Chapter 4

Use of Organic Fertilizers to Enhance Soil Fertility, Plant Growth, and Yield in a Tropical Environment

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Abstract

Soils rarely have sufficient nutrient for crops to reach their potential yield. Applying organic fertilizers without prior knowledge of their properties may cause yield decline under low application or pollute the environment with excessive application. Understanding the nutrient variability and release pattern of organic fertilizers is crucial to supply plants with sufficient nutrients to achieve optimum productivity, while also rebuilding soil fertility and ensuring protection of environmental and natural resources. This chapter presents the authors' experiences with different organic amendments under Hawaii's tropical conditions, rather than an intensive literature review. For meat and bone meal by-products (tankage), batch-to-batch variability, nutrient content/release pattern and quality, and plant growth response to the liquid fertilizer produced from tankage were evaluated. For animal livestock, dairy manure (DM) and chicken manure (CM) quality, changes in soil properties, and crop biomass production and root distributions were evaluated. For seaweed, an established bio-security protocol, nutrient, especially potassium (K) variability, and plant growth and yield response were evaluated in different tropical soils.

Keywords: organic fertilizers, tropical soils, nutrient variability, mineralization, plant growth, yield

1. Introduction

Sustainable and organic agriculture practices apply management ideals that include a diverse assembly of farming methods, usually with a reduced reliance on purchased inputs [1], this is especially for new farmers with limited resources [2]. As commercial fertilizer/shipping costs increase, a wide range of food producers in the Hawaii and the Pacific region have realized the need for locally available fertilizers from organic sources to improve soil fertility, crop health, and productivity. In addition to concerns surrounding availability of affordable soil amendments, interest in sustainability and organically produced crops has risen among American consumers in the past few decades. Increased tourism has further amplified the need for fresh local fruits and vegetables, especially “locally grown” labeled goods. Shifting from conventional farming to organic farming has many benefits to the human's well-being, protecting the environment (soil, water, and air), rebuilding soil fertility through improving its physical, chemical, and biological characteristics, and improving the quality of produced crops [3]. However, producing crops organically may come with higher production costs (i.e., lower yield and higher labor costs). Recycling, composting, and using local inputs may decrease the production cost [4]. In general, soils rarely have sufficient nutrients available for crops to reach their potential yield. Therefore, farmers tend to apply soil amendments (synthetic or organic amendments) that are rich in nutrient, i.e., N, P, and K to enhance soil fertility and increase crop productivity [5]. However, most growers apply fertilizers based on the general recommendations for each crop [6], without prior knowledge of the soil fertility status and nutrient mineralization and release pattern from the fertilizers [7]. In addition, Hawaii farmers face the continuous challenge of declining soil organic matter (SOM) and fertility [8] due to the optimum environmental condition (e.g., temperature and rainfall) for SOM decomposition [9]. These losses are more critical with the use of organic amendments, where nutrients have to be converted from organic to inorganic forms in order to be available for plant uptake [10]. Also, rebuilding/restoring soil fertility and improving the physical, chemical, and biological function of soils are critical to support optimal plant growth, yield, and quality [11]. Sustainable health of the soil relies on carbon-rich amendments that will feed the biological processes that are the core foundation of a healthy soil [12]. Short-term needs must also be met with fertilizers that rapidly become available to plants, so that nutrients are available in synchrony with plant needs [13]. In Hawaii, there are many locally available resources to meet both long- and short-term crop nutrient and soil function needs when used properly [14]. Improving farmers’ knowledge and their capacity to determine the quality of different fertilizers and soil and crop's needs are essential elements in organic agriculture [15]. This chapter focuses on the authors’ experiences with certain organic fertilizers that are available in Hawaii rather than being an extensive review of them.

2. Meat and bone meal by-products (tankage)

Tankage is the solid by-product of animal waste rendering (**Figure 1**). The nutrient content of tankage varies with feedstock and storage time, but the product available in Hawaii has been fairly consistent on average 9.5, 2.5, and 0.75% of N, P, and K, respectively, With a Carbon/Nitrogen (C/N) ratio of 5:1 [16, 17]. The Hawaii material is derived from fish scraps (~50%), waste meat, carcasses, and other mixed materials (~45%) and offal (~5%). The current and only running plant in Hawaii is producing about 25 tons/month. Often called meat and bone meal, tankage is a valuable agricultural input used as fertilizer in Hawaii for at least 20 years [18, 19]. The material is National Organic Program (NOP) compliant and listed as an approved generic material by OMRI. The primary agricultural use of tankage is as a supplemental N source [20], especially for, but not limited to, certified organic growers. Nitrogen (N) mineralization rates for tankage have always been assumed to be high given its low C/N ratio and high N content, but actual mineralization rates in Hawaii soils have not been readily available. Other gaps in our knowledge of this material include batch-to-batch variability in the material and N loss during storage.

Figure 1. Meat and bone meal by-products (tankage).

2.1. Nutrient content and nitrogen release pattern

2.1.1. Nutrient content variability among tankage batches

Batch-to-batch evaluation was carried out for 2 years by collecting tankage samples (every 3 months) from Island Commodities Co., on Oahu. Initial subsamples were submitted to the University of Hawaii's Agricultural Diagnostic Services Center (ADSC) for total nutrient content analysis. The results showed that tankage can provide fairly good amount of the macro- and micro-nutrient, except potassium (K), which was fairly low. N content in tankage initial samples varied between 8.7% and 12.1% with an average of 9.8%, and C/N ratio varied between 3.5 and 5.3:1 with an average of 4.7:1 (**Table 1**). Periodical analysis of N content in the stored initial tankage samples under lab condition showed a significant continuous decline in N content from 10% to 30% of the initial N (date not presented). N volatilization in the form of ammonia (NH_3) is a major source of N loss to the atmosphere. Soil acidification is caused by an increase in H^+ resulting from the deposition of the NH_3 into the soil. Under field/farm condition (higher temperature, humidity, rainfall, etc.), N loss is expected to be higher and faster because climate is the major factor leading to increased N loss [21].

Collection date	%								μg/g				
	N	C	C/N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	B
May 2012	10.6	45.57	4.3	3.21	0.92	6.06	0.18	0.78	1069	12	97	4	5
Aug 2012	10.3	45.50	4.4	3.54	0.83	6.22	0.17	0.77	788	9	96	4	2
Nov 2012	12.1	42.26	3.5	3.22	1.07	5.81	0.19	0.92	662	12	106	4	4
Feb 2013	9.8	47.10	4.7	3.50	0.73	6.18	0.17	0.72	730	8	91	5	3
May 2013	8.7	45.93	5.1	3.16	0.74	5.70	0.17	0.65	745	10	85	1	3
Aug 2013	8.9	46.81	5.3	3.23	0.83	5.88	0.18	0.83	728	8	91	3	4
Nov 2013	8.8	46.13	5.3	3.07	0.81	5.55	0.17	0.72	738	10	85	1	3
Feb 2014	9.3	45.81	4.9	3.09	0.81	5.43	0.17	0.69	667	9	75	2	3
May 2014	9.4	45.93	4.9	3.48	0.85	6.05	0.17	0.72	725	9	88	4	3
Mean	**9.8**	**45.6**	**4.7**	**3.27**	**0.84**	**5.87**	**0.17**	**0.75**	**761**	**9.7**	**90**	**3.1**	**3.3**
SD	**1.09**	**1.38**	**0.58**	**0.18**	**0.10**	**0.28**	**0.01**	**0.08**	**121**	**1.5**	**8.8**	**1.5**	**0.8**
CV	**0.11**	**0.03**	**0.12**	**0.06**	**0.12**	**0.05**	**0.04**	**0.11**	**0.16**	**0.16**	**0.1**	**0.5**	**0.2**

* Each value is a mean of three replicates.

