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Evaluating the application of biochar on sweet corn production, soil health, and its role in regenerative agriculture

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Title: Evaluating the application of biochar on sweet corn production, soil health, and its role in regenerative agriculture

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ABSTRACT

Biochar, which is a carbon-based organic material that can be used as a soil amendment, has been found to improve many aspects of crop production and soil health. Studies have been conducted to see the effect biochar has on weathered tropical soils, but not many have focused on biochar's effect on overall crop production locally. This study was conducted to determine the effect biochar has on plant growth, yield, quality, and soil health in Hawai'i's conditions using sweet corn (*Zea mays*) as a test crop. For this study, biochar was applied at the rate of 12.3 t/ha in an Oxisol and Mollisol soils. The biochar application in the Oxisol resulted in significant ($p < 0.05$) differences with a 18.8% increase in vegetative growth, a 19.1% increase in yield, and 1.7% increase in sugar content compared to the no biochar application. The biochar application in the Mollisol resulted in significant ($p < 0.05$) differences with a 33% increase of vegetative growth, 8.3% increase in yield, 10.1% increase in sugar content, 53.1% increase in TEC, 40.1% increase in carbon, 41.8% increase in nitrogen, 8% increase in pH, 34.5% increase in CO_2 soil respiration rate, and a 33.3% increase in infiltration rate compared to the control. These results show that the application of biochar improves the overall crop production of sweet corn and soil health in Hawai'i and would be a beneficial amendment for regenerative agricultural practices.

Keywords: Regenerative agriculture, Crop yield, Nutrient management, Tropical soils.

1. INTRODUCTION

The human population in 2019 was at 7.7 billion, with predictions by the United Nation (UN) to reach 8.5 billion by 2030 and is expected to reach 9.8 billion by 2050 [1,2]. To accommodate the increasing population, utilizing regenerative agriculture practices, reclaiming arable land, protecting land and other natural resources, and improving soil nourishment for healthier crop production are critically necessary [3]. Agricultural soils alone rarely contain sufficient nutrients for optimum crop growth and yield [4], so it is important to find additional ways to improve these conditions. A variety of soil amendments, including manure, organic matter, lime, and gypsum, are utilized for the purpose of enhancing soil properties, health, and fertility [5]. However, incorporating biochar into the soil is one of the most efficient and environmentally beneficial methods for preserving soil fertility [6]. Biochar is generated through the process of pyrolysis of organic waste in anaerobic conditions and the result is a solid product with a high recalcitrant carbon proportion [7]. Biochar as one of the recommended regenerative agriculture practices has many

potential benefits as a soil amendment: it improves soil structure, decreases bulk density of soil, and neutralizes acidic soil [8]. It also improves pore volume and soil porosity, enhances soil cation exchange capacity [9], facilitates a positive change in soil organic matter [10], and increases the plant-available water and nutrients by improving the soil physical, chemical, and biological properties [11,12]. The biochar stores carbon in the soil organic matter, which assists in carbon sequestration [13]. It also helps to reduce the release of greenhouse gases in the atmosphere [14]. Biochar improves water retention by increasing soil porosity and enhancing water-holding capacity due to its high surface area, which helps plants survive during drought [15]. It also promotes nutrient cycling by enhancing microbial activity, creating a more favorable environment for microorganisms that break down organic matter and release essential nutrients like nitrogen and phosphorus [16]. These mechanisms collectively improve soil structure, water availability, and overall plant health.

In the past few years, there has been an increasing need and demand for regenerative agricultural practices. With this increase, more studies have emerged that reinforce the science behind the concepts of regenerative agriculture which includes the importance of soil health, increasing carbon sequestration, and improving ecosystem services [17]. While there is not one definition for regenerative agriculture, the themes of improving soil health, reducing environmental damages, minimizing waste, and improving water quality all fall under the term of regenerative agriculture in an attempt to improve the natural environment and work to reduce thedamages already done [18]. Regenerative agriculture includes practices that revolve around crop rotation, minimal external inputs, use of manure and compost, use of perennials, mixed farming, minimal tillage, and other soil health improvement activities such as incorporating biochar, with the main objectives focusingon improving soil, environment, and human health [19,20]. With many different applicable practices for regenerative agriculture andimproving soil health, utilizing biochar is a great method to incorporate into agricultural practices.

Krismawati [21] conducted two trials in the Java area on Maize under biochar applications. Their results showed a significant increase of in crop yield by ~36% when biochar was applied on top of the farmer's practices. Naeem [22] evaluated the application of biochar at 12.3 and 24.7 t/ha on maize yield under different irrigation regimes in Pakistan. They found that maize total seed weight increased significantly by 29% compared to control (0 t/ha biochar) application, with the 12.3 t/ha rate yielding superior results compared to the 24.7 t/ha. Maize is very versatile and grown widely for food, feeds, biofuels, medicine, and industrial purposes [23]. As per the International Production Assessment Division (IPAD) of United States Department of Agriculture (USDA), the global production

of maize was 1.16 billion MT in 2022. Hawai‘i specifically has value in growing sweet corn as there is high demand for the vegetable in local markets, along with the state having a large production of sweet corn seed [24]. There has been growing interest in the use of biochar as a soil amendment in different soil types, especially in tropical soils, but limited research has been done on this subject. It is believed that biochar could yield different results depending on the soil type [25]. Specific objectives of this study were to evaluate 1) effects biochar on sweet corn growth and yield; 2) effects of biochar on soil health; and 3) the performance of biochar in different soil types.

2. MATERIALS AND METHODS

2.1 Study sites:

This study was conducted at two sites: one at Hawai‘i Agriculture Research Center (HARC), Kunia and the other at the Waimanalo Research Station (WRS), Waimanalo which both are on Oahu, representing the two major agricultural soils in Hawai‘i. Long-term average precipitation in Kunia is 762 mm/year and in Waimanalo is 1,132 mm/year; most of which occurs between November and April with mean annual soil temperature at both sites is 23°C [26]. The soil at Kunia is classified as a Oxisol Molokai series (very-fine, kaolinitic, *isohyperthermic rhodic haplustox*), whereas the soil at Waimanalo is classified as a Mollisol Waialua series (very-fine, mixed, superactive, *isohyperthermicpachic haplustolls*). These soils are also found in basins and on alluvial fans (primary agricultural areas) on the islands of Oahu, Maui and Molokai and were formed on alluvium derived from igneous rock [26].

2.2 Field trials:

Two field trials were conducted in Kunia and Waimanalo, respectively. Sweet corns were planted into soil treated or not treated with biochar prepared according to the method described in section 1.1.4. Experiments were both arranged in randomized complete block designs (RCBD) with five replicates. Two varieties of sweet corn were used at each field trial: ‘Supersweet #9’ and ‘Resolve’ were used in the Oxisol/Kunia trial, and ‘Freedom’ and ‘Resolve’ were used in the Mollisol/Waimanalo trial. The biochar was applied at 12.3 t/ha (approximately 2% of soil weight) to the plots. Feather meal (12-0-0 N-P-K) was applied at the rate of ~200 kg/ha in a split application (50% pre-planting and 50% after a month of planting). A drip irrigation system was used in each growing plot with a timer being used to irrigate twice a day for an hour and adjusted based on environmental conditions. Weeding, pest control, and other agronomic treatments were performed based on the needs of each location.

Initial soil samples were collected before each field trial to ensure sufficient nutrients for the crop and to measure changes in soil fertility. Soil samples were collected at the end of each growing season to evaluate changes in soil fertility. The soil samples were sent to Brookside Laboratories (https://www.blinc.com/) for macronutrient and micronutrient content, pH, and EC. A Solvita "Soil Respiration" Kit (https://solvita.com/) was used to measure changes in soil respiration parameters. Sweet corn leaf relative chlorophyll content, using SPAD Chlorophyll Meter (Minolta Inc., USA), were measured at the time of harvest. Crop yield and quality (fresh and dry biomass and corn husked and un-husked ear weights along with BRIX level) was measured at the end of each growing season. Soil infiltration rate was measured by using a double ring infiltrometer. Method of collecting data was followed as per the instructions of the manufacturer (https://store.turf-tec.com/IN2lit.html). Data was collected at all treatment plots and significant dates during the growing season, along with during the trials (Table 1).

Table 1. Dates of significant times during the growing season for two sweet corn varieties in Kunia and Waimanalo under biochar and no biochar applications.

Corn variety	Sowing	Tasseling	Silking	Harvesting
		Kunia		
Supersweet #9	7/18/24	8/28/24	9/2/24	10/3/24
Resolve	7/18/24	8/20/24	8/23/24	9/17/24
		Waimanalo		
Freedom	6/11/24	7/17/24	7/20/24	8/5/24
Resolve	6/11/24	7/17/24	7/20 /24	8/5/24

2.3 Statistical Analysis:

Analysis of Variance (ANOVA) was performed using Statistix V.10 software (https://www.statistix.com/). Once this was run, a means separation test was run using Tukey's mean separation at 95% confidence, which shows statistical differences between treatments and which of the treatments performed significantly higher. Along with this, a Pearson's correlation test was run to calculate the parameter-to-parameter (sweet corn growth, yield, quality and tissue nutrient content) correlation coefficient.

3. RESULTS

3.1 Statistical Analysis:

At the trial in Kunia, the results showed a consistent pattern, with higher growth parameters in biochar treated plots compared to the control (no biochar) treatment. However, only fresh weight and husked ear weight reached a highly significant ($p < 0.001$) level and then dry weight, ear weight, and BRIX reached a significant ($p < 0.05$) level for the

variety Supersweet #9. Also at Kunia, husked ears reached a highly significant ($p < 0.001$) level and leaf chlorophyll content (SPAD) and plant height reached a significant ($p < 0.05$) level for the Resolve variety. In the trial at Waimanalo, both 'Freedom' and 'Resolve' had numerically higher growth parameters under biochar compared to the no biochar treatment. However, only husked ears and BRIX in Freedom variety reached a significant ($p < 0.05$) level. In Kunia, for the Supersweet #9 variety, the results showed highly significant ($p < 0.001$) difference in nitrogen (N), calcium (Ca), and zinc (Zn) content. While the results showed significant ($p < 0.05$) difference only for phosphorus (P), potassium (K), magnesium (Mg), sulfur (S), boron (B), manganese (Mn), and copper (Cu). However, for the Resolve variety, the ANOVA results presented in showed highly significant ($p < 0.001$) difference in Ca content and significant ($p < 0.05$) difference in K, and sodium (Na) content. The analysis of variance (ANOVA) for the sweet corn tissue macro- and micro-nutrient content in Freedom and Resolve varieties at the Waimanalo location showed that there was a significant difference in some of these nutrients, with the biochar treatment having a higher accumulation/content percentage in both variety's tissue. At Waimanalo, the Freedom variety tissue showed a highly significant ($p < 0.001$) level in S content and significant ($p < 0.05$) levels in Ca, Mg, and Zn content. However, Resolve variety's tissue showed a highly significant ($p < 0.001$) level in P content and significant ($p < 0.05$) levels in S, B, and Cu.

3.2 Sweet Corn Growth, Yield, and Qualities:

The sweet corn fresh weight, dry weight, total ear weight, husked ear weight, BRIX, plant height, and SPAD were collected at harvest. In Kunia, there was a significant ($p < 0.05$) increase in plant growth parameters of 48.4%, 48.1%, 12.5%, and 2.8% of fresh weight (Figure 1), dry weight (Figure 2), husked ear weight (Figure 4), and BRIX (Figure 5), respectively, under biochar application compared to no biochar for the variety Supersweet #9. Also in Kunia, there was a significant ($p < 0.05$) increase in plant growth parameters of 12.7%, 16.2%, and 11.6% for husked ear weight (Figure 4), SPAD (Figure 6), and plant height (Figure 7), respectively, for the variety Resolve. In Waimanalo, there was a significant ($p < 0.05$) increase of 38.5% and 9.12% in husked ear weight and BRIX, respectively (Figure 4 and 5), under biochar application compared to no biochar for the variety Freedom. However, in Waimanalo, there were no significant increases in plant growth parameters for the variety Resolve (Figure 1 to 7).

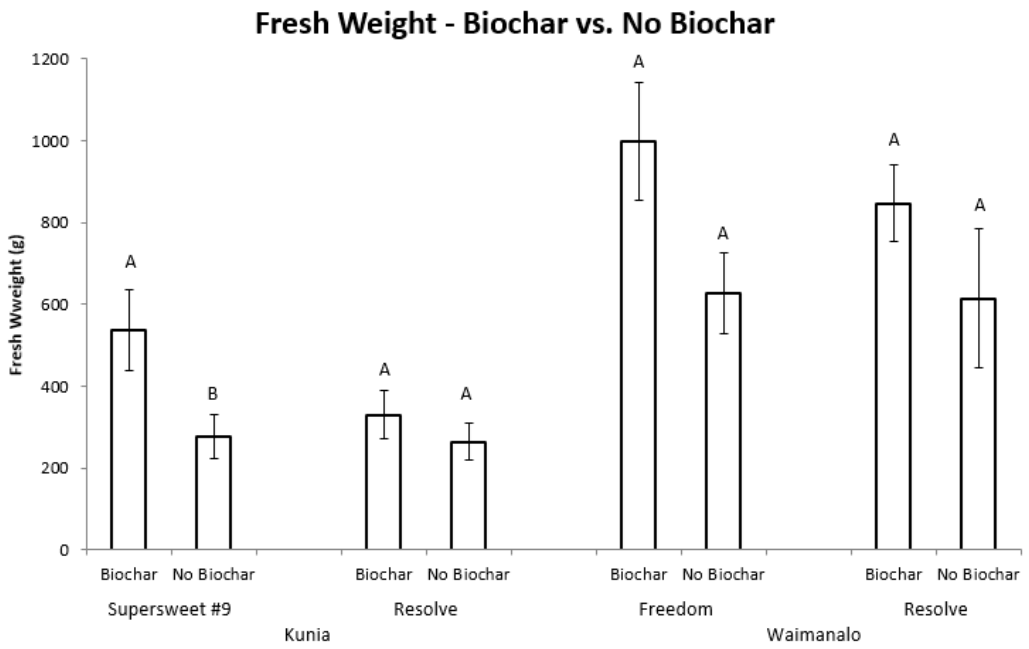


Figure 1. Sweet corn biomass fresh weight (g) for sweet corn varieties Supersweet #9 and Resolve at Kunia and sweet corn varieties Freedom and Resolve at Waimanalo trials under biochar and no biochar treatment.

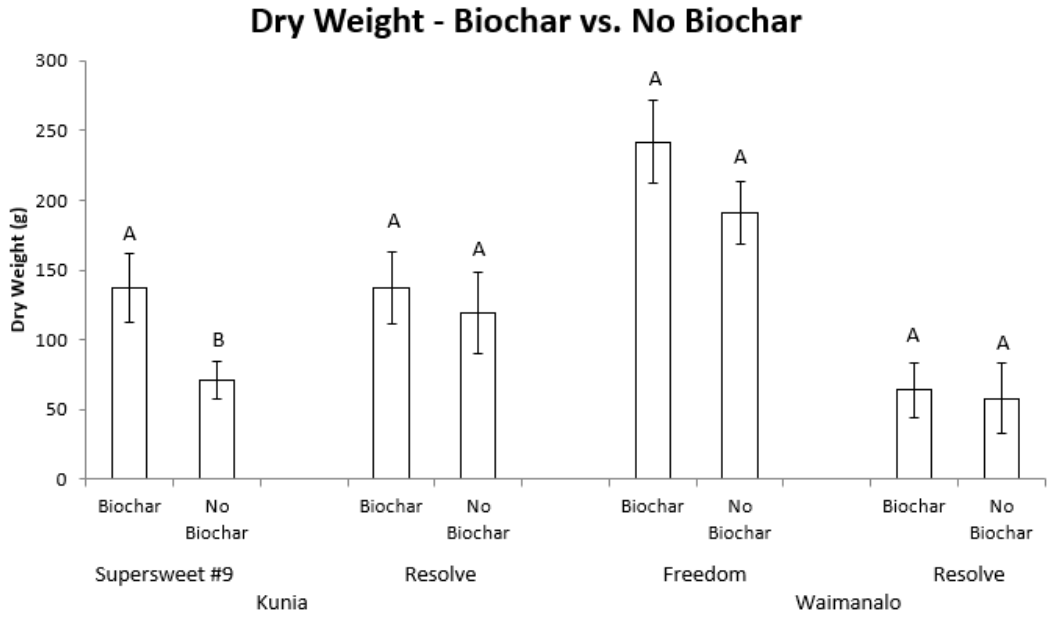


Figure 2. Sweet corn biomass dry weight (g) for sweet corn varieties Supersweet #9 and Resolve at Kunia and sweet corn varieties Freedom and Resolve at Waimanalo trials under biochar and no biochar treatments.

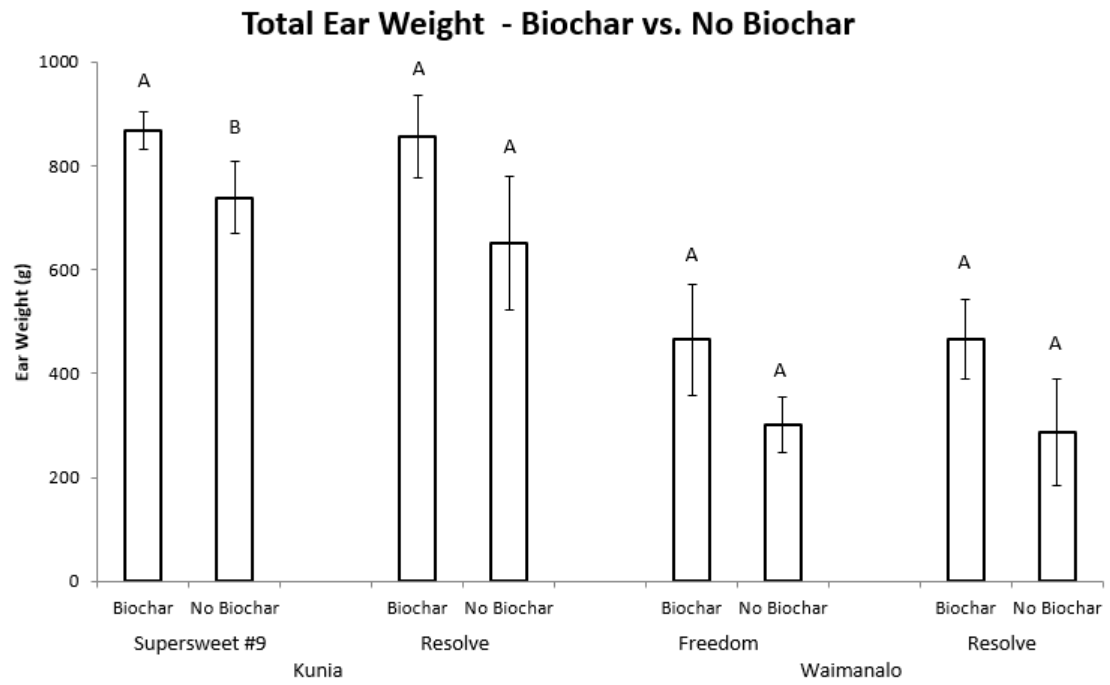


Figure 3. Sweet corn total ear weight (g) for sweet corn varieties Supersweet #9 and Resolve at Kunia and sweet corn varieties Freedom and Resolve at Waimanalo trials under biochar and no biochar treatments.

