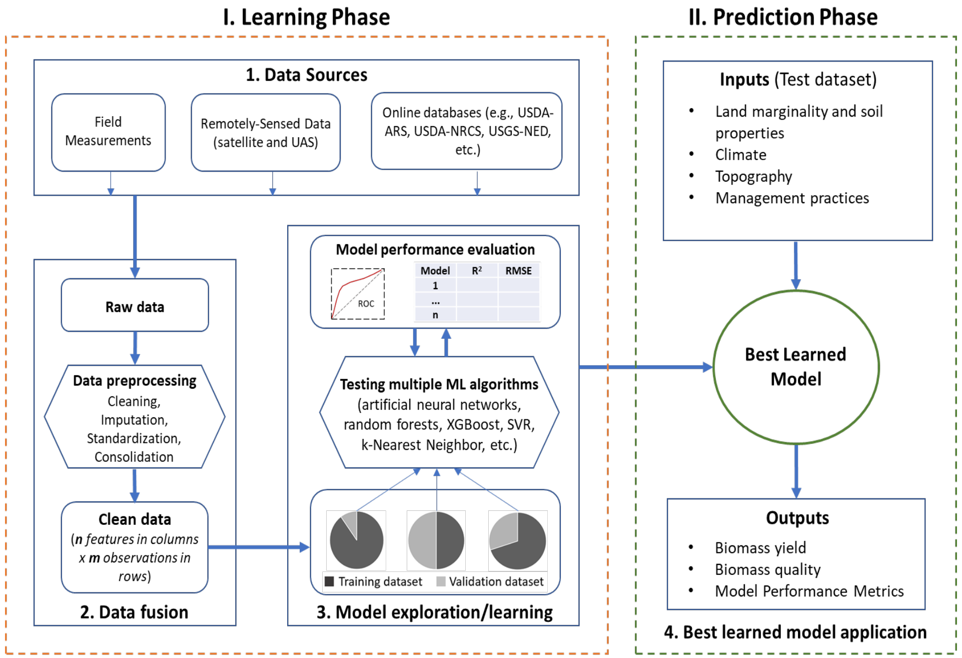


Cayote

2- Progress and Outcomes

(Machine Learning [ML] Model Development)

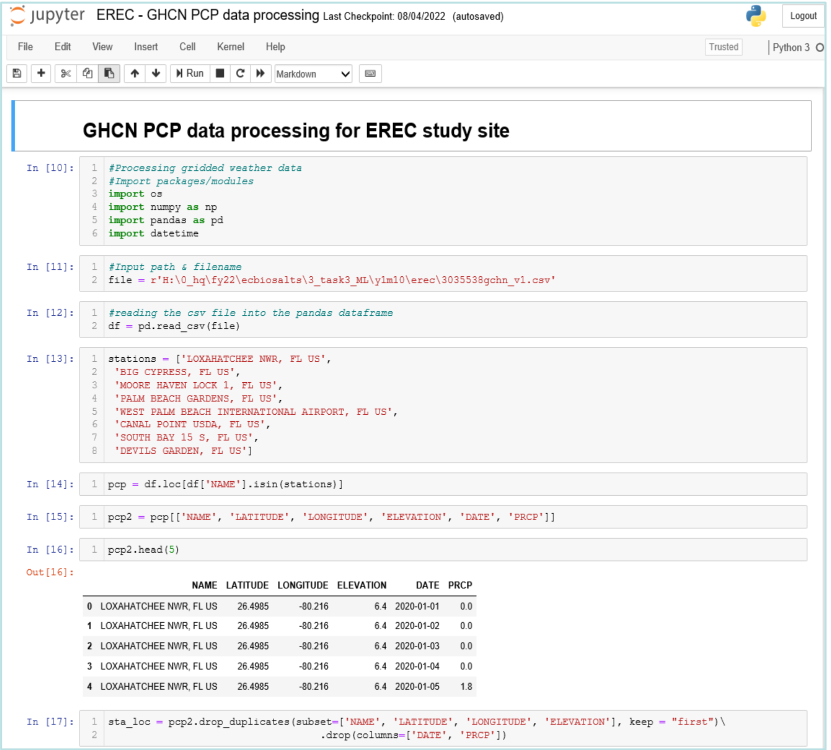
- Developed the Python-based ML model's conceptual framework



- Identified relevant data and sources

Predictors	Variable Code	Variable description and units	Source
Climate	tmp_jan_avg	average of January temperature (°C)	Weather stations at the study sites and of the USDA-ARS, NOAA, and COOP close to the study sites
	tmp_feb_avg	average of February temperature (°C)	
	tmp_mar_avg	average of March temperature (°C)	
	tmp_apr_avg	average of April temperature (°C)	
	tmp_may_avg	average of May temperature (°C)	
	tmp_jun_avg	average of June temperature (°C)	
	tmp_jul_avg	average of July temperature (°C)	
	tmp_aug_avg	average of August temperature (°C)	
	tmp_sep_avg	average of September temperature (°C)	
	tmp_oct_avg	average of October temperature (°C)	
	tmp_nov_avg	average of November temperature (°C)	
	tmp_dec_avg	average of December temperature (°C)	
	tmp_JM_avg	average of the Jan-Mar temperature (°C)	
	tmp_AJ_avg	average of the Apr-June temperature (°C)	
	tmp_AS_avg	average of the Aug-Sep temperature (°C)	
	tmp_SD_avg	average of the Sep-Dec temperature (°C)	
	tmp_YR_avg	average annual temperature (°C)	
	pcp_JM_sum	sum of the precipitation from Jan-Mar (m	
	pcp_AJ_sum	sum of the precipitation from Apr-Jun (mr	
	pcp_AS_sum	sum of the precipitation from Aug-Sep (mr	
	pcp_SD_sum	sum of the precipitation from Sep-Dec (mr	
	pcp_YR_sum	sum of the annual precipitation (mm)	
Soil	nccp_idx	national commodity crop productivity index	Field Data, remotely-sensed data, and SSURGO (USDA-NRCS)
	awwater_cap	available water capacity	
	sand_prcnt	percentage of sand (%)	
	silt_prcnt	percentage of silt (%)	
	clay_prcnt	percentage of clay (%)	
	som_cntnt	soil organic matter (%)	
	tn_cntnt	total nitrogen content	
	tp_cntnt	total phosphorus content	
	k_cntnt	potassium content	
	cationex_cap	cation exchange capacity	
	pH	potential of Hydrogen	
	bulk_d	bulk density, g/cm3	
Topography	elev	elevation (m)	Field Data, USDA-NRCS, and USGS
	slope	slope (%)	
	curvature	soil surface curvature (10^{-2} m)	
Management	n_rate	kg per ha	Field data
	p_rate	kg per ha	
	k_rate	kg per ha	
	pstcyd_rate	kg per ha	
Response Variable			
Agronomic Attributes	yld	dry biomass yield, Mg per ha	Field data and UAS generated data
	biomass qualit	biomass quality parameters (% of biomass yield)	

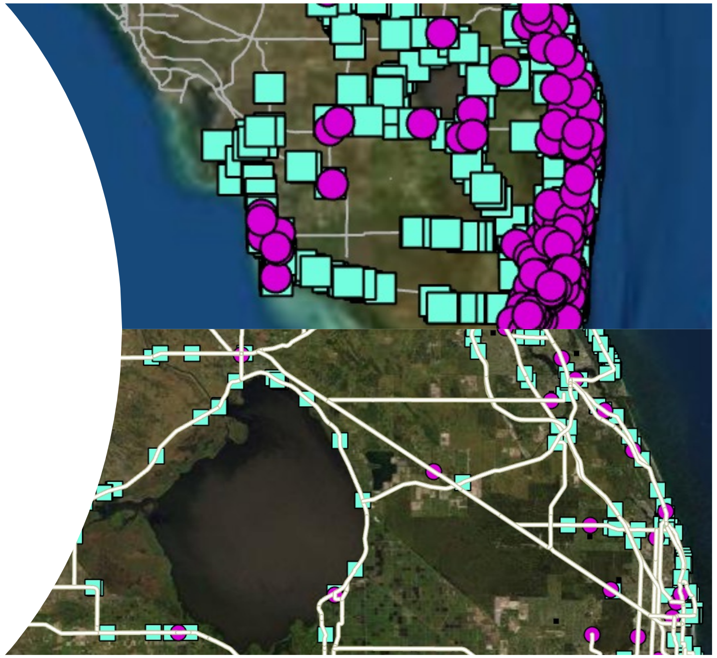
- Developed Python programs to automate input data processing



2- Progress and Outcomes

(Technoeconomic analyses)

- Estimate changing water quality on outdoor recreation economy, wastewater treatment plants
- Estimate establishment costs on fallow & marginal land at scale, compare to business as usual, water farming (on-going)
- Valuate ecosystem services of planted crops (pending)



Crop/ BMP	Production cost (ha-1)	Yield (ha-1)	Unit Cost	Gross (ha-1)	Revenue (ha-1)
Sugar Cane+	$1,350	86 tons	$25.00	$2,150	$800
Sweet Corn*	$13,892	260 cwt	$56.20	$14,600	$708
Citrus (oranges)†	$4,450	383 boxes	$12.50	$4,780	$330
Water Farming	n/a	n/a	n/a	n/a	$120
Energy Cane+	$1,350	74 tons	TBD	TBD	TBD

- Connect spatial prioritization of facilities and their needs (minimum biomass) to transportation costs for producers

3-Impact (Significance of Outcomes)

- Combining high biomass production of EC with the value of provided ES such as increased soil carbon and decreased nutrient loading will increase its economic viability and sustainability.
- Our field-scale trials for fallow lands lay down the template at working scale for transforming vast areas of citrus groves currently abandoned/idle due to citrus greening into a sustainable EC feedstock production system that contributes to positive farm productivity and economics, while protecting land and water resources.
- We will develop remote sensing (RS) methods specifically for EC feedstock production systems and an ML model with predictive capabilities of EC's agronomic attributes.
- Accurate ML model coupled with validated RS technology is a big step towards utilizing precision agriculture platform in bioenergy production systems for improved allocation of resources and maximizing returns.

3-Impact (Significance of Outcomes)

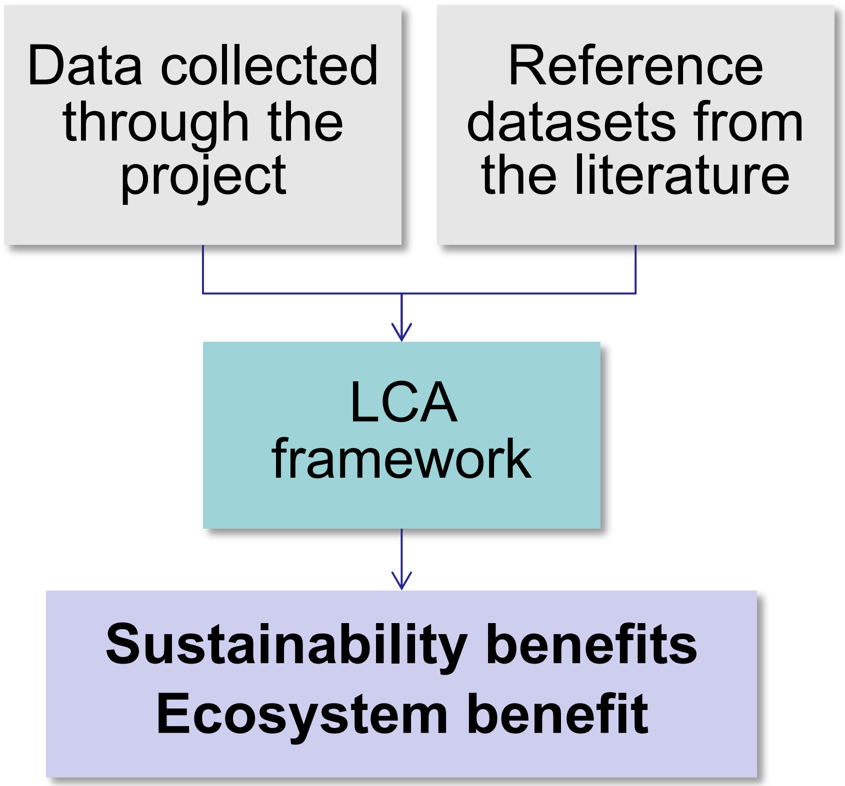
- This project will
  - Contribute to overall goal of producing >4 dry tons/ac annually at a cost of <$84/dry ton with high-yielding bioenergy energycane on marginal and fallow croplands
  - Contribute to establishing USSCP as a potential region outside of the Midwest, Southwest, Northwest, and Northeast where feedstock for sustainable aviation fuel and co-products can be produced
  - Facilitate the establishment of USSCP as a major SAF hub through scientifically informed technoeconomic analyses and market transformation plan and collaboration with LanzaTech, a leading SAF producer
  - Help address water quality issues through innovative feedstock production practices and boost rural economics by providing an alternative production system to citrus farmers who are severely impacted by “citrus greening”
  - Encourage producers to integrate energycane on their farms by 1) demonstrating how energycane can be sustainably produced through ILM at scale, 2) showing the economic benefits of feedstock production and ES benefits of energycane, and 3) providing new decision-making tools integrating data science and precision farming technology.

3-Impact (Significance of Outcomes)

- This project will
  - Educate the public and stakeholders on sustainable biomass production systems and practices through annual on-site field day
  - Contribute to scientific and technical information dissemination through peer-reviewed publications, technical reports, and presentations at professional conferences
  - Contribute to BETO data repository (Knowledge Discovery Framework) and the general public archive for ML model source code (e.g., GitHub).
  - Provide the general public with additional accessibility to project findings through ANL and UF team research program webpages
  - Contribute to BETO’s efforts in diversity, equity, and inclusion as well as bioeconomy workforce development by involving students from diverse backgrounds in research project activities through the DOE’s Student Undergraduate Laboratory Internship program.

3-Impact: Sustainability benefits (cont.)

- Through LCA, reductions in GHG emissions at farm level or SAF production level are quantified. By comparing the results with conventional systems, overall emission reduction benefits are estimated.
- Energycane-derived SAF can help meet the U.S. federal goal of SAF production – 3 billion gallons per year by 2030 while achieving GHG emissions reduction.
- Other sustainability benefits are presented by using marginally productive and fallow/abandoned crop lands to restore health of surrounding ecosystems.



Summary

- Blue-green algal blooms and red tides are major environmental challenges in the U.S. Southeast Coast Plains, particularly in Florida
- Developing an energycane (EC) production system that utilizes fugitive N and P from commodity croplands could provide needed feedstock for a thriving bioeconomy and help address the region's water quality problems
- Two field trials: one with ILM approach and the other to provide an alternate crop
- Successful propagation of EC seed cane and planting of field trials (Go/No-go decision #1)
- Baseline data collection completed
- Data on biomass and ecosystem services in plant cane crop already started
- Combining high biomass production of EC with the value of provided ES such as increased soil carbon and decreased nutrient loading will increase its economic viability and sustainability.

Quad Chart Overview

Timeline
- *10/01/2020*
- *09/30/2026*

	FY22 Costed	Total Award
DOE Funding	*(10/01/2021 – 9/30/2022)* *$353,485*	*(negotiated total federal share)* *$3,992,520*
Project Cost Share *	$72,241	$999,401

TRL at Project Start:

TRL at Project End:

Project Goal
The overall goal of this project is to develop and evaluate an energycane (EC) feedstock production system on marginal and fallow croplands of the U.S. Southeast to support the emerging bioeconomy.

End of Project Milestone
The end goal is to develop sustainable bioenergy feedstock production systems in marginal and fallow croplands of the USSCP utilizing 1) a dependable (low input, high yielding, pest/disease resistant, and regionally adaptable) crop cultivar, and 2) quantification of ecosystem services measured as a 20% nutrient loading reduction and a 25% avian abundance increase compared to traditional cropping systems.

Funding Mechanism
DE-EE0009281

Bio-Restore

Project Partners*
- Argonne National Lab (ANL)
- Lanzatech Inc.
- Florida Department of Environment Protection

*Only fill out if applicable.