THE EFFECT OF INVASIVE SEAWEED (*EUCHEUMA SPP.)* AND TANKAGE, AS A SOIL AMENDMENT, ON SWEET POTATO GROWTH IN TWO HAWAIIAN SOILS.

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ABSTRACT

Sustainable agriculture practices apply management ideals that include a diverse assembly of farming methods, usually with a reduced reliance on purchased inputs. In Hawai‘i, some foreign aquatic non-indigenous invasive seaweed species have established in high abundances, especially around the most populous island of O‘ahu. Seaweed and seaweed products have been historically utilized in agriculture, and seaweed, kelp and macroalgae have been previously collected for use as a soil amendment for centuries. One of the attractive features of the non-native invasive seaweeds that are harvested on O‘ahu is the apparent high K obtainability. Sweet potato grown in two Hawai‘ian soils and amended with invasive seaweed (*Eucheuma spp.*) demonstrate adequate plant quality when compared to control treatments.

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DF: Degrees of Freedom

BMFW: Biomass Fresh Weight

RFW: Roots Fresh Weight

BMDW: Biomass Dry Weight

RDW: Roots Dry Weight

CHAPTER 1: INTRODUCTION

Agriculture in the Pacific

Hawaiʻi is located approximately 4,000 kilometers from the nearest landmass, and is one of the most geographically isolated areas in the world (McDonald *et al.,* 1986). Hawaiʻi imports over 85% of the food consumed in the sate, leaving it extremely vulnerable to changes in oil prices, political whims, food safety scares, and global events (HDOA, 2012). Reducing the state's dependence on imported foods is of great concern among Hawaiʻi residents, business and government leaders. The goal of food independence also provides many economic benefits to the local community (Leung and Loke, 2008).

The high level of in-shipments of goods that are imported and distributed throughout the state also poses a treat of introducing invasive plants and animals. These introduced pests can pose a threat to Hawaiʻi's agricultural economy and it's vulnerable environment (Leung and Loke, 2008). Previous introductions of invasive pests have proven costly to remove or contain with hundreds of millions of public dollars spent on control programs (Ikuma, et al, 2002).

Increasing the production of locally grown foods can reduce the risks involved with importation as well as support the local agricultural economy. According to the Hawaiʻi Department of Agriculture (HDOA), replacing 10% of imported consumed food would result in approximately $313M remaining in the State. This revenue would support the economy with an additional $188M in sales, $47M in earnings, and $6M dollars in state tax revenues, as well as 2,300 more jobs (HDOA, 2012).

Local farmers are able to supply much of Hawaiʻi's demands for fruits and vegetables such as watermelon, papaya, banana, watercress, chinese cabbage, mustard cabbage, green onions, and Asian vegetables. In addition, an estimated 75% of tomato, sweet potato, cucumber and sweet corn is locally grown and sold (Lee and Bittenbender, 2008). Furthermore, estimates suggest that only 102,000 acres made it into crops in 2005, leaving 48,000 acres of arable land available for future farming efforts (Lee and Bittenbender, 2008). As the opportunity to produce more locally grown food increases, the need for soil amendments also increases, opening a niche for local and affordable soil amendments. Affordability of soil amendments has been a major issue for local agriculture for more than a century. In the last ten years, the cost of fertilizer, has increased fourfold (Huang, 2009).

Sustainable agriculture practices apply management ideals that include a diverse assembly of farming methods, usually with a reduced reliance on purchased inputs (Hue and Silva, 2000). As new farmers tend to encounter limited financial resources, affordability of soil amendments plays a huge part in the success of the farm (Shinshiro and Bowen, 2006). In addition to concerns surrounding availability of affordable soil amendments, interest in sustainability has risen among American consumers. The population in Hawaiʻi is estimated to increase by 13,000 people per year until 2020 (Gangnes, et al, 2008) and as population increases, food resources will need to become available for them. In addition, increased tourism can also demand a greater need for local food production, demanding fresh local fruits and vegetables. Attaining food security and increasing sustainable farming practices in the State follows the national trend for a market that appeals for sustainable food production.

Additional issues limiting local food production include poor land availability and unused acreage through long-term leases or purchase, an increasing cost of labor, and the cost of importing soil amendments (Lee and Bittenbender, 2008). Although Hawaiʻi would need an estimated additional 261,000 acres in production in order to produce 100% of its food resources locally, it is conceivable to reduce its dependency on imported goods (Lee and Bittenbender, 2008). Utilizing locally available soil amendments is one step in increasing the opportunity for sustainable food production in Hawaiʻi.

Invasive Plants

Since Captain Cook's visit, Hawaiʻi has seen numerous introductions of plants and animals. These introductions have been both intentional (such as agricultural) and accidental (such as weeds) with some becoming both invasive and destructive. The term non-native invasive species refers to a species that is introduced to an area and exerts dominant growth over the native ecosystem (Helm, 2013). This results in a dramatic shift in the native ecosystem, which may have non-reversible negative effects on the flora, fauna and natural processes of the system constituents and external systems affected by them (Vitousek et al*.,* 1997).

Non-native introduced generalists and opportunistic species often dominate ecosystems, especially in locations affected by environmental degradation, amplified by species introductions (McKinney and Lockwood, 1999; Schaffelke, et al, 2007). Invasive species are second only to habitat loss in terms of the risk posed to overall global biodiversity (Gramling, 2000).