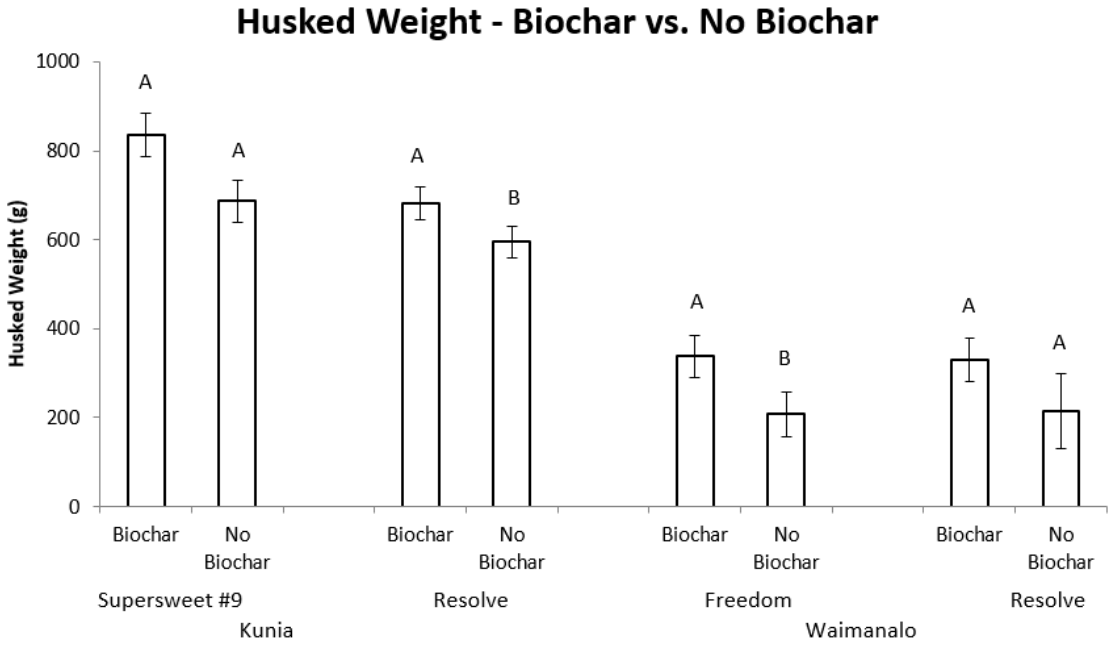


Figure 4. Sweet corn husked ear weight (g) for sweet corn varieties Supersweet #9 and Resolve at Kunia and sweet corn varieties Freedom and Resolve at Waimanalo trials under biochar and no biochar treatments.

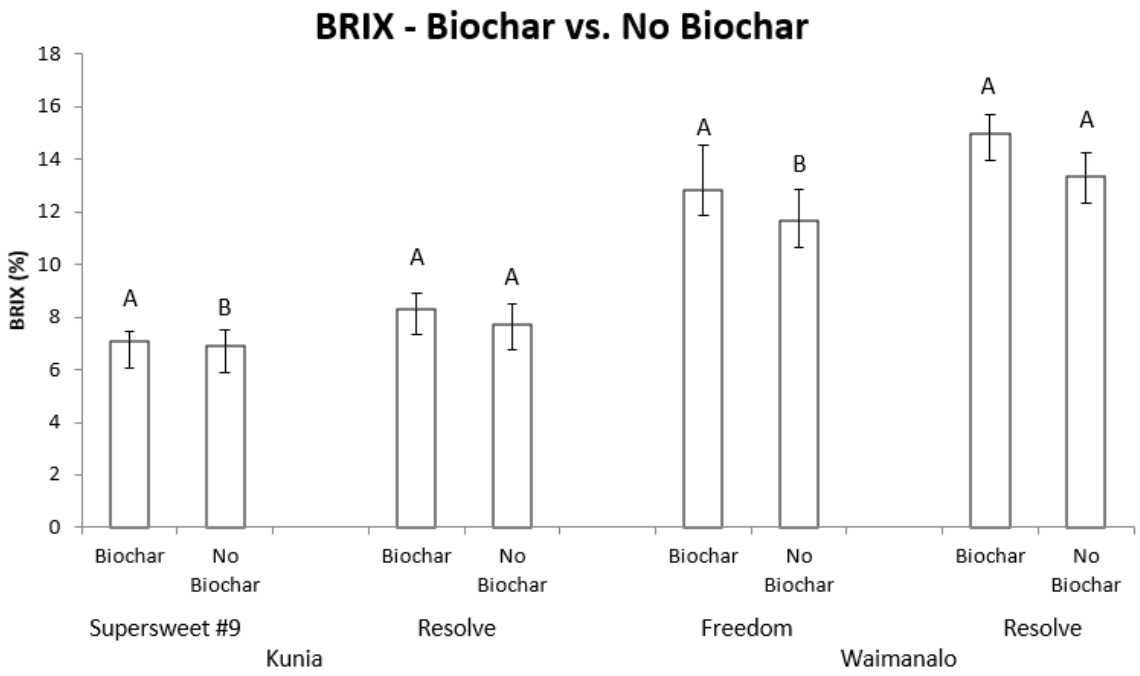


Figure 5. Sweet corn BRIX for sweet corn varieties for sweet corn varieties Supersweet #9 and Resolve at Kunia and sweet corn varieties Freedom and Resolve at Waimanalo trials under biochar and no biochar treatments.

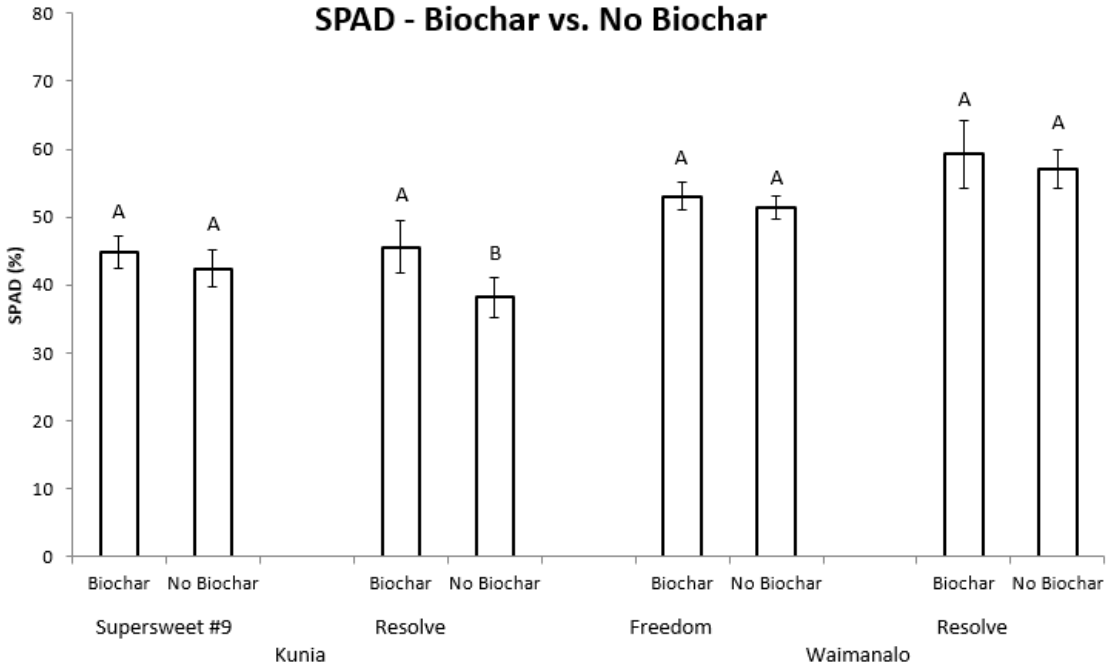


Figure 6. Sweet corn SPAD (relative chlorophyll content) for sweet corn varieties Supersweet #9 and Resolve at Kunia and sweet corn varieties Freedom and Resolve at Waimanalo trials under biochar and no biochar treatments.

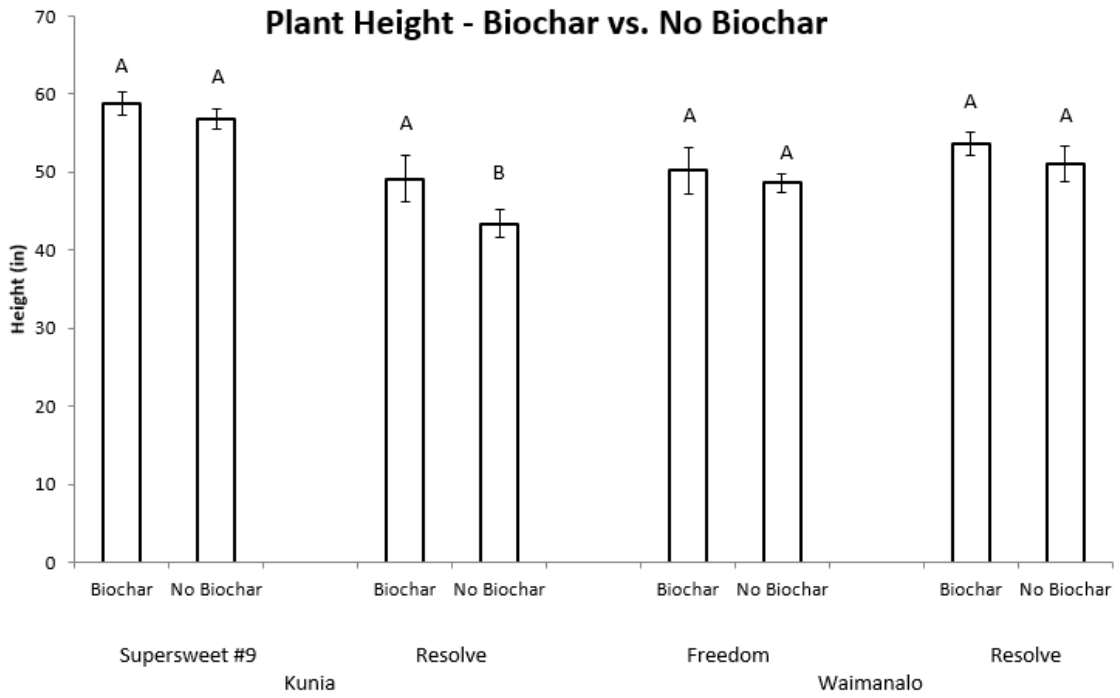


Figure 7. Sweet corn plant height (cm) for sweet corn varieties Supersweet #9 and Resolve at Kunia and sweet corn varieties Freedom and Resolve at Waimanalo trials under biochar and no biochar treatments.

3.3 Sweet Corn Tissue Nutrient Content:

In the trial at Kunia, there was a significant increase of plant tissue nutrient content of 21.6%, 44.5%, 23.1%, 14.8%, 21.4%, 20.3%, and 31.9% of N (Figure 8), P, K, Ca, Mg, S, B, and Cu, (Table 2), respectively, under biochar application compared to no biochar for the variety Supersweet #9. There was a significant decrease of 14.1% in plant tissue content of Mn under biochar application compared to no biochar (Table 2). Also in Kunia, there was a significant increase of plant tissue nutrient content of 6.6%, 12%, and 14.8% of P, Ca, and Na, respectively, under biochar application compared to no biochar for the variety Resolve (Table 2).

At the trial in Waimanalo, there was a significant increase in plant tissue nutrient content of 24%, 24.2%, 32.2%, and 33.2% of Ca, Mg, S, and Zn, respectively, under biochar application compared to no biochar for the variety Freedom (Table 3). Also in Waimanalo, there was a significant increase in plant tissue nutrient content of 29.8%, 32%, and 20.9%, for P, B, and Cu, respectively, under biochar application compared to no biochar for the variety

Resolve (Table 3). However, there was a significant reduction in plant tissue nutrient content of 18.6% and 40.29% of S and Al, respectively, under biochar application compared to no biochar for the variety Resolve.

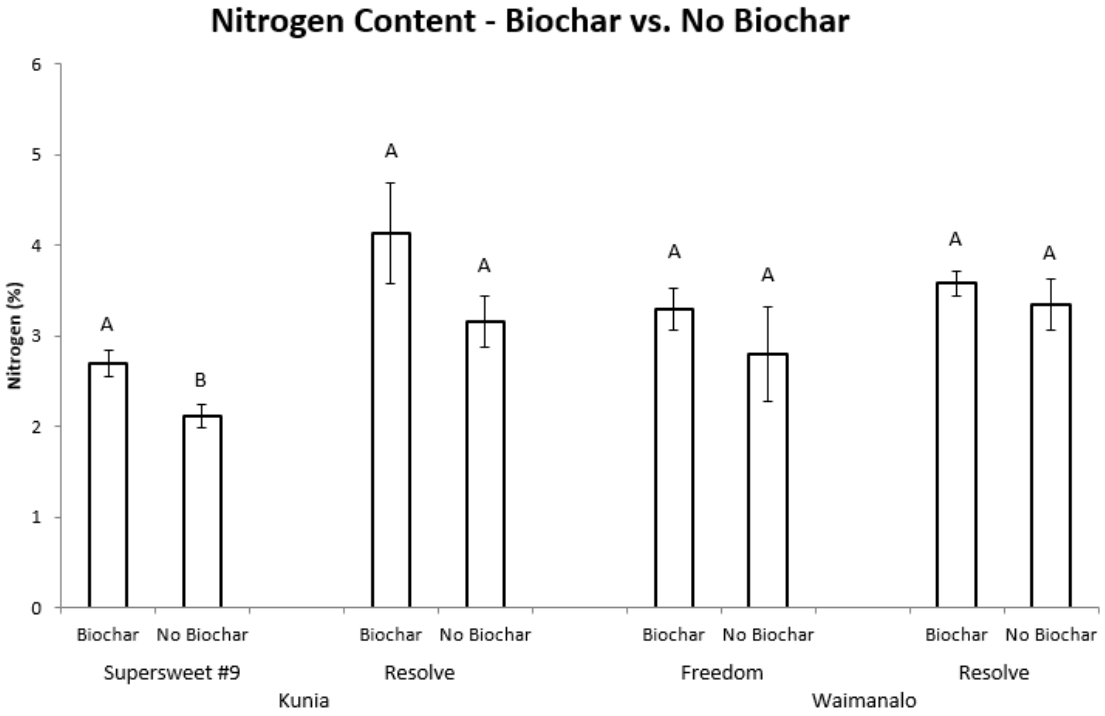


Figure 8. Sweet corn tissue nitrogen content (%) for sweet corn varieties Supersweet #9 and Resolve at Kunia and sweet corn varieties Freedom and Resolve at Waimanalo trials under biochar and no biochar treatments.

Table 2. Nutrient content in sweet corn biomass of Supersweet #9 and Resolve varieties under biochar and no biochar treatments in Kunia.

Trt/Nutrient	Supersweet #9					
	P	**K**	**Ca**	**Mg**	**S**	**B**
Biochar	0.33A ±0.06	1.69A ±0.09	0.5A ±0.03	0.29A ±0.01	0.21A ±0.01	30.8A ±3.4
No Biochar	0.18B ±0.04	1.3B ±0.25	0.4B ±0.02	0.23B ±0.03	0.18B ±0.01	24.6B ±3.56
Trt/Nutrient	**Fe**	**Mn**	**Cu**	**Zn**	**Al**	**Na**
Biochar	450.9A ±99.3	98.6B ±18.8	11.2A ±2.16	44.1A ±3.1	192.8A ±25.7	291.5A ±51.5
No Biochar	341.8A ±64.7	114.8A ±20.8	8.0B ±0.97	34.1B ±5.3	265.2A ±37.0	295.2A ±48.7
Trt/Nutrient	**Resolve**					
	P	**K**	**Ca**	**Mg**	**S**	**B**
Biochar	0.13A ±0.03	1.2A ±0.01	0.3A ±0.017	0.15A ±0.009	0.16A ± 0.02	8.2A ±1.07
No Biochar	0.13A ±0.02	1.1B ±0.05	0.2B ±0.02	0.13A ±0.01	0.15A ±0.02	7.2A ±0.96
Trt/Nutrient	**Fe**	**Mn**	**Cu**	**Zn**	**Al**	**Na**
Biochar	284.8A ±67.9	89.9A ±14.1	9.2A ±0.8	27.9A ±5.3	163.4A ±43.9	250.2A ±31.6
No Biochar	242.5A ±65.0	103.3A ±16.0	8.4A ±0.6	26.8A ±5.9	192.8A ±24.1	212.9B ±18.9

*Trt = Treatment; Means followed by different letters means they are significantly different at 95% probability.

Table 3. Nutrient content in sweet corn biomass of Freedom and Resolve varieties under biochar and no biochar treatments in Waimanalo.

Trt/Nutrient	Freedom					
	P	**K**	**Ca**	**Mg**	**S**	**B**
Biochar	0.3A ±0.02	2.1A ±0.07	0.6A ±0.07	0.3A ±0.02	0.28A ±0.01	9.9A ±1.1
No Biochar	0.3A ±0.05	2.2A ±0.2	0.4B ±0.03	0.3B ±0.03	0.19B ±0.01	9.3A ±1.3
Trt/Nutrient	**Fe**	**Mn**	**Cu**	**Zn**	**Al**	**Na**
Biochar	160.6A ±45.7	79.1A ±46.4	10.2A ±0.8	37.6A ±0.8	88.8A ±21.5	188.3A ± 25.2
No Biochar	136.6A ±27.9	75.3A ±24.8	8.9A ±0.8	25.1B ±5.6	110.7A ±19.7	179.5A ±19.7
Trt/Nutrient	**Resolve**					
	P	**K**	**Ca**	**Mg**	**S**	**B**
Biochar	0.41A ±0.07	2.2A ±0.4	0.6A ±0.1	0.3A ±0.03	0.24B ±0.03	11.9A ±1.2
No Biochar	0.29B ±0.03	2.1A ±0.2	0.6A ±0.1	0.3A ±0.08	0.3A ±0.08	8.1B ±1.8
Trt/Nutrient	**Fe**	**Mn**	**Cu**	**Zn**	**Al**	**NA**
Biochar	168.7A ±34.7	69.6A ±30.8	12.8A ± 0.7	34.7A ±5.2	71.5A ±15.9	179.8A ± 19.9
No Biochar	144.2A ±47.5	71.3A ±22.9	10.1B ±2.1	28.6A ±3.56	90.6A ±15.6	177.1A ± 21.8

*Trt = Treatment; Means followed by different letters means they are significantly different at 95% probability.

3.4 Correlation between the sweet corn growth and tissue nutrient content parameters:

A Pearson's correlation analysis was conducted using the plant growth, yield, quality, and tissue nutrients parameters. The correlation analysis results showed significant positive correlation between the plant fresh weight and ear weight in Kunia for Supersweet #9 ($r = 0.77$) and Resolve ($r = 0.68$) (Table 4). In Waimanalo, similar stronger positive highly significant correlation between the plant fresh weight and ear weight in Kunia for Freedom ($r = 0.85$) and Resolve variety ($r = 0.98$) (Table 5). Additionally, BRIX showed positive significant correlation with the plant growth parameters (F.W., D.W., and E.W.) in Waimanalo for Freedom and Resolve variety (Table 5). However, no significant correlation for BRIX was shown at Kunia for either variety (Table 4). Significant correlations ($p < 0.05$) were found between vegetative growth, yield, and quality and tissue nutrient content for both varieties in Kunia (Table 4) but only significant correlations for the variety Freedom in Waimanalo (Table 5). There was a positive correlation between these parameters that showed the biochar application influenced (Table 2 and 3; Figure 8).

In Kunia, there were strong correlations in macronutrient tissue content with the vegetative growth, yield, and quality parameters, especially for Supersweet #9 (Table 4). Micronutrient presence was also found to have a strong correlation for the nutrients Ca, S, Mn, Cu, and Zn for Supersweet #9 and Cu for Resolve (Table 4). In Waimanalo, there were no strong correlations between vegetative growth, yield, and quality compared to tissue nutrient analysis for either variety (Table 5). Micronutrient presence had a strong correlation with both vegetative growth and yield

for the nutrients Ca, Mg, S, Cu, and Zn for Supersweet #9 and no strong correlations for Resolve (Table 5). There were weak or inverse correlations between parameters for Resolve variety, but they were neither strong nor significant ($p < 0.05$) (Table 5).

Table 4. Correlation coefficient values between growth and tissue nutrient content for Supersweet #9 and Resolve varieties in Kunia.

Variety		Resolve																	
	TRT	F.W.	D.W.	E.W.	H.W.	BRIX	N	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn	Al	Na
Ssupersweet #9	F.W.		0.1	0.68*	0.77**	0.04	0.56	0.53	0.2	0.34	-0.14	0.37	0.08	-0.26	0.07	0.48	0.18	-0.04	0.18
	D.W.	0.99**		-0.18	0.44	-0.38	0.19	0.01	0.75*	0.29	0.16	0.18	0.18	0.48	0.03	0.2	0.15	0.39	0.24
	E.W.	0.77**	0.82**		0.70*	0.09	0.58	0.41	0.13	0.37	0.35	0.1	0.18	-0.13	0.19	0.27	-0.23	-0.01	0.46
	H.W.	0.42	0.47	0.73**		0.02	0.61	0.63*	0.57	0.58	0.33	0.38	0.48	0.23	0.18	0.66*	0.1	0.4	0.46
	BRIX	0.23	0.16	0.10	0.07		0.27	0.48	-0.09	0.35	0.01	0.05	0.13	-0.14	0.21	0.21	0.29	0.01	0.1
	N	0.77**	0.80**	0.90**	0.47	0.12		0.34	0.33	0.42	0.11	-0.05	0.06	-0.18	0.16	0.26	0.02	-0.09	0.48
	P	0.77**	0.78**	0.70**	0.34	-0.09	0.71**		0.01	0.53	0.32	0.54	0.56	0.23	0.25	0.70*	0.39	0.44	-0.07
	K	0.52	0.51	0.65	0.30	0.50	0.83*	0.43		0.61	0.07	0.24	0.31	0.34	0.05	0.32	0.03	0.28	0.76**
	Ca	0.59	0.64*	0.88**	0.61	-0.07	0.87**	0.71*	0.60		0.24	0.71*	0.63*	0.41	0.43	0.61	0.38	0.34	0.54
	Mg	0.56	0.57	0.50	0.08	-0.38	0.57	0.67*	0.16	0.64		0.1	0.61	0.75*	0.62	0.33	0.11	0.73*	0.01
	S	0.58	0.63*	0.78**	0.59	0.07	0.86**	0.56	0.74*	0.81**	0.27		0.71*	0.5	0.49	0.78**	0.70*	0.5	-0.06
	B	0.53	0.56	0.61	0.39	0.01	0.77**	0.75**	0.68*	0.76*	0.42	0.87**		0.80*	0.62*	0.86**	0.52	0.86*	0.09
	Fe	0.56	0.57	0.43	0.27	-0.33	0.55	0.43	0.14	0.59	0.70*	0.55	0.52		0.64*	0.54	0.48	0.91*	-0.08
	Mn	0.62	0.64*	0.73*	0.16	0.16	0.87**	0.42	0.73*	0.70*	0.52	0.66*	0.47	0.47		0.56	0.73*	0.65*	-0.16
	Cu	0.69*	0.70**	0.77**	0.46	0.29	0.83**	0.60	0.66*	0.81**	0.34	0.84**	0.71**	0.54	0.75**		0.68*	0.73*	0.03
	Zn	0.53	0.60	0.79**	0.56	-0.29	0.83**	0.69*	0.53	0.92**	0.70**	0.80**	0.81**	0.68*	0.60	0.62		0.56	-0.41
	Al	0.46	0.47	0.47	0.36	0.35	0.58	0.10	0.55	0.50	0.15	0.72*	0.51	0.62	0.59	0.68*	0.48		-0.15
	Na	0.21	0.27	0.25	0.34	-0.38	0.14	-0.02	-0.26	0.30	0.27	0.34	0.09	0.72**	0.19	0.29	0.37	0.56	

*, ** = Significant and highly significant, respectively.

Table 5. Correlation coefficient values between growth and tissue nutrient content for Freedom and Resolve varieties in Waimanalo.

Variety		Resolve																
	TRT	F.W.	D.W.	E.W.	H.W.	BRIX	N	P	K	Ca	Mg	S	B	Fe	Mn	Cu	Zn	Al
Freedom	F.W.		0.72*	0.98**	0.98*	0.72*	0.34	0.33	0.56	0.12	-0.14	-0.13	0.27	0.09	-0.48	0.49	0.37	0.15
	D.W.	0.46		0.62*	0.7*	0.95**	0.34	0.085	0.46	0.09	0.20	0.05	-0.08	0.19	-0.33	0.26	0.28	0.50
	E.W.	0.85**	0.22		0.98**	0.62*	0.34	0.36	0.44	0.14	-0.20	-0.18	0.36	0.09	-0.40	0.54	0.41	0.55
	H.W.	0.86**	0.08	0.92		0.7*	0.34	0.29	0.44	0.15	-0.13	-0.1	0.25	0.08	-0.39	0.51	0.39	0.54
	BRIX	0.81**	0.75**	0.50	0.48		0.34	0.08	0.46	0.09	0.20	0.05	-0.08	0.19	-0.33	0.26	0.28	0.53
	N	0.47	0.47	0.25	0.29	0.46		0.66*	0.34	0.76**	0.56	0.37	0.15	0.80**	0.39	0.76**	0.16	0.70**
	P	0.11	-0.54	0.16	0.38	-0.08	-0.50		0.34	0.50	0.01	-0.05	0.68*	0.67*	0.40	0.73*	0.63*	0.80**
	K	-0.25	-0.11	0.01	-0.13	-0.38	-.66*	0.08		0.25	0.18	0.18	0.02	0.27	-0.43	0.36	0.03	0.47
	Ca	0.76**	0.38	0.61	0.60	0.66*	0.64*	0.01	-0.37		0.76	0.76	0.04	0.86**	0.57*	0.81**	0.25	0.46
	Mg	0.76**	0.62	0.53	0.51	0.82**	0.29	0.06	0.03	0.76		0.90**	-0.42	0.68*	0.47	0.35	-0.13	0.16
	S	0.85**	0.52	0.71*	0.70*	0.73*	0.69*	-0.14	-0.30	0.92**	0.81**		-0.42	0.55*	0.43	0.32	-0.01	0.00
	B	0.27	0.50	0.27	0.27	0.27	0.05	0.16	0.34	0.29	0.53	0.33		0.31	0.16	0.48	0.65	0.59
	Fe	0.55	0.46	0.46	0.45	0.48	-0.14	0.23	0.40	0.11	0.55	0.22	0.58		0.64*	0.81**	0.42	0.72**
	Mn	-0.16	0.21	-0.50	-0.30	0.11	0.61	-0.31	-0.52	0.17	0.06	0.18	-0.01	-0.40		0.35	0.36	0.23
	Cu	0.67*	0.68*	0.69*	0.63*	0.63*	0.47	-0.12	-0.03	0.61	0.67*	0.76*	0.73*	0.46	-0.01		0.54	0.80**
	Zn	0.73*	0.06	0.76**	0.82**	0.38	0.01	0.39	0.24	0.51	0.67*	0.65*	0.37	0.49	-0.30	0.53		0.66*
	Al	0.36	0.52	0.30	0.26	0.46	-0.28	0.22	0.24	-0.10	0.35	0.02	0.57	0.84**	-0.42	0.44	0.24	

*, ** = Significant and highly significant, respectively.

3.5 Soil health, infiltration rate, and fertility:

Analysis of variance (ANOVA) for the soil samples measured paramters (chemical analysis for total exchangable carbon (TEC), carbon (C), nitrogen (N), C:N ratio, pH, and EC, CO_2 and infiltration rate) from both sites showed that in Kunia site, there were a significant ($p < 0.05$) difference in C content and CO_2 level. However, at Waimanalo, TEC and C content showed a highly significant ($p < 0.01$) differences while N, pH, CO_2, and infiltration rate reached a significant ($p < 0.05$) level. In Kunia, there were a significant increases in soil health metrics of 40.6% in C (Figure 10). In Waimanalo, there was a significant increase in soil health metrics of 53.1%, 40.1%, 41.8%, and 8% in TEC (Figure 9), C (Figure 10), N (Figure 11), and pH (Figure 13), respectively, under biochar application compared to no biochar application. Statistically, there was no significant difference in the infiltration rate at Kunia but the infiltration rate was statistically different in the biochar application in Waimanalo with a significant ($p < 0.05$) increase of 33.3% (Figure 15) compared to the no biochar application. The CO_2 respiration rate of the soil samples taken showed significant differences ($p < 0.05$) with an increase of 70.8% in Kunia, and there was a significant difference ($p < 0.05$) in Waimanalo with an increase of 34.5% (Figure 16) under biochar compared to no biochar applications.

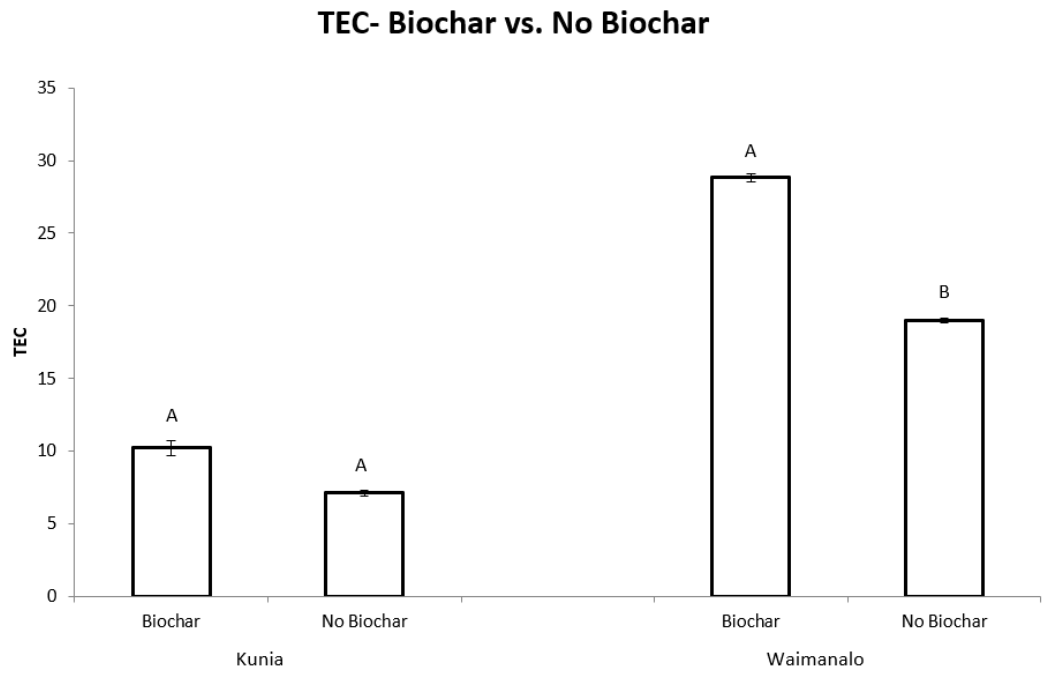


Figure 9. TEC under biochar and no biochar application in Kunia and Waimanalo.

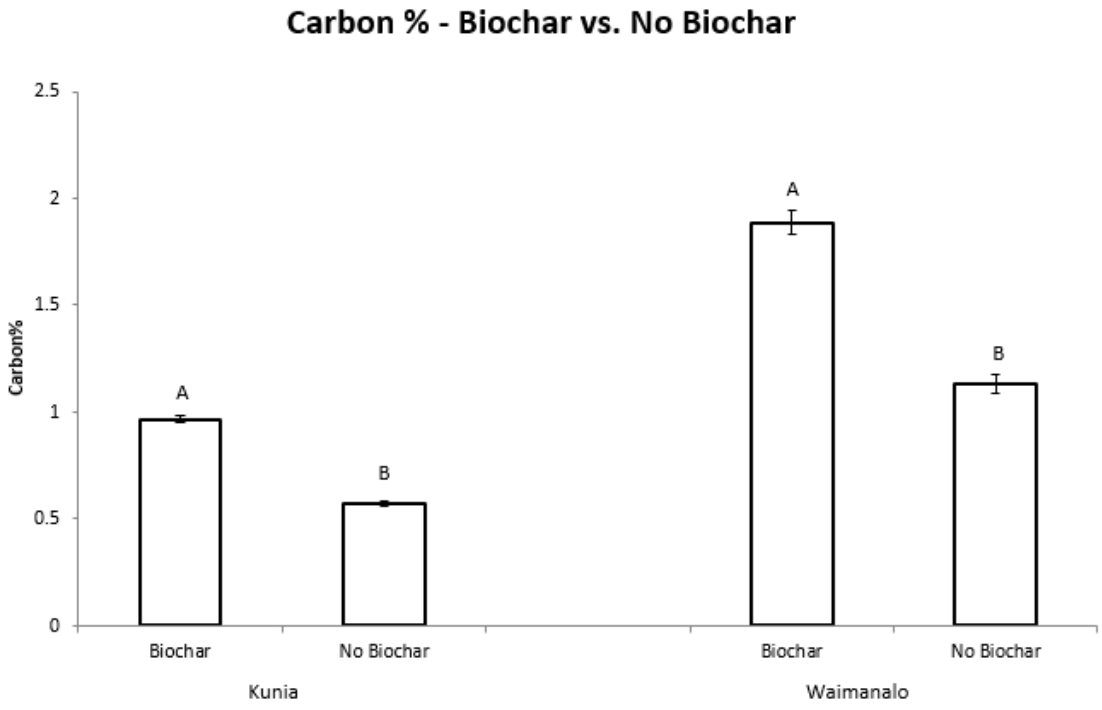


Figure 10. Percent carbon under biochar and no biochar application in Kunia and Waimanalo.

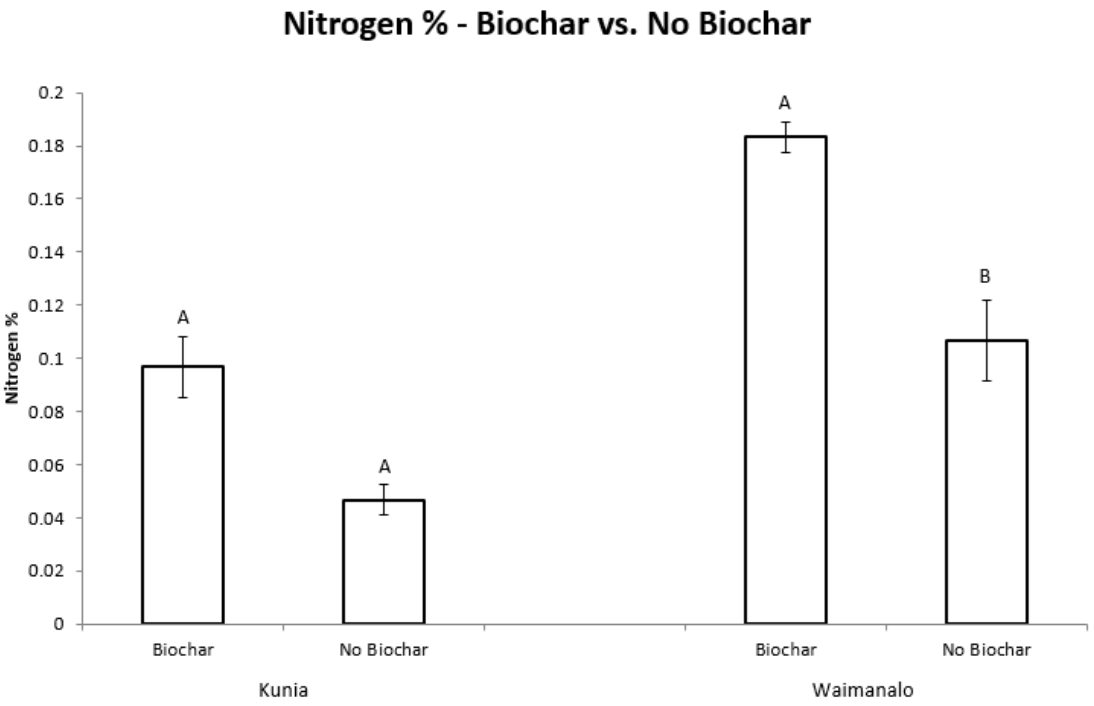


Figure 11. Percent nitrogen under biochar and no biochar application in Kunia and Waimanalo.

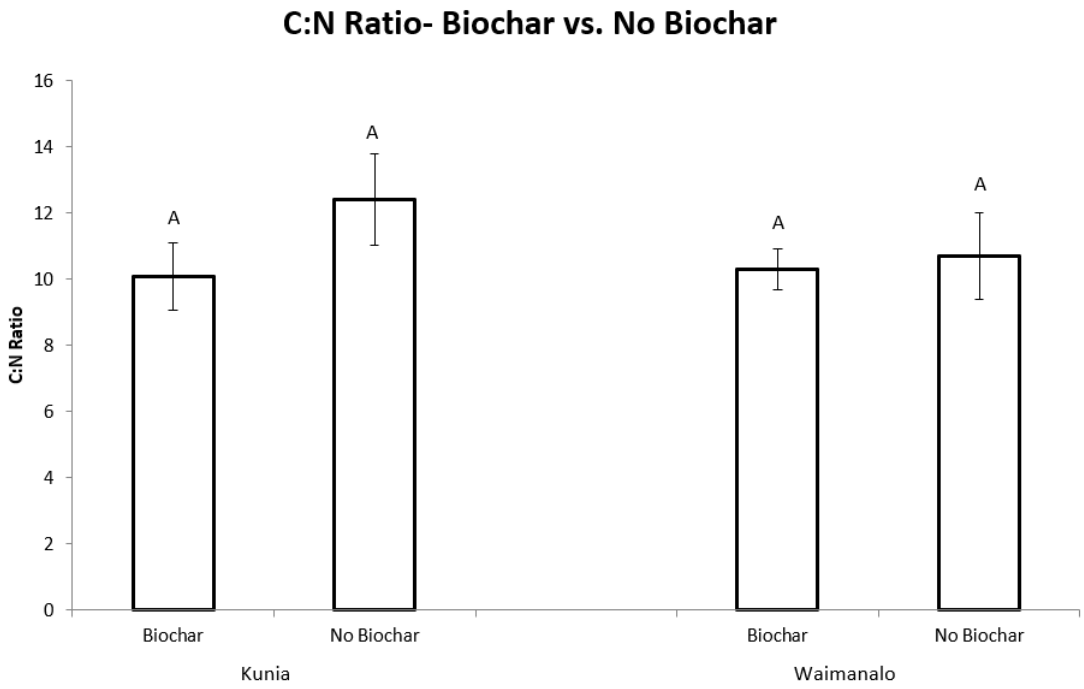


Figure 12. C:N ratio under biochar and no biochar application in Kunia and Waimanalo.

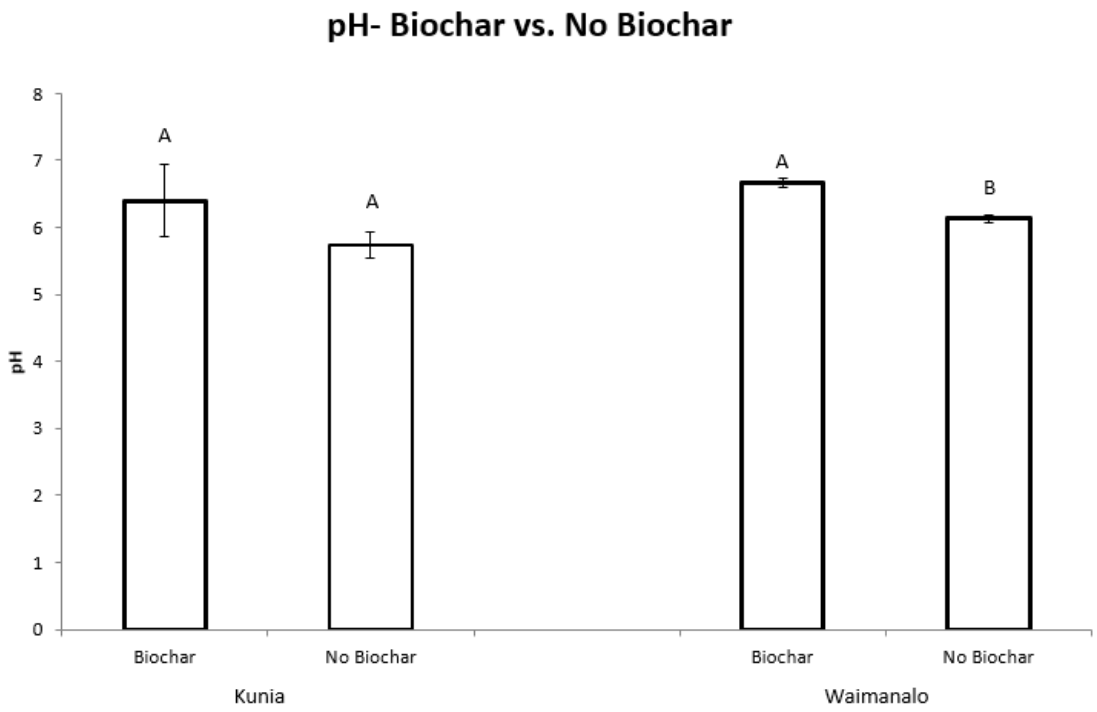


Figure 13. pH under biochar and no biochar application in Kunia and Waimanalo.

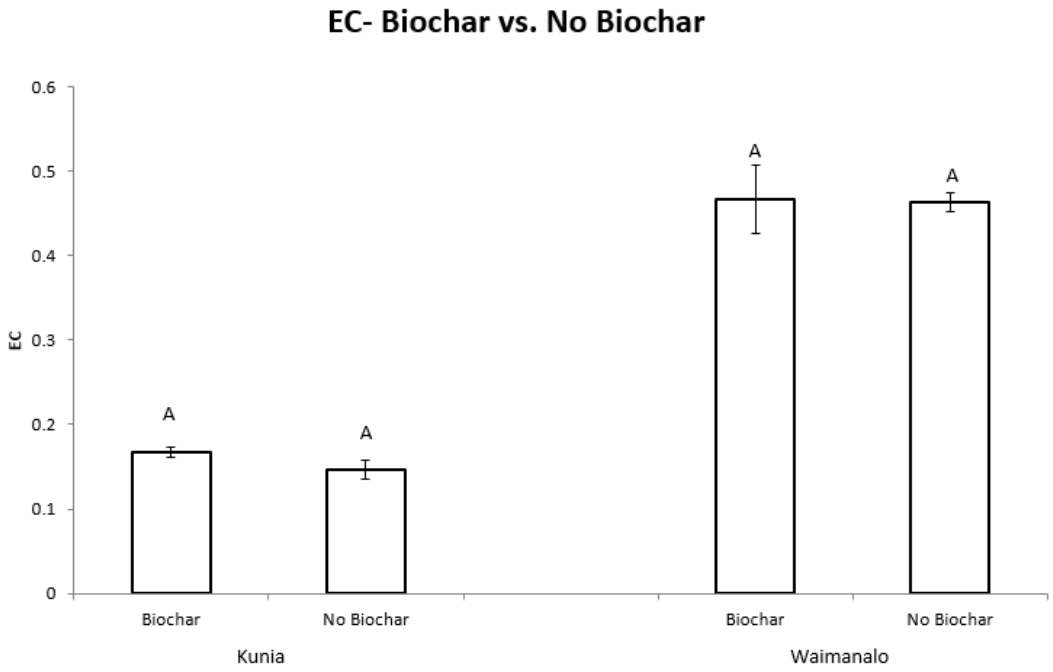


Figure 14. EC under biochar and no biochar application in Kunia and Waimanalo.

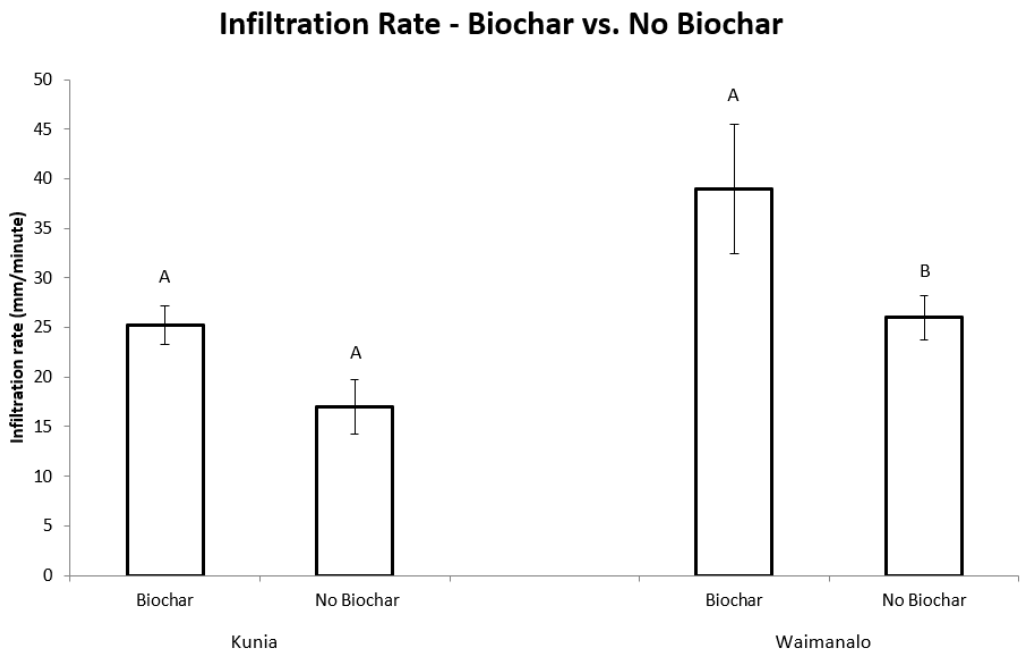


Figure 15. Soil infiltration rate (mm/minute) under biochar and no biochar application in Kunia and Waimanalo.

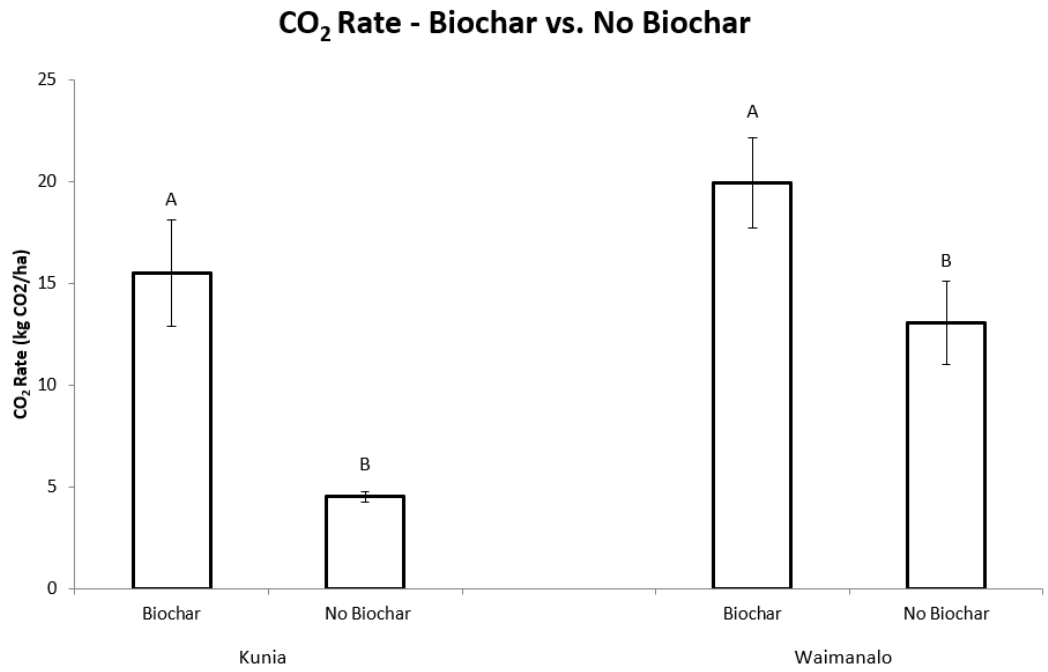


Figure 16. CO_2 (kg CO_2/ha) respiration rate in soil under biochar and no biochar application in Kunia and Waimanalo.

In Table (6), the soil parameters for the biochar vs. no biochar applications is outlined with the pre- and post-trial values. In both Kunia and Waimanalo locations for all parameters taken, which were pH, CEC, S, P, Olsen-P, Ca,

Mg, K, Na, B, Fe, Zn, Cu, Mn, Al, NO_3^-N, and NH_4^-N, the biochar application had a higher numerical value than the no biochar application. However, the post-trial values were sometimes lower than the pre-trial values. But both post-trial values followed a similar trend if they did decrease from the pre-trial value. The biochar used in the trial was also run for analysis to understand the content of the biochar used (Table 7).

Table 6. Soil parameters for biochar and no biochar applications.

	Kunia				Waimanalo		
Soil Analysis	**Pre Trial**	**Post Trial**		**Soil Analysis**	**Pre Trial**	**Post Trial**	
		Biochar	**No Biochar**			**Biochar**	**No Biochar**
pH	6.3	7.3	6.8	**pH**	6.8	7.2	6.8
CEC(meq/100g)	14.86	0.35	0.19	**CEC(meq/100g)**	42.82	0.39	0.21
S (ppm)	16	27	22	**S (ppm)**	69	25	20
P (ppm)	9	10	8	**P (ppm)**	59	37	20
P* (ppm)	7	20	13	**P* (ppm)**	1065	40	20
Ca (ppm)	1009	1508	926	**Ca (ppm)**	439	2590	2006
Mg (ppm)	399	378	211	**Mg (ppm)**	508	342	180
K (ppm)	371	272	157	**K (ppm)**	70	371	216
Na (ppm)	60	43	39	**Na (ppm)**	0.63	66	42
B (ppm)	0.64	0.81	0.79	**B (ppm)**	168	0.82	0.78
Fe (ppm)	35	31	22	**Fe (ppm)**	223	35	28
Mn (ppm)	165	171	110	**Mn (ppm)**	7.49	196	160
Cu (ppm)	4.44	4.07	3.01	**Cu (ppm)**	10.3	5.98	5.01
Zn (ppm)	3.36	2.52	1.75	**Zn (ppm)**	894	6.87	6
Al (ppm)	664	568	525	**Al (ppm)**	3.2	621	555
NO_3-N (ppm)	8.6	3.1	0.8	**NO_3-N (ppm)**	5.4	15.7	5.6
NH_4-N (ppm)	2.3	2.1	1.9	**NH_4-N (ppm)**	7	2.8	2.7

*reflecting Olsen-P value.

Table 7. Analysis of biochar produced from coconut shell used in the biochar application.

Parameter/Biochar type	**Coconut Shell****	**Parameter/Biochar type**	**Coconut Shell****
Total Carbon	76.2%	**Water Insoluble Organic Nitrogen**	0.35%
Carbonates (as $CaCO_3$)	0.8%	**Phosphoric Acid (P_2O_5)**	0.01%
Organic Carbon	76.1%	**Soluble Potash (K_2O)**	0.34%
Ash	7.5%	**Total Potash (K_2O)**	0.73%
Butane Activity	0.6 g/100g	**Calcium (Ca)**	0.21%
Surface Area Correlation	151 m^2/g	**Aluminum (Al)**	1300 mg/kg
pH (saturated paste)	7.68	**Sodium (Na)**	0.12%
Total Nitrogen (N)	0.35%	**Iron (Fe)**	0.22%
Nitrate Nitrogen	0.0%	**Magnesium (Mg)**	0.061%
Ammoniacal Nitrogen	0.0%	**Manganese (Mn)**	0.01%

*Analyzed by the Soil Control Lab and used IBI standards for tests.

**Coconut shell biochar was the feedstock for the biochar that was purchased from CoolTerra and used in the trials.

4. DISCUSSION

4.1 Sweet Corn, Growth, Yield, and Qualities:

The results showed that the biochar treatment performed better than the no biochar treatment might be related to the various benefits of biochar as a soil amendment [21,22]. Biochar may have allowed for more nutrient availability to the crop due to factors such as its high CEC and allowed for better nutrient uptake [9]. This analysis of data supported the theory that biochar would be a beneficial soil amendment for improving overall plant growth and soil parameters[27].The biochar application showed improvements on fresh weight, dry weight, husked ear weight, BRIX, SPAD, and plant height. Comparable results have been found when applying biochar to crops [28] and especially in corn [29].

Biochar can improve the ability of plants to absorb necessary nutrients which has a direct correlation with the improved performance of the crop [30]. While the biochar treatment had influence on the plant growth parameters, there was more influence on those parameters in the trial located in Kunia than in Waimanalo, based off reviewing numerical and statistical data. Specifically, the variety Resolve had no significant differences of plant growth parameters in Waimanalo, but the increase of husked ear weight, SPAD, and plant height in Kunia suggests that maybe soil type can influence the impact biochar has on plant growth [31,32] this might be related to that biochar applications have been found to perform differently under different soil type and fertility level [25]. A similar assertion was found in the tissue nutrient content where the corn had higher nutrient content in the trial at Kunia compared to Waimanalo. The Mollisol in Waimanalo already has good nutrient availability due to being a fertile soil with a neutral pH, but it is believed the differences in the Oxisol in Kunia were more noticeable because the biochar improved the nutrient availability of this infertile soil by raising the pH (Table 7) from an acidic level to a neutral level [33].

The biochar application showed improvement of nutrient content in the plant tissue of N, P, K, Ca, Mg, S, B, and Zn. As mentioned before by Mansoor [30], biochar improves plant's ability to uptake nutrients, which may lead to the increased nutrient content in the tissue samples in the biochar treatment [28]. The Al and Mncontent in plant tissue was numerically lower under the biochar application compared to no biochar, but it didn't reach a significant level. It might be related to the increase in soil pH under the the biochar (Table 7), which may lead to lower Al and Mn availability in the soil and uptake by plants [28,34]. It is also beleived that genetic variances between the varieties could have played a factor in differences between growth, yield, and quality.

The two mainland varieties (Freedom and Resolve) were used due to multiple factors, including lack of sufficient locally produced sweet corn variety "Supersweet #9" during the time to initiate the trial at Waimanalo, and because there was not enough information on the mainland hybrid varieties under Hawai'i's conditions and we wanted to ensure data was gathered in case there were any issues with growing them in Hawai'i. In Kunia, we used Resolve again since it was the better performing variety between Freedom and Resolve at Waimanalo and to have at least 1 similar variety between the two locations. During the growing season in Waimanalo, the small amount of Supersweet #9 variety (open pollination variety) seeds available were planted for propagation purposes and used in the trial at Kunia.

4.2 Soil Fertility and Infiltration Rate:

Soil data was only collected based off of the treatments and not separated based off of variety because it was not expected for the variety to impact changes in soil health, and the infiltration rate was recorded from 2-3 spots in each plot, which showed no difference. The high pH of biochar can also raise the pH of the Oxisol which is known to be low, which occured in both experimental sites [35]. It could reduce the potential for Al and Mn toxicity in these soils by raising the pH, and bring it up to a range that increases nutrient availability for crops [36]. In both Kunia and Waimanalo, the significant increase in C% is to be expected due to biochar being 50%-90% carbon, with exact percentage depending on feedstock and pyrolysis process [35]. The biochar used for this trial was 76.2% carbon (Table 7) which is in the range mentioned. CO_2 rate, which shows microbial activity, also increasing in both sites is expected as biochar provides many benefits to increasing microbial activity by providing a suitable habit for the populations, and improving soil health metrics such as TEC and pH which will help biological activity [37]. Soil infiltration rate was improved by the addition of biochar because it can help enhance pore density and connectivity, especially since it was applied in the top layer of the soil [38].

5. CONCLUSIONS

These results showed that biochar was beneficial to both soil types, Oxisol and Mollisol in Hawai'i. While there were differences in the results between the two corn varieties studied, we found that biochar still performed superior to the control despite different soil types or sweet corn varieties. The metrics taken showed biochar treatment improved the vigor of the plants leading to this conclusion. Also, the two soil types we conducted our studies in had very different properties but biochar still showed that it was a beneficial amendment in both. Along with the two

different soil types, biochar also showed benefit across sweet corn varieties. This reiterates that biochar can be a benefical soil amendment and useful for regenerative agricultural practices in Hawai‘i. Biochar does have a high persistence in the soil and has been found to have continued benefits in the soil once applied so in future growing seasons it is possible that these benefits will perpetuate and increase [39]. However, it was not possible for us to evaluate this in our trials due to constraint of time, but could be a future study to evaluate the long term effects of biochar on crop growth, yield, and soil health in Hawai‘i.

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Ethics, Consent to Participate, and Consent to Publish declarations: not applicable.

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request.

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