Table 1. Tankage macro- and micro-nutrient content (μg/g), C/N ratio, standard deviation, and CV of samples collected over a 2-year period.

2.1.2. Nitrogen release pattern

To determine the N release pattern from tankage, a leachate column incubation experiment was conducted using tankage applied at four application rates (0, 100, 200, and 400 kg N/ha) with two soils [Wahiawa series (Oxisol) and Waialua series (Mollisol)] with three replicates for each application rate. A total of 24 PVC leachate columns (30 cm long and 10 cm diameter) were used. The columns were set up from top to bottom with 10 cm soil and tankage mixed layer, 15 cm soil layer, 2 cm gravel layer, and plastic fine mesh to prevent soil passing through. Incubation started with adding half-pore volume of deionized water for each column. At each collection time (weekly), half-pore volume of deionized water was added, and leachate subsamples were collected with glass beaker up to 3 months. Leachate subsamples were analyzed for nitrate (NO_3-N) and ammonium (NH_4-N) using a Vernier meter and electrodes. Results showed that NO_3-N concentration in the leachate solutions followed the application rate (**Figure 2A** and **2B**), and NH_4-N concentration in the leachate samples was very negligible (0.1–2.7 ppm). The mineralization rate in a 3-month period was between 50% and 75%. Under field conditions, actual mineralization is expected to be at or above the higher end of this range. The N release pattern under the two soils was the same. However, the NO_3-N values were higher under the Oxisol soil (Wahiawa series), which might be related to the fertility level and structural differences between the two soil types [22].

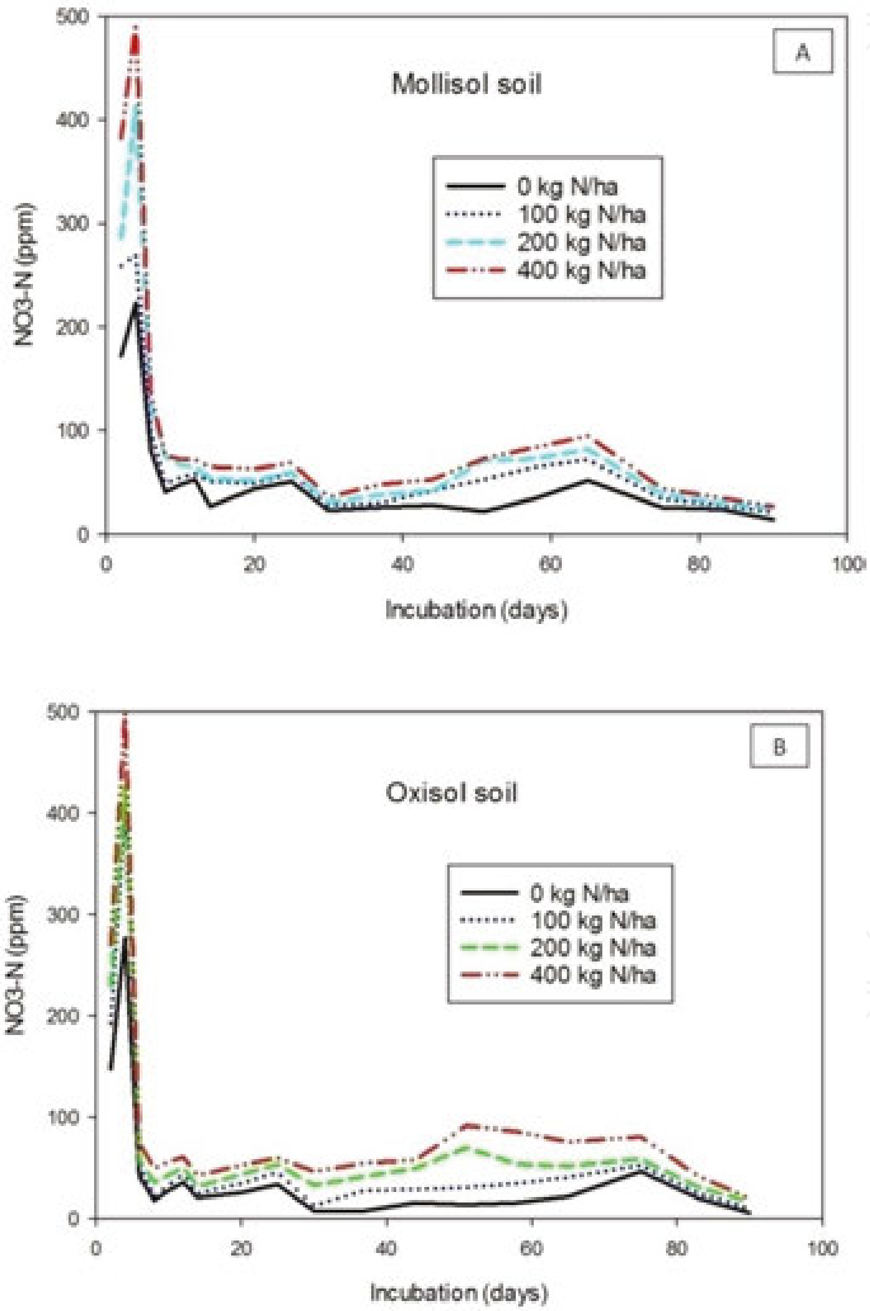


Figure 2. NO_3-N (ppm) release in a leachate column study from tankage applied at 0, 100, 200, and 400 lbs N/acre over 90-day periods under Mollisol (A) and Oxisol (B) soils.

2.2. Liquid fertilizer from tankage for fertigation purposes

Fertigation (fertilizer + irrigation) is a practice when both water and nutrient are supplied together through drip irrigation [23]. The practice is very beneficial for long-term crops, to meet the demand of crops for nutrient, integrated with the use of mulching, and to reduce nutrient losses [24]. Through a Western Sustainable Agriculture Research and Education grant, producing liquid fertilizer with high-N content from tankage was carried out at the University of Hawaii at Manoa (**Figure 3**).

Figure 3. Flask contains 1 g tankage and 50 ml water. Each treatment was replicated three times.

2.2.1. Factors studied and final recipe

Treatment factor	Level
Incubation time	0, 4, 8, 24, and 48 hours
Incubation temperature	24°C and 35°C (75°F and 95°F)
Cover/lid	Covered and open/uncovered
Inoculants/accelerators	Baking soda, soil, sugar, and vermicompost

On the basis of the results from the previous study (**Figure 4**), different factors in various combinations were evaluated for the N release from tankage. Based on these results, a suggested recipe was developed for greenhouse and on-farm trials:

- Add 1 kg (2.2 lbs) of tankage into 60 l (~15 gallon) water.
- Add about 40 g (1.5 oz) of vermicompost.
- Air (brew) for 12–24 hours.
- Strain and apply with drip irrigation (fertigation).

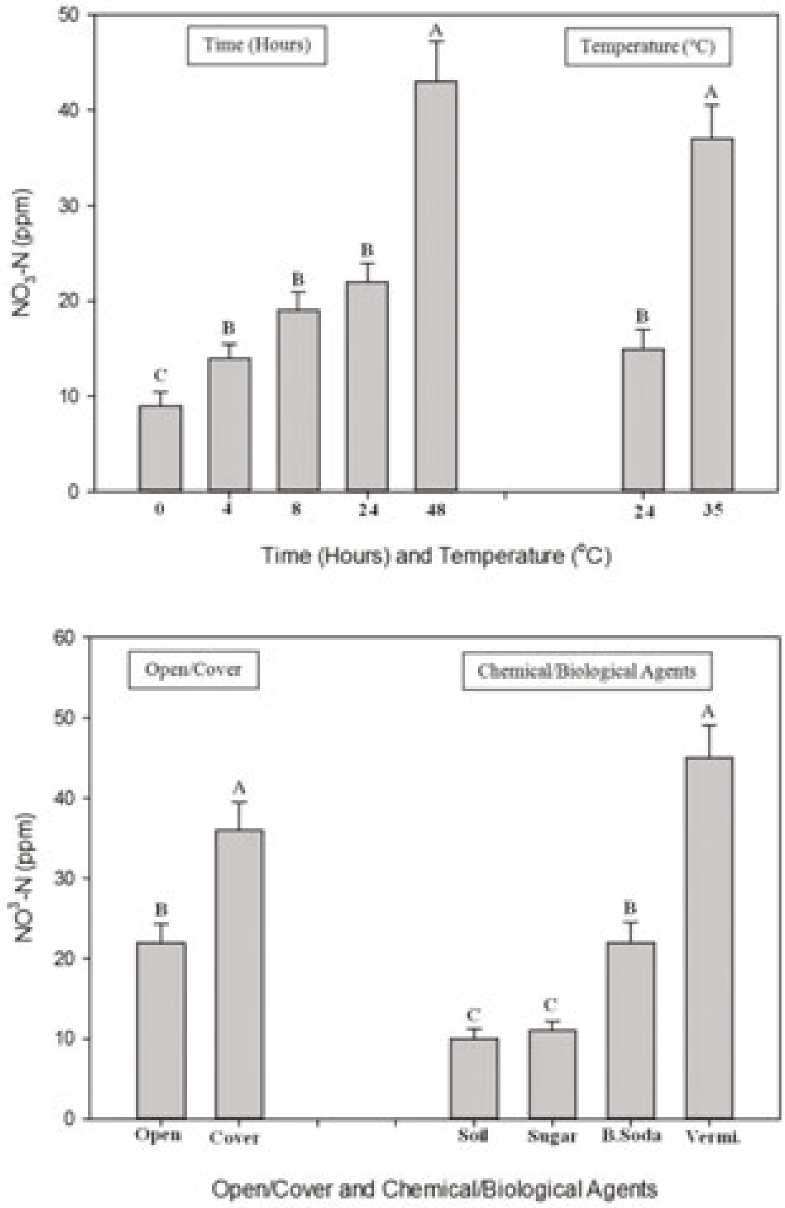


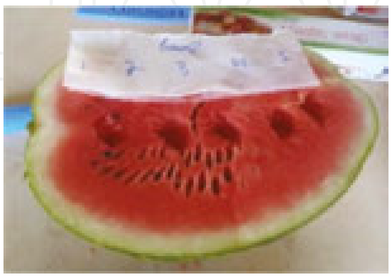
Figure 4. Nitrate release (ppm) from tankage under the effect of time (hours); temperature (°C); open or covered conditions, and chemical and biological agents. Bars with different letters, within each factor, are significantly different under 5% probability.

We found that the use of fresh tankage and vermicompost resulted in a higher N concentration in the liquid fertilizer. In addition, the use of thick cotton un-dyed bag to mix the tankage and vermicompost prior to brewing helped significantly reduce the need to strain the liquid fertilizer before fertigation.

2.2.2. On-farm and field trials

The above recipe was provided to a local farmer in Hawaii. The farmer used the recipe to grow watermelon on a 1-acre field with a Oxisol soil (Molokai series). The liquid fertilizer recipe was applied weekly till 2 weeks prior to harvest. The experiment was not fully replicated, but the results were consistent throughout the field. Randomly selected watermelon subsamples were taken, and the average weight and total soluble solid (TSS) contents were taken (**Table 2**). The TSS values were within the excellent range (10.2–13.0) for watermelon [25]. Also, the average weight and watermelon flesh color were representative of the overall crop quality. The yield and high TSS value suggested that the liquid fertilizer provided good amount of nutrient to the watermelon to grow well and accumulate the high-sugar content. As the on-farm field trial was not fully replicated, we conducted a field trial on Oahu Island at Poamoho Research Station on an Oxisol (Wahiawa series) soil. The objectives of the trial were to evaluate the effect of two liquid fertilizers (organic and synthetic) on the yield of different vegetable crops. The experiment was conducted on a 21 × 18 m area for three consecutive harvests of lettuce (*Lactuca sativa*), pak-choi (*Brassica rapa*, Chinensis Group), and daikon (*Raphanus sativus*) in a randomized complete block design (RCBD) with three replicates. Lettuce and pak-choi seedlings were transplanted after 2 weeks of seeding into trays in the greenhouse. Daikon was directly seeded into the field. The liquid fertilizers (tankage- and synthetic-based) were injected into the drip irrigation weekly. To ensure a uniform distribution of the liquid fertilizer, the irrigation water was applied till the drip pipes were completely filled, and then the liquid fertilizers were injected. Lettuce, pak-choi, and daikon were harvested at 4, 5, and 9 weeks, respectively. Leaf chlorophyll content of five randomly selected plants from each replicate was measured weekly using SPAD Minolta 502 m. At harvest, five random plants from each replicate were measured for fresh weight and dry weight (samples were dried at 70°C for 72 hours). The analysis of variance results were consistent throughout the three consecutive harvests, where the results showed a significant effect of the liquid fertilizer treatments on the fresh and dry weights of the harvested crops and leaf chlorophyll content. The fresh and dry weight means from tankage-based liquid fertilizer treatments were significantly higher ($P < 0.01$) than the synthetic-based liquid fertilizer (**Figure 5A** and **5B**). Also, the leaf chlorophyll content values were significantly higher under tankage-based liquid fertilizer than synthetic-based liquid fertilizer (**Figure 6**).

Melon	**Weight (lbs)**	**TSS/sample location**					**BRIX mean**
		1	**2**	**3**	**4**	**5**	
1	24	10.2	12.0	12.2	12.3	12.1	**11.8**
2	19	10.8	12.0	12.2	11.8	10.8	**11.5**
3	18	11.2	13.0	13.0	13.0	12.0	**12.4**
Mean	**20.3**	**10.7**	**12.3**	**12.5**	**12.4**	**11.6**	



Data were taken from different locations in each watermelon fruit.

Data were collected by Alton Arakaki, an Extension Agent on Molokai Island.

Table 2. Average weight (lbs) and TSS of three watermelon fruit harvested randomly from the Molokai on-farm trial.

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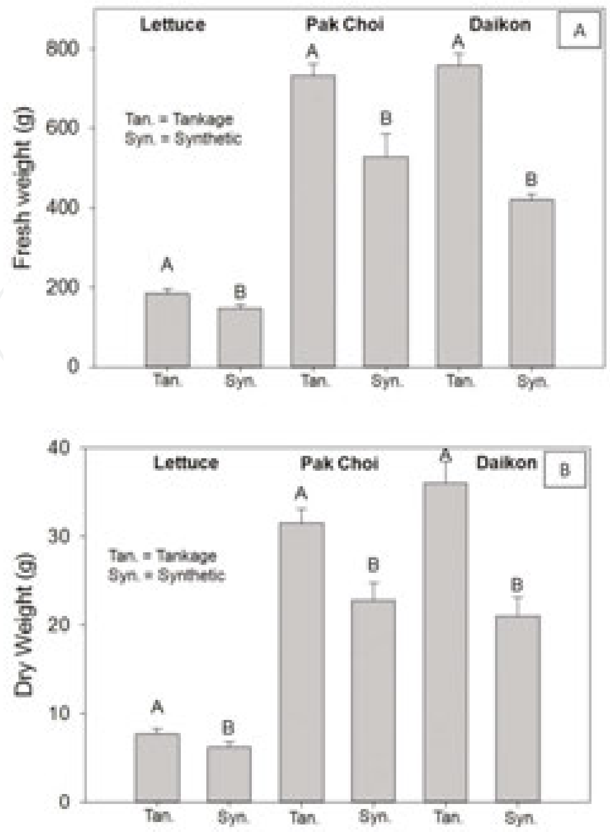

Figure 5. Fresh weight (A) and dry weight (B) for lettuce, pak-choi, and daikon under organic (tankage) and synthetic (30–10–10) liquid fertilizer application.

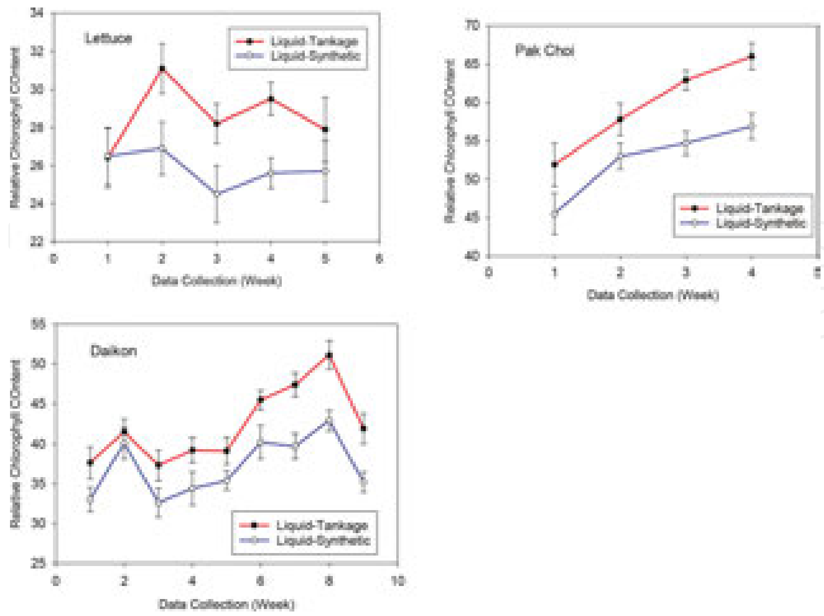

Figure 6. Weekly changes in leaf chlorophyll content under liquid-tankage and liquid-synthetic treatments for lettuce, pak-choi, and daikon crops, respectively, using Minolta Chlorophyll Meter.

3. Livestock manure

Using livestock on small-scale farms is beneficial for supplying small family needs for milk, eggs, meat, and other goods/products. Also, it can be a good source of organic fertilizer [26]. For example, on average, a 1000-pound cow may produce about 15 tons of manure annually. This 15-ton may contain about: 200 lbs of N, 190 lbs of phosphorus (P_2O_5), and 250 lbs of potassium (K_2O). Also, dairy manure (DM) contains the essential micro-nutrients [calcium (Ca), magnesium, sulfur, manganese, copper, zinc, chlorine, boron, iron, and molybdenum] [27]. Another example is chicken manure (CM), which contains all of the essential nutrients needed for healthy plant growth [28]. These include N, phosphorous, K, Ca, magnesium, sulfur, manganese, copper, zinc, chlorine, boron, iron, and molybdenum. Nutrient content and percentages vary based on the feed, supplement, medications, and water consumed by the animals. CM is known to provide a good portion, if not all of the nutrients required by plants [29]. Livestock manure is commonly applied in irrigated agriculture to improve soil fertility and crop yields [30, 31] and to improve the soil biology [32]. Soil physical properties, for example, bulk density and total soil porosity may change with agricultural management practices [33]. Manure amendments increase SOM, which may decrease soil bulk density and increase porosity of the amended soil [34]. Animal manures need to be well composted before application to benefit both soil and plants [6]. However, NO_3-N leaching can be a problem in organic and conventional farming. Under aerobic soil condition and with heavy application of manure, organically bound N is rapidly converted biologically into NO_3-N and that is highly leachable in soils or runoff and can lead to environmental and health issues. In a field study, we used CM applied to a Mollisol soil (Waialua series) under sweet corn crop, at a high-application rate (30 ton/ha); the NO_3-N concentration in soil water leached below the root zone

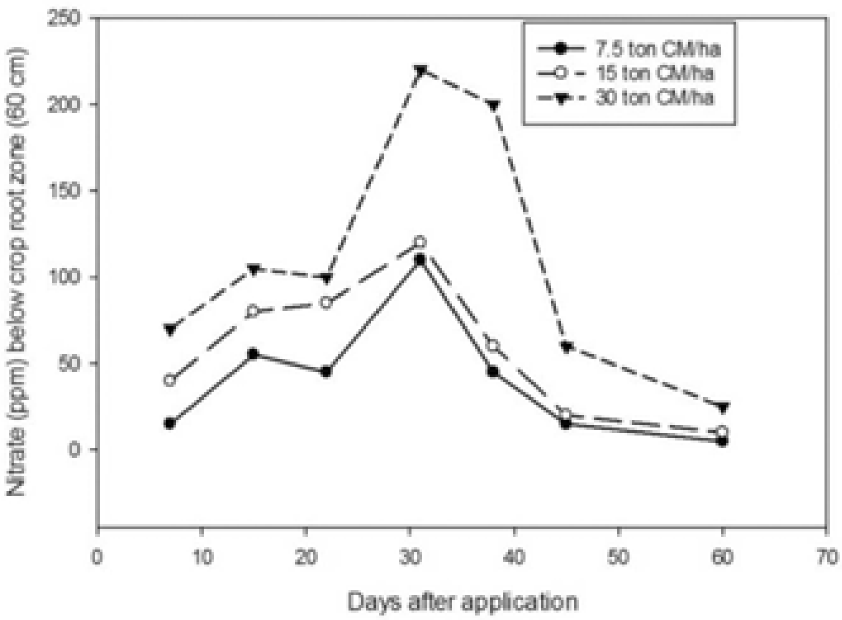

Figure 7. Nitrate (ppm) below the root zone of sweet corn under different application rates (ton/ha) of chicken manure (CM) applied to Mollisol soil (Waialua series) in Hawaii.

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of corn was very high and could lead to potential groundwater contamination (**Figure 7**). Moderate applications (7.5 and 15 ton/ha) and timing of manure application to meet plant needs may reduce the environmental pollution risks [35].

3.1. Livestock manure effects on soil physical properties and root distribution

3.1.1. Soil physical properties

Most commonly available animal manures in Hawaii are CM and DM. Macro- and micro-nutrient content and C/N ratio for the CM and DM used for field trials on Oahu, Hawaii, are presented in **Table 3**. Under the Wahiawa series soil using CM and DM applied at four application rates (0, 165, 335, and 670 kg N/ha), soil bulk density (ρ_b) and total porosity (θ_t) were measured using soil core samples. Soil bulk density significantly decreased with increased manure type ($P < 0.01$) and application rate ($P < 0.05$). Soil bulk density values for manure type and application rate were significantly different from the control treatment (**Figure 8A**). The soil bulk density was lowest under CM/high-application rate (670 kg N/ha) as compared to all other treatments. Bulk density decreased by 4%, 8%, and 9% for the low, medium, and high application rates, respectively, compared to control. Total soil porosity significantly ($P < 0.05$) increased with manure type and application rate. Soil porosity increased by 3%, 5%, and 10% for low, medium, and high application rates, respectively, compared to control. However, there was no significant difference between manure type and application rate (**Figure 8B**). The changes in soil physical properties could be related to the increase in SOM depending upon the animal manure type and application rate, and as Ref. [36] suggested the organic matter (animal manure) application can have different effects on soil properties by adding “less dense” material or by changing soil aggregate.

Manure type	%							μg/g					C/N ratio
	N	C	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	B	
Chicken	3.0	21.5	1.5	1.9	14.0	0.7	0.4	209	967	397	43	30	7.1
Dairy	1.8	15.0	0.5	1.8	2.0	1.0	0.5	1317	330	123	191	44	8.2

Table 3. Macro- and micro-nutrient and C/N ratio in chicken and dairy manure used in the field trials on Oahu, Hawaii.

Changes in soil bulk density and total porosity under chicken manure (CM) and dairy manure (DM) applied at 0 (Con), 165 (L), 335 (M), and 670 (H) kg N/ha. Means followed with different letters are significantly different at 5% probability based on Duncan's multiple test.

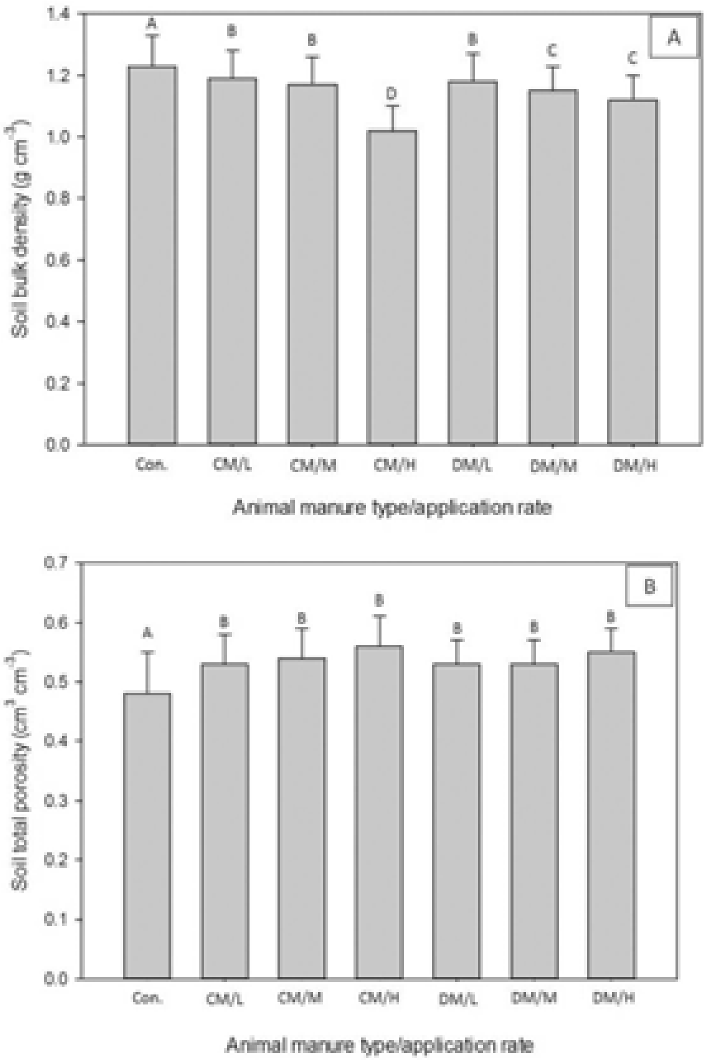

Figure 8. Changes in soil bulk density and total porosity under chicken manure (CM) and dairy manure (DM) applied at 0 (Con), 165 (L), 335 (M), and 670 (H) kg N/ha. Means followed with different letters are significantly different at 5% probability based on Duncan's multiple test.

3.1.2. Sweet corn root distribution

In the same field study above, sweet corn (*Zea mays* L. subsp. *mays*) percent roots at three depths (0–15, 15–30, and 30–45 cm depth) were evaluated for same animal manure types and application rates. The study included collecting soil cores from three locations, total of nine soil cores/plant, around the plant stem of five randomly selected plants in plots that measured 2 × 9 m each. The roots were collected from each soil core manually. As no visible roots were found in the cores collected from 30 to 45 cm depth, the results were considered for the top two depths (0–15 and 15–30 cm) only. The root percentage at the 0–15 cm depth under the CM and DM treatments was significantly ($P < 0.05$) higher than the control treatment (**Figure 9A**). However, the root percentage at the 15–30 cm depth showed the opposite pattern and root percentage under the CM and DM treatments was significantly ($P < 0.05$) lower than the control treatment (**Figure 10B**). The animal manure application rate increased significantly ($P < 0.05$) the root percentage at the top (0–15 cm depth) layer as compared to control treatment. The highest root percentage was for 670 kg N/ha (high) application rate, and the lowest mean was the control treatment. However, the reversed results were obtained from the lower (15–30 cm depth) layer, where the highest root percentage was the control treatment (**Figure 9B**). The increase in root biomass at 15–30 cm depth under the control treatment might be related to the expansion of roots' seeking water and nutrients beyond the top 15 cm (plowing layer) of soil as compared to the availability of nutrient (animal manure) within the top 15 cm soil layer under CM and DM treatments [37] or due to changes in soil bulk density as previously mentioned by Celik et al. [38].

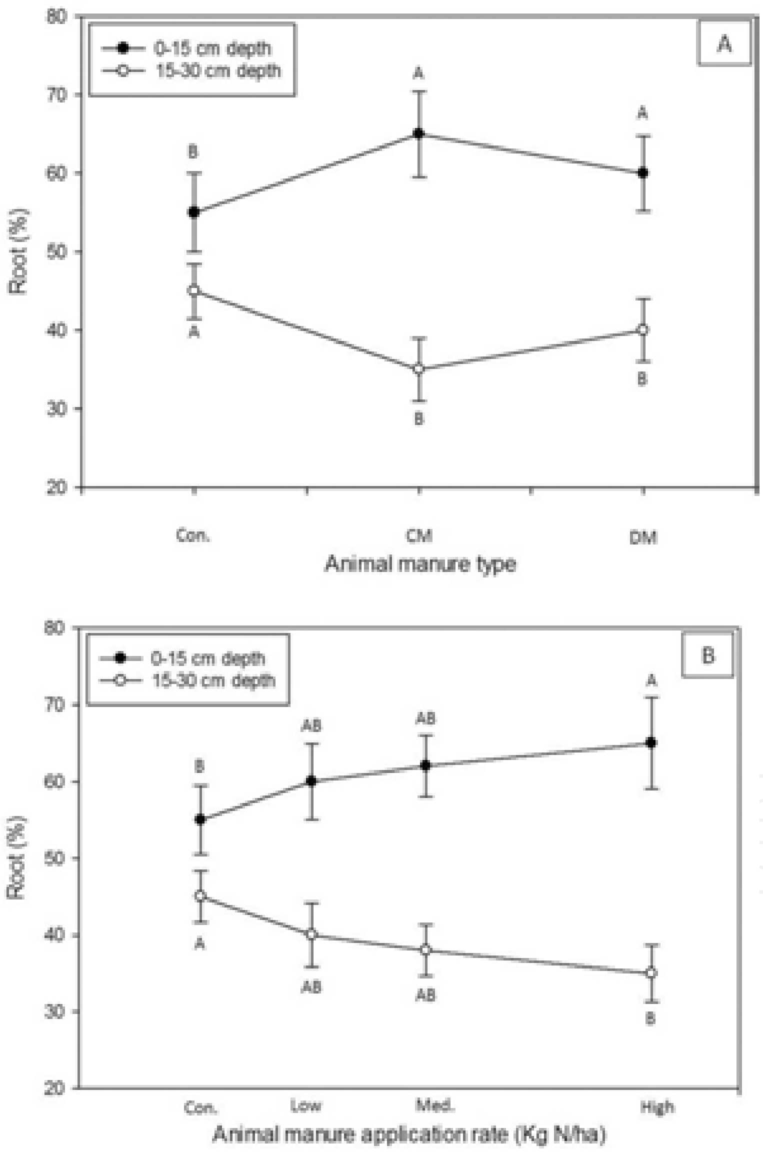

Figure 9. Sweet corn root distribution (%) at two depths (0–15 and 15–30 cm) under manure type (A) and application rate (B). Means followed with different letters are significantly different at 5% probability based on Duncan's multiple test.

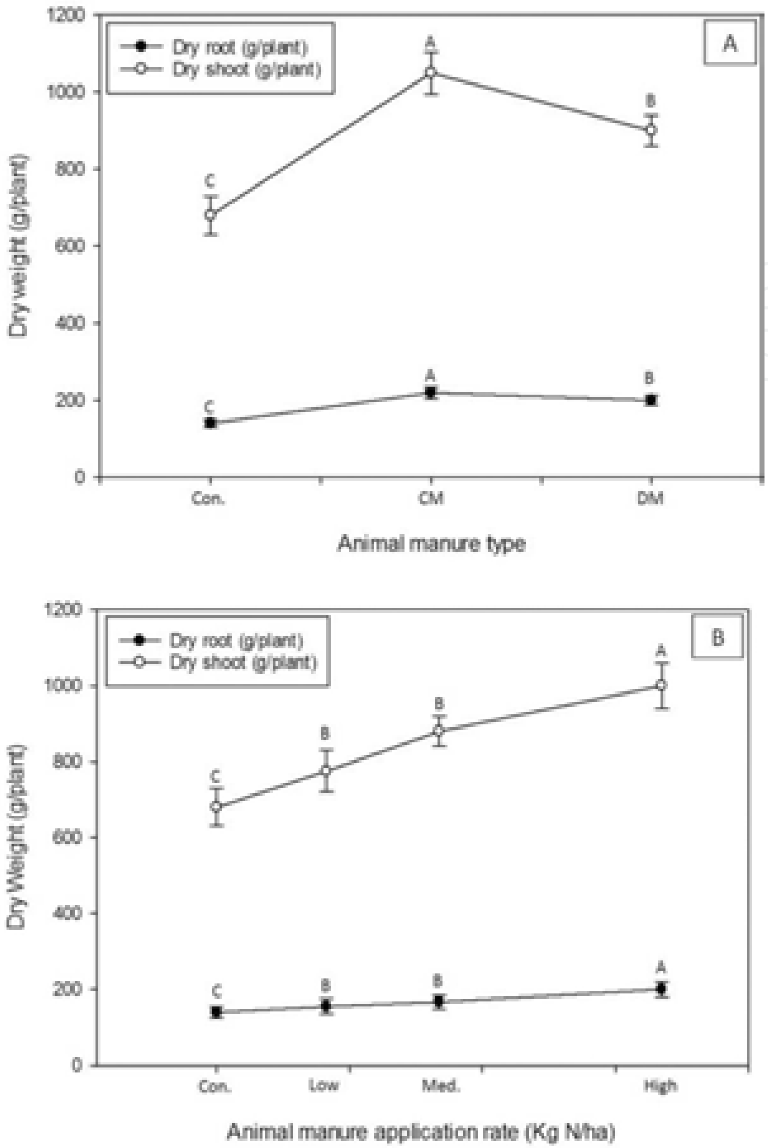

Figure 10. Sweet corn root and shoot dry weight (g/plant) under manure type (A) and application rate (B). Means followed with different letters are significantly different at 5% probability based on Duncan's multiple test.

3.2. Livestock manure effects on sweet corn biomass

In a field trial for two consecutive growing seasons, root and shoot biomass of sweet corn were evaluated under the application of CM and DM applied at 0 (Con), 165 (L), 335 (M), and 670 (H) kg N/ha. The analysis of variance showed a highly significant ($P < 0.01$) effect of both manure type and application rate on sweet corn root and shoot biomass. Sweet corn root biomass increased by 57% and 42% for the CM and DM treatments, respectively, compared to the control. Also, root biomass under CM was higher (10%) than DM treatment (**Figure 10A**). The shoot biomass increased by 54% and 32% for CM and DM treatments, respectively, compared to the control treatment. The shoot biomass under CM treatment was higher (17%) than DM treatment. Sweet corn root biomass increased by 42%, 20%, and 11% under high, med, and low application rates, respectively, compared to the control. Shoot biomass increased by 47%, 29%, and 13% under high, med, and low treatments, respectively, compared to the control (**Figure 10B**). The significant increase in root and shoot biomass might be related to increased nutrient availability and improved soil structure and SOM content [39]. The second-growing season data showed a similar pattern with higher means and no significant effect for the season on the studied parameters. The significant increase in sweet corn root and shoot biomass with the animal manure (type and rate) application is a good indicator of improved growth of sweet corn and forage produced under organic manure application, resulting in more feed for livestock and consequently more food for human consumption [28].

4. Algae species

Hawaii imports about 85% of the food consumed in the state, leaving it extremely vulnerable in terms of food safety and global events [40]. High level of goods imported and distributed throughout the state also poses a threat of introduced invasive plants (**Figure 11**) and animals [41, 42]. Marine non-native invasive seaweed has proven to be very costly to control in addition to developing a threat to the marine native ecosystem [43, 44]. The non-native seaweed species that have settled along the reefs of Hawaii grow and propagate more readily than the native seaweeds in Hawaii [45]. This is most likely because these seaweeds have less natural predators and herbivorous grazers since they are non-native to the area. Below is a description of the most common seaweed species found in Hawaii.

Figure 11. *Eucheuma* spp. sample collected on Oahu Island.

Gracilaria salicornia, also known as the Giant Ogo, is one of the most successful invasive seaweed species in Hawaii and is found mostly on Oahu and Hawaii Island. *G. salicornia* was first discovered in Hilo Bay on Hawaii Island and is believed to have originated somewhere throughout the Indian and Pacific Oceans [46]. This seaweed is much fitter than the native seaweeds and is more tolerant to light adjustments. It forms a thick mat that inhibits the growth of native seaweed species. This seaweed propagates both sexually and asexually by cloning through the fragmentation process [47].

Kappaphycus spp. (*K. striatum* and *K. alvarezii*) are coarse, spiny, and invasive seaweed and are usually dark green in color but may appear red if shaded. It was first introduced in Kaneohe Bay, Oahu, in 1979 for experimental aquaculture. This seaweed mostly resides in shallow subtidal reef flats in Kaneohe Bay on Oahu. Its fast vegetative growth increases with the environmental temperatures, allowing it to reproduce very rapidly [46] (http://www.botany.hawaii.edu/invasive).

Eucheuma spp. (*E. dentriculatum* and *E.* spp.) are much like *K.* spp. characteristics that make them difficult to distinguish between species. Rather, the term (clades) has been used to describe the physically different *E.* spp. without the use of molecular markers to distinguish between types. These types are commonly found on the east shores of Oahu Island as well as in the Waikiki area in Honolulu [48].

Avrainvillea amadelpha, also known as the mud weed, consists of wedge-shaped blades that are thin, diaphanous, 1–3 cm tall, and 1–4 cm wide. It has a dense cluster shape from attaching the blades by stalk to a compact basal holdfast. Blades are green to green-gray in color with smooth to lacerated edges. Clumps are muddy brown from being covered with silty sand. In Hawaii, *A. amadelpha* can be found in abundance on the shallow reef flats of Oahu's south shores, where it has disturbed and replaced native seaweed beds. It is expected to be a natural component of the deep-water community in Hawaii (http://www.botany.hawaii.edu/invasive).

Acanthophora spicifera seaweeds are abundantly found on calm, shallow reef flats, tide pools, and rocky intertidal benches. Often free floating, much of the success of these seaweeds is credited toward its brittle nature, allowing more widespread asexual distribution. The success of these seaweeds has contributed to the displacement of the native species of seaweeds. Evidence of its success in Hawaii is found in Maui, Molokai, Lanai, Kohoolawe, Oahu, and Kauai Islands (http://www.botany.hawaii.edu/invasive).

Hypnea musciformis is mostly recognized by its broad curls at the ends of some branches, allowing it to twine around other seaweeds. *H. musciformis* seaweeds are usually red in color but can also be yellow to brown in high-light environments or nutrient poor waters. During the bloom stage, it may be found free floating but is otherwise found on intertidal and shallow subtidal reef flats, tidepools, and rocky benches. It tends to grow on other large seaweeds and reproduces by fragmentation. These invasive seaweeds are destructive because they grow much faster than the native seaweed and shade out coral (http://www.botany.hawaii.edu/invasive).

The species that are currently targeted by cleanup efforts on Oahu Island are *G. salicornia*, *K.* spp., and *E.* spp. [49]. These species are predominantly found in Kaneohe Bay, reproduce asexually, and have not been observed to reproduce sexually in Hawaii. However, they are very capable of dominating the reefs with fragments of 0.5 cm and bigger [46, 50]. Some species of invasive seaweed have shown potential for use as an agricultural amendment due to its

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high K (13.5–18%) content (**Table 4**) and provide an opportunity to utilize an otherwise ecologically disruptive species.

Species	Washed/unwashed	%					μg/g						
		N	C	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu	B
G. salicornia	Unwashed	1.43	20.44	0.11	**12.48**	6.93	1.24	3.53	3564	553	22	11	316
G. salicornia	Washed	1.32	18.23	0.09	**9.15**	3.21	0.91	2.65	3204	482	19	9	286
E. spp.	Unwashed	1.01	21.14	0.07	**18.02**	1.08	0.63	4.81	123	18	18	3	196
E. spp.	Washed	0.78	17.78	0.06	**16.94**	0.37	0.61	3.71	45	9	14	2	166
K. spp.	Unwashed	1.39	22.10	0.07	**14.81**	0.47	0.53	4.71	83	8	14	5	139
K. spp.	Washed	1.21	21.78	0.06	**14.11**	0.28	0.52	4.43	67	7	12	3	135
A. amadelpha	Unwashed	0.67	12.21	0.05	**0.36**	30.13	2.21	1.81	9157	215	2	10	42
A. amadelpha	Washed	0.48	11.13	0.04	**0.21**	26.44	2.08	1.56	7853	197	2	6	42

Washing was by soaking each sample in a bucket of tap water for 3 minutes. Each value is a mean of three values.

Table 4. Seaweed species macro- and micro-nutrient content (with and without washing).

4.1. Nutrient variability and bio-security protocol for algae

4.1.1. Nutrient variability among algae species

Different batches of the four main species (*G. salicornia*, *Kappaphycus* spp., *Eucheuma* spp., and *A. amadelpha*) were collected from the Department of Land and Natural Resources (DLNR) "SuperSucker" team on Oahu at Kaneohe Bay. To reduce the salt content from the seaweeds and to evaluate the washing effect on nutrient content, the samples were split into two portions. One portion was washed with tap water, by soaking the sample in a bucket for 3 minutes. The other half was not washed. The two portions were dried at 95°C for 96 hours, and three subsamples of washed and not washed species of nutrient contents were determined. The results (**Table 4**) showed a high content of K in the *E.* spp. (18.02%), *K.* spp. (14.81%), and *G. salicornia* (12.4%). However, *A. amadelpha* was found to contain 0.36% K only, but a high content of Ca was 30.13%. Also, all species had a relatively good amount of N and other macro- and micro-nutrients beneficial for plant growth, yield, and rebuilding soil fertility [51]. Washing decreased the content of all macro- and micro-nutrients of all four species. However, the nutrient loss did not reach a significant level, and it is believed to significantly reduce the sodium content.

4.1.2. Viability and bio-security protocol

Viability and the spread of alien algae species into new shores and beaches across the Hawaiian Islands is a major concern and limitations to the use of these species as a major organic source of K fertilizer in agriculture, especially for direct application (without composting). A lab experiment was conducted to evaluate the effect of time and temperature on four seaweed species (*K.* spp., *E.* spp., *G. salicornia*, and *A. amadelpha*). The samples were dried in a conventional oven at ~90°C for 3 or 4 days (72 and 96 hours). Viability of dried samples was tested in a lab experiment with fresh (tap) and salt (ocean) water. Three random samples of 10 g from each species were placed in a 200 ml beaker with 100 ml of fresh or salt water. The lab experiment was repeated twice for 2 weeks each time. Monitoring changes on the seaweed species was performed over the 2-week test duration by taking pictures for each subsample. The results were identical for the repeated experiment. In both trials, the four seaweed species show no signs of growth or changes in volume, as a sign of water absorption during the first week. In the second week, the species showed decomposition signs (**Figure 12**). No differences were found between drying the samples for 72 or 96 hours and soaking the subsamples in fresh or salt water.

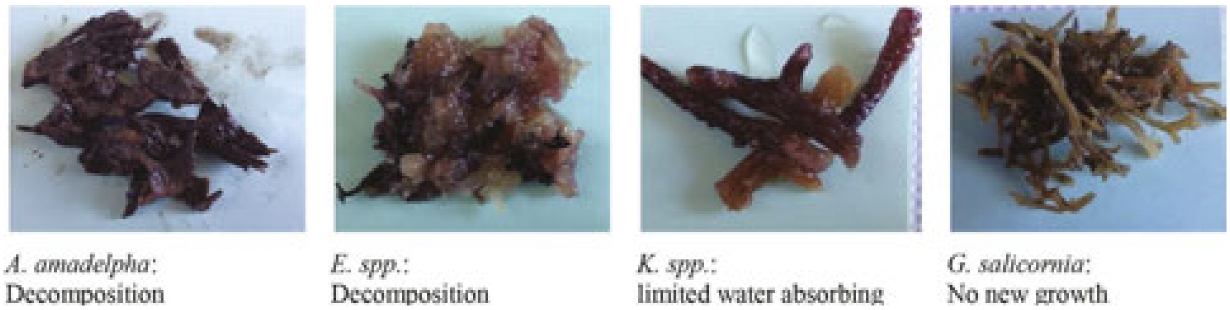

Figure 12. The four algae species showing signs of decomposition at the end of the second test experiment.

4.2. Direct application as organic source of potassium

Two field trials were conducted to evaluate the effect of different application rates of K on sweet potato growth and yield. K was applied at four application rates (0, 55, 110, and 220 kg K/ha) under two soil series (Wahiawa and Waialua). The experiment was under RCBD with three replicates. At harvest, the tuber fresh weight was recorded. Harvested tubers were cut down to pieces and dried at 75°C for 72 hours and then dry weight was recorded. The analysis of variance showed a highly ($P < 0.01$) significant effect of K application rates on the fresh and dry weights of sweet potato tubers. The highest means were at 220 kg K/ha, and the lowest was in the control (**Figure 13A** and **B**). The results were similar in pattern for both soils. However, the fresh and dry weights of tubers were higher in the Oxisol (Wahiawa series) soil than the Mollisol (Waialua series) soil, although the Mollisol is thought to have higher fertility than the Oxisol soil that might be related to the differences in structure between the two soils [22]. The initial K content in the two soils was higher than 300 ppm. However, the application showed a significant effect on the sweet potato growth and yield. This suggested that the soil K might not be available to the plant [52], and/or that the seaweed application improved the SOM, and/or the improvement in soil physical properties [53], allowing good tuber growth.

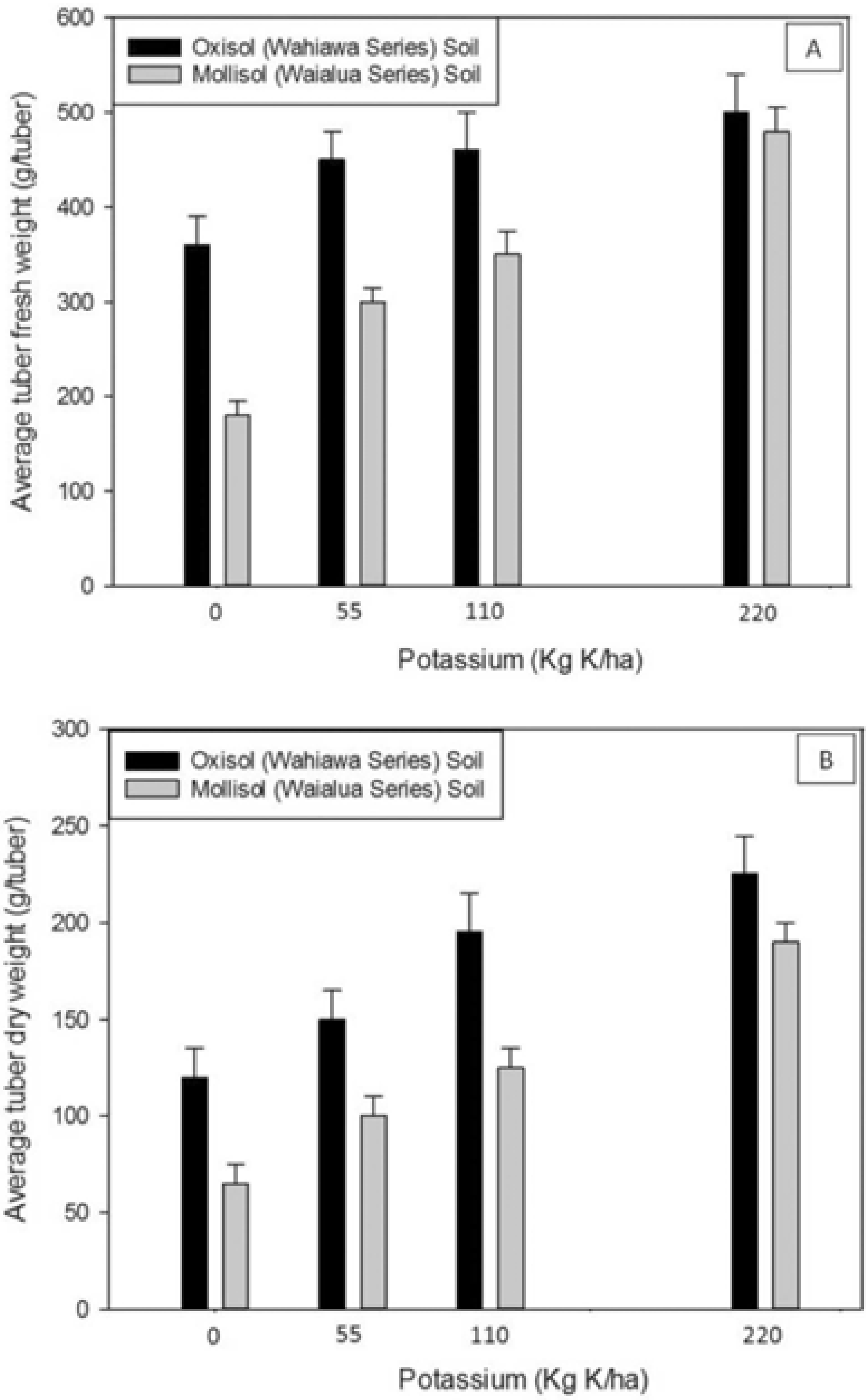

Figure 13. The effect of different potassium (K) application rates (kg K/ha) on average sweet potato tuber fresh (A) and dry (B) weight under Oxisol and Mollisol soils.

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