In Hawaiʻi, some foreign aquatic non-indigenous invasive seaweed species have established in high abundances, especially around the most populous island of O'ahu. Studies have shown that the introduction and proliferation of these invasive seaweeds monopolize the coastal waters and alter food webs. As a result, sediment nutrient levels remain elevated, resulting in degraded reef biodiversity and habitat (Littler, 2006).

In addition to the loss of biodiversity, the degradation of natural ecosystems can also have profound negative effects on the local economy. Some of the economic impacts of the introduction of non-native invasive species include fishery losses, drops in tourism activity, damage to municipal water systems, as well as the loss of the money spent for eradication of non-native invasive species (NOAA, 2011). The control and eradication efforts of non-native invasive species in the United States cost an estimated $100 billion annually in economic losses (National Ballast Information Clearinghouse; Bateman, 2011).

Non-native invasive species can be problematic for native ecosystems and can cause major economic losses when they act as vectors for new diseases, alter ecosystem processes, and reduce biodiversity (Vitousek et al. 1996; Mack et al. 2000; Bax, et al. 2001). However, non-native invasive species are not unique to Hawaiʻi, and have been noted to transform marine habitats around the world. The most harmful of these invaders can displace native species, change community structure and food webs, and alter fundamental processes, such as nutrient cycling and sedimentation (Molnar, et al. 2008)

The recent Intergovernmental Panel on Climate Change (IPCC) indicates that many factors, including increasing sea-surface temperatures, rising sea levels, increasing atmospheric CO_2 and ocean acidification will have a significant impact on coastal habitats in the coming decades (Bindoff et al. 2007; Williams and Grosholz, 2008). Slight temperature increases alone can lead to the stress of native ecosystems and an increased success of introduced species which are often better able to cope with environmental changes than their native counterparts (Stachowicz et al. 2002).

Estuaries and coasts are particularly susceptible to introductions of non-native invasive species partly as a consequence of hosting activity that represents the major vectors for non-native invasive introductions (Williams and Grosholz, 2008). Currently, Hawaiʻian waters are classified as tropical, with near shore water temperatures ranging from 71 degrees Fahrenheit during winter months to 80 degrees Fahrenheit in the summer (NOAA). However, sea level rise under global warming may change the current environment that is suitable for native ecosystems, to make way for non-native invasive species, which may be more tolerant of water condition fluctuations. Recent studies on climate change have predicted profound effects on coastal societies and ecological communities around the world (Michener et al. 1997; Nicholls and Lowe 2004; Kerr 2006; Williams and Grosholz, 2008) and the trends in Hawaiʻi are soon to follow.

Once alien species become established in marine habitats, they can be nearly impossible to eliminate. Ensuring that proper policies are in place to prevent the arrival of new non-native invasive species, and mitigation procedures, after their arrival and establishment, is critical (Molnar, et al., 2008).

For established non-native invasive species populations, many successful terrestrial management programs rely on mechanical removals and chemical applications (Mack and Lonsdale, 2002), while aquatic eradications often rely on chemical control. However, some manual mitigation efforts to control the existing populations of non-native invasive aquatic introductions have already been instituted in Hawaiʻi. Although the rate of growth is currently undetermined, introduced marine macroalgae growth is projected to increase and spread around the island of O’ahu, as well as the outer islands (TNC, 2013). The impacts of marine macroalgae have encouraged efforts by some groups to collect the seaweed for disposal. One example is the mechanical removal of introduced marine macroalgae with a suction device, called the “Supersucker” (Coordinating Group for Alien Pest Species, 2006; Williams and Grosholz, 2008). Maybe talk about the super sucker in more detail before the next paragraph; it sucks up large quantities of seaweed that is currently disposed of by… this will be a nice Segway to your next topic.

While there are many ways to approach this issue of the increased biomass of established non-native invasive species, one method is to adapt and use the material. Seaweed has been historically used in agriculture as a soil amendment to improve soil and crop quality (Stephenson, 1968). The increasing cost of chemical fertilizer, especially in the Pacific, paired with a growing trend towards a use of sustainable resources makes locally available by-products, such as seaweed, an attractive source of plant nutrition for agricultural use.

Three currently collected species of invasive seaweed (*Gracilaria salicornia, Aravinvillea amadelphia,* and *Eucheuma spp.*) found around Oahu, show potential for use as locally available soil amendment. Research of potential seaweed candidates for agricultural use indicate significant levels of potassium and calcium (Radovich et al., unpublished data 2012). Increased levels of such nutrients may prove to be beneficial for local users of soil amendments. Understanding the potential benefit of utilizing this readily available local resource could be economically beneficial to local food producers, provide an outlet of an invasive by-product and potentially improve the quality of locally produced agricultural products.

Seaweed in Agriculture

In addition to its use for human consumption, food additives, industrial uses and medicine, seaweed, kelp and macroalgae have been previously collected for use as a soil amendment for centuries (Craigie, 2011). References from the sixteenth century described the use of seaweed in the British Isles used on barley, potato, oats and other vegetable crops. These seaweeds may have even been used as a soil substitute in Ireland, mixed with sand and laid on bare rocks (Stephenson, 1968). In addition, fresh seaweed may have also been used in combination with chicken manure in Europe in the late 1600s. Seaweed was also found to be collected after the Second Word War, when farmyard manure could not keep up with farming needs (Stephenson, 1968). In addition, experiments in the mid 1900s also described reduced pest pressure as well as increased growth with applications of seaweed to agricultural crops.

An imbalance of coral and seaweed dominