Final Project Report
Pacific Islands Climate Adaptation Science Center

Project Title: Can compost from a nitrogen-fixing tree, *Falcataria moluccana*, replace chemical fertilizer and store carbon in agricultural systems?
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General summary

The challenges of food production, invasive species control, and climate change are intersecting, as they all stem from our ongoing use of land and energy on a global scale. In East Hawaiʻi, two problems involving these issues are reflective of global trends. First, an expansion of agriculture is needed here, yet upland agricultural tracts are typically troubled by inherent low fertility, physically degraded, and depleted of soil carbon from tillage. They can require fertilizer inputs that are environmentally costly. Second, the invasive, nitrogen-fixing tree *Falcataria moluccana* (albizia) is dominating landscapes and altering ecosystems with rapid-cycling carbon and nitrogen inputs. These two problems are predicted to intensify with climate change, as growing conditions in each region shift and higher temperatures and carbon dioxide levels favor fast-growing, N-fixing species. Yet each of these problems could hold a remedy for the other, using practices described in the new field of climate-smart agriculture (CSA). Hawaiʻi Island presents a unique opportunity to test whether or not accumulated nutrients from *F. moluccana* growth can be used as a compost that can benefit agricultural systems lacking in fertility, due to the intensity and grave consequences of the *F. moluccana* invasion, as well as the underutilization of agricultural land and lack of food self-sufficiency in Hawaiʻi. The Big Island Invasive Species Committee (BIISC) has deemed *F. moluccana* one of the worst invasive species on this island, and while they have made great strides controlling the tree near power lines and human habitation, there is a gap in knowledge about how the biomass from this tree can be utilized. This study examined whether compost from *F. moluccana* can replace chemical fertilizer and store carbon in agricultural lands in East Hawaiʻi. This research was designed and completed with the partnership of invasive species managers and farmers to maximize the usefulness of the research to the local community.

Technical Summary

Agriculture accounts for most land conversion globally, and this large-scale depletion of earth's surface biomass and soil, along with further offsite emissions, accounts for a quarter of total climate change forcing (IPCC 2014). The UN has adopted a conceptual framework of climate-smart agriculture (CSA) to inform how agriculture can address climate change while continuing to feed the global population. CSA involves best management practices but also a rethinking of goals and decision factors surrounding agriculture (FAO 2013). The depleted state of agricultural soil carbon (Stewart et al. 2008) and the inefficiencies of some practices make agricultural a promising sector for carbon sequestration (Lal 2010) and emissions reduction (Steenwerth et al. 2014). Composting is one of the recommended management practices in climate smart agriculture, and an additional benefit of compost production and application comes when the feedstock used is an invasive species.

Invasive species are defined by their ability to accumulate carbon and nitrogen in growing biomass to the point of being problematic, but these are generally short term stores that decompose quickly and lead to rapid nutrient cycling through the ecosystem and higher overall losses to the atmosphere and waterways (Hughes & Uowolo 2006). Removing these species from ecosystems and possibly storing their nutrients in stable pools in the soil can lead to a net sequestration of C and N, compared with an uncontrolled invasion.

The purpose of this research is to develop and test a CSA method of compost application using invasive species. The methods studied here have been shown to maintain or increase crop yields and increase soil carbon, but there are large gaps in knowledge about crop response in different settings. The trade-offs between environmental costs/benefits and crop yields need to be examined closely because agriculture involves many conflicting priorities. In some agricultural trials, intensifying production with synthetic fertilizers can lead to lower net GHG emissions per yield than organic methods, because higher yields per area lets more land stay uncultivated and in its natural state (Robertson & Grace 2004). In other trials, organic methods produce equivalent yields to fertilizer, but the labor involved with the organic methods makes them prohibitively costly (Miyasaka et al. 2001).

Hawaiʻi presents a unique set of conditions for testing alternative methods of agricultural production and invasive species control. The lack of food sustainability in Hawaiʻi is a subject of much concern here, both because of the under-utilization of available land and the vulnerability that dependence on long-distance shipping brings to the food supply. While production of plants for food is lacking, other plants that are invasive species are growing vigorously here. One nitrogen-fixing tree that has become problematic throughout the islands of Hawaiʻi is *Falcataria moluccana* (albizia), which displaces native forest and deposits large amounts of carbon and nitrogen into soils, which drive further invasion (Hughes & Uowolo 2006). BIISC is tasked with addressing invasive species on this island, and they have deemed this tree one of the worst invasive species here. While they have succeeded in clearing much of the problematic trees from areas above power lines and human habitation, the invasion continues in other areas, and funding to do more control is lacking. More uses for the tree would facilitate more control efforts by the public. In this study we examined crop performance using albizia compost as an amendment, in comparison to a control treatment using chemical fertilizer. This is one of many potential CSA methods that could improve the food production system, but trials must be done in local conditions to see if methods compare favorably to status quo approaches. This research has been done with a focus on asking useful questions and providing useful results to managers and the public, including invasive species managers such as BIISC but also farmers, gardeners, and residents of Hawaiʻi.

Goals

This research seeks to answer the following questions: 1.) How does application of albizia (*F. moluccana)* compost to crops affect plant yield, plant and soil nutrient levels, and soil aggregation compared to chemical fertilizer with equivalent levels of available nitrogen? 2.) What are the differences in economic cost and carbon emissions and/or storage arising from the different treatments? Answering these questions will help farmers and land managers decide if composting albizia for farmland use is a viable solution.

Methods

Agricultural field trials were conducted over one growing season and included two crops, *Zea mays* (corn) and *Manihot esculenta* (cassava), and 4 replicates across a spectrum of East Hawaiʻi farmland sites representative of varying soil conditions and land use history (Table 1).

Table 1. Soil series, taxonomic class, and land use history for study sites (Melrose et al. 2016; NRCS 2017, 2019).

Site	soil series	Taxonomic class	Land use history
Pepeʻekeo	Kaiwiki hydrous silty clay loam	Hydrous, ferrihydritic, isothermic Acrudoxic Hydrudands	sugarcane, then sweet potato
Kolekole	Hilo hydrous silty clay loam	medial over hydrous, ferrihydritic, isohyperthermic Acrudoxic Hydrudands	sugarcane, sweet potato, cassava
Honomū	Hilo hydrous silty clay loam	medial over hydrous, ferrihydritic, isohyperthermic Acrudoxic Hydrudands	sugarcane, then fallow
Kapaʻau	Ainakea medial silty clay loam	medial, ferrihydritic,isohyperthermic, Acrudoxic Hydric Hapludands	fallow

Treatments included a control, a typical application of chemical fertilizer (1N nitrogen applied), two levels of albizia compost (1N and 2N levels of nitrogen applied), and two levels of combinations of chemical fertilizer and compost (1N and 2N) (Fig. 1).

Tr.1 control	Tr. 3 1N albizia compost	Tr. 5 1N combo
Tr. 2 1N fertilizer	Tr. 4 2N albizia compost	Tr. 6 2N combo

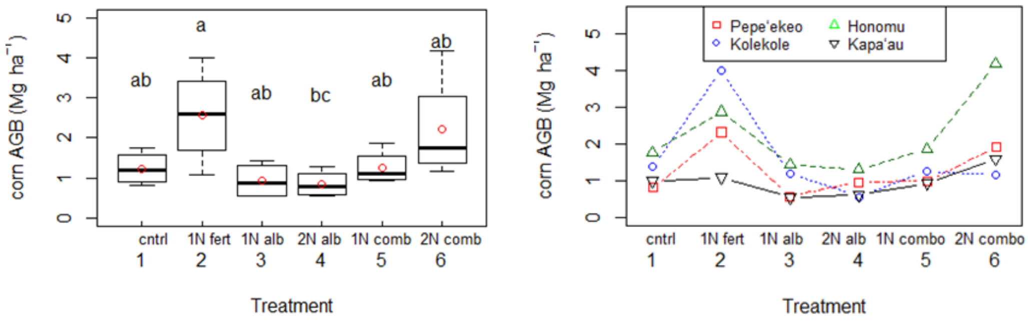
Fig. 1. Treatment numbers and description at each site for each crop. Albizia is the common name for the invasive N-fixing tree *Falcataria moluccana*.

Harvest yield results were analyzed, and plant and soil nutrients including carbon, nitrogen, phosphorus, and other elements were also assessed in the lab and compared across treatments. Soil aggregation was measured and analyzed as a proxy variable indicative of soil carbon storage and microbial activity. Economic and carbon costs were compared across treatments using measured soil carbon levels and costs and emissions resulting from the inputs of fertilizer and fuel usage (for the chipper used to process albizia for composting). Treatments and locations were compared using ANOVAs or Kruskal-Wallis tests for non-parametric variables. To look at relationships between individual plant and soil nutrients and yield, correlation tests were run, using Pearson's method or Spearman's method for non-parametric variables.

Results

Corn trial

Yields and costs for the alternative treatments versus the control treatments varied with the crop tested. Harvest yield results showed that the albizia compost was not an adequate replacement for chemical fertilizer in the corn crops. Yields were higher in the 1N chemical fertilizer treatment than the 2N albizia compost treatment, and all other treatments were equal (Figs. 2a and 2b). Economic and carbon costs were also equal across most treatments, though they were actually higher in the 2N albizia treatment due to low yields per area (Table 2). Results suggest that more distinct differences in treatment yields and costs were present at each site, but large variation between sites led to large standard deviations and made these patterns statistically not significant.



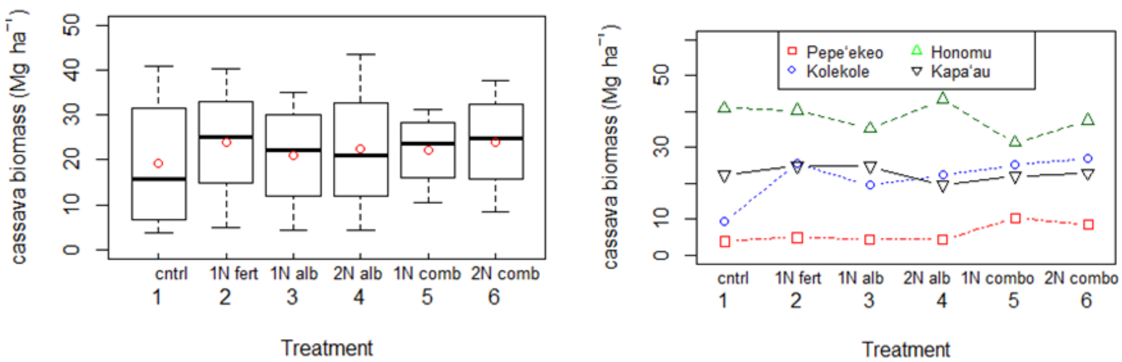
Figs. 2a and 2b. 2a. Boxplot of corn aboveground biomass (AGB) yields by treatment. Means are represented by red circles, medians by the midline of each box, edges of the box shows the upper and lower quartiles, whiskers show the highest and lowest value excluding outliers. and letters indicate groupings with different means. 2b. Interaction plot of corn AGB yields by treatment, lines showing yields by site.

Table 2. Economic and carbon costs, and soil carbon gain or loss for each treatment in the corn trial. Results of ANOVAs and Kruskal-Wallis tests are listed, significant p values are in bold. Letters indicate groupings with different means. Standard deviation in parentheses.

Treatment	**economic cost ($ kg yield^{-1})**	**CO_2 emissions (kg CO_2 kg yield^{-1})**	**increase in soil C (Mg C ha^{-1})**	**CO_2 emissions (Mg CO_2 ha^{-1})**	**total C gain or loss (Mg ha^{-1})**
(1)control	0.00 (0.00) [a]	0.00 (0.00) [a]	0 (0)	0.00	0 (0)
(2)1N fert	0.31 (0.22) [ab]	0.46 (0.33) [ab]	-1.19 (5.85)	0.45	-1.31 (5.85)
(3)1N albizia	0.93 (0.73) [ab]	2.43 (1.90) [ab]	2.45 (1.17)	0.43	2.33 (1.17)
(4)2N albizia	1.53 (0.98) [b]	4.00 (2.56) [b]	4.11 (2.80)	0.86	3.88 (2.80)
(5)1N combo	0.64 (0.23) [ab]	1.33 (0.48) [ab]	1.16 (2.42)	0.65	0.98 (2.42)
(6)2N combo	0.68 (0.34) [ab]	1.41 (0.70) [ab]	6.42 (5.25)	1.31	6.07 (5.25)
F stat					2.259
Chi-sq	14.774	17.205			
df	5	5			5,18
p-value	**0.011**	**0.004**			0.093
transformed	no	no			no

Cassava trial

In contrast to the corn trial, albizia compost produced cassava yields equal to chemical fertilizer (Figs. 3a and 3b). Variation among locations and within locations was larger than variation due to treatment in the cassava trial, but results suggest that the compost application was more effective on more degraded farm sites, which were the Kolekole and Pepe‘ekeo sites. (see Fig. 3b for yields by site). Economic and carbon costs associated with the chemical fertilizer and albizia compost applications were generally not different across treatments, and a partial analysis of carbon gained or lost was also similar across treatments (Table 3).



Figs. 3a and 3b. 3a. Boxplot for cassava total biomass yield by treatment. Means are represented by red circles, medians by the midline of each box, edges of the box shows the upper and lower quartiles, and whiskers show the highest and lowest value excluding outliers. 3b. Interaction plot for cassava yields by treatment, lines indicate yields by site.

Table 3. Economic and carbon costs, carbon storage for each treatment in the cassava trials. Letters that are similar within a column are not significantly different.

Treatment	**economic cost ($ kg yield^{-1})**	**CO_2 emissions (kg CO_2 kg yield^{-1})**	**increase in soil C (Mg C ha^{-1})**	**CO_2 emissions (Mg CO_2 ha^{-1})**	**total C gain or loss (Mg ha^{-1})**
(1)control	0.00 (0.00) ^{a}	0 (0) ^{a}	0 (0)	0.00	0 (0)
(2)1N fert	0.041 (0.037) ^{ab}	0.061 (0.055) ^{ab}	7.38 (9.27)	0.36	7.28 (9.27)
(3)1N albizia	0.024 (0.022) ^{ab}	0.064 (0.059) ^{ab}	7.94 (10.2)	0.32	7.86 (10.2)
(4)2N albizia	0.048 (0.046) ^{ab}	0.126 (0.119) ^{ab}	7.11 (9.33)	0.64	6.94 (9.33)
(5)1N combo	0.033 (0.012) ^{ab}	0.067 (0.024) ^{ab}	6.96 (10.2)	0.50	6.83 (10.2)
(6)2N combo	0.072 (0.040) ^{b}	0.148 (0.083) ^{b}	8.02 (11.3)	1.00	7.75 (11.3)
F stat					
Chi sq	13.91	13.93			10.003
df	5	5			5
p-value	**0.016**	**0.016**			0.075
transformed	no	no			no

Soil aggregation was only measured in the cassava trial, as aggregation would not have time to accrue in the time span of corn's three month growing season. While most plant and soil nutrients measured did not correlate with yield results, and did not change with treatment, soil aggregation did correlate with cassava yield ($r = 0.59$, $p = 0.002$) (Fig. 4). This integrative measure of soil health, structure, and microbial activity also did not differ by treatment ($F_{5,18} = 1.6$, $p = 0.211$), but it did differ by site (($F_{3,20} = 5.8$, $p = 0.005$). Together these results indicate that soil aggregation and general physical structure of the soil is key to improving cassava yields, but the treatments applied had little effect on this variable compared to the pre-existing differences seen across locations of farm sites.

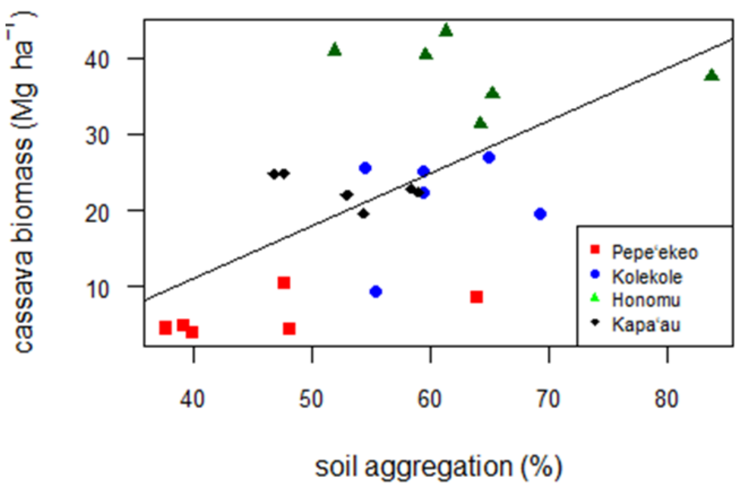


Fig 4. Scatterplot of cassava biomass and soil aggregation. Sites are indicated by colors and symbols of data points.

The results of these field trials show that CSA using albizia compost is a viable economic and environmental alternative to chemical fertilizer in some sites and with some crops. When the site is in need of organic matter (OM) and soil carbon, and when the crop has characteristics such as a long growing season or ability to grow in low fertility areas, then this alternative approach becomes a more viable option.

Collaborative Elements

This research has been done with a focus on asking useful questions and providing useful results to managers and the public, including invasive species managers such as BIISC but also farmers, gardeners, and residents of Hawaiʻi. With that focus in mind, I crafted a research question together with BIISC and local farmers that addressed problems in their fields and also considered questions related to climate science. Could an approach to invasive species control also help farmers? Could an alternative agriculture technique also address the invasive species issue? Could any of these approaches also help farmland and invaded lands adapt to climate change, and/or store carbon to mitigate climate change? These questions percolated in my mind for years as I listened to community members and farmers voice their ideas about farming alternatives and potential uses for albizia. The specific design of the study was decided on through discussions with Springer Kaye, the director of BIISC and also a knowledgeable farmer, and with Alan Hoeft, a farming colleague who has been implementing a similar method at his farm for years. The involvement of BIISC and farmers throughout the research has helped to keep this study integrated and applicable across disciplines.

These results are being shared with all involved community partners, including BIISC and local farmers and gardeners. I am publicizing the results of this work in the community by giving talks, tours of the farm trial, and most commonly having conversations with interested people. When I gave a tour of the farm sites at harvest, I had the help of local filmmaker Jordan Christopher in getting the event filmed. He has helped me produce a short film for the general public that summarizes this study, so that the results can be shared widely into the future. I plan on collaborating further with BIISC to publicize the results of this study through media and community meetings, and to be part of ensuing discussions on the economic uses of albizia compost. This research could lead to development of a business that makes and distributes albizia compost.

This study uses a simple framework for analyzing the costs and benefits of different agricultural approaches that the general public might find feasible. It is my hope that this study can join other research on local alternative agricultural methods in creating a fuller library of climate-smart agriculture options.

Conclusions

Transformations in agricultural practices and invasive species management are necessary to address the global issues of climate change and land degradation. Composting is an accessible climate-smart agriculture strategy and using local invasive species as feedstock could turn a problem waste material into a valued product. The research done here was designed and conducted with the involvement of invasive species managers and local farmers to ensure that the questions posed and the answers reached are useful for the community of people working on the land. Harvest results showed that in the corn trial compost alone was not as good as chemical fertilizer. In the cassava trial, the albizia compost produced equal yields to the chemical fertilizer and had similar costs, emissions, and carbon storage. For this crop, composting can be a viable substitute for fertilizer that also stimulates harvesting and use of the invasive tree *F.*

moluccana. Site conditions including soil nutrients and land use history outweighed the treatment effect for cassava, but not for corn. Cassava trials were similar across treatments while corn trials responded to the treatments. Awareness of soil conditions and characteristics of the crop species is key before deciding whether to use albizia compost or other organic amendments. This study is one early step in working with community partners to test climate-smart agricultural techniques in Hawaiʻi. While crop species, site, and quantities of compost applied have a large effect on viability of this technique, results point to the potential of organic methods to decrease fertilizer use and store carbon in farmland soils.

Presentations

All presentations below given by Joanna Norton, listed by date presented. Name of presentation is thesis title unless otherwise listed.

- UH Hilo Thesis defense, Hilo, HI. April 2019.

- UH Hilo TCBES Symposium, Hilo, HI. April 2019

- Farm tour and presentation of research plots to local stakeholders, Honomū, HI. November 2018

- Sustainable Agriculture Education Association (SAEA) annual conference, Kapolei, HI. Listening to community needs and testing community solutions: Can compost from an invasive tree replace fertilizer and store carbon in agricultural systems in Hawai'i? July 2018

- Hawaiʻi Conservation Conference, Honolulu, HI. July 2018

- Hawaiʻi Ecosystems Meeting, Hilo, HI. June 2018

- Graduate Climate Conference, Woods Hole, MA. November 2017

- Hawaiʻi Conservation Conference, Honolulu, HI. Knowledge coproduction forum. July 2017

- Hawaiʻi Ecosystems Meeting, Hilo, HI. June 2017

- Islands Sustainability Conference, Tumon, Guam. April 2017

- UH Hilo TCBES Symposium, Hilo, HI. April 2017

- Hawai‘i Ecosystems Meeting, Hilo, HI. June 2016

- UH Hilo TCBES Symposium, Hilo, HI. April 2016

Research Products

In addition to presenting this research at local and national conferences, and in more casual conversations with farmers and land managers, we have created a short film with filmmaker Jordan Christopher that summarizes the research. It will be available on YouTube (film is in final stages of editing, no link at the time this report is written). This film will be the primary way that I convey the results of the study to the general public, and I intend to make it available to BIISC. I will also be collaborating on future events with BIISC to publicize and discuss the work, when they feel the events are fitting. This film can also be shown at farmers' gatherings such as CTAHR Agricultural Extension events and meetings of HFUU (Hawai‘i Farmers Union United), HOFA (Hawai‘i Organic Farming Association), and the Farm Bureau.

Photos

Plate 1. Planting of corn trial at Kolekole site.

Plate 2. Cassava trial growing at Honomū site.

Plate 3. Land prep at Kapa'au site, with helpers.
All photos taken by J. Norton.

Collaborators

Collaborators for this project have remained the same for the duration of the work, including my three committee members Drs. Rebecca Ostertag (UH Hilo, TCBES), Bruce Mathews (UH Hilo, Agriculture), and R. Flint Hughes (U.S. Forest Service, IPIF). Springer Kaye, director of BIISC, has been a crucial community partner both in her role as manager on the frontline of albizia control here on Hawaiʻi Island, and as an experienced farmer growing diverse crops in the South Hilo district. Many other farmers have contributed knowledge, effort, and land to this project, including Ann Kobsa, Celia and Ian Bardwell-Jones, Alan Hoeft, Victor Cabada, George Hirowatari, and Atto Assi.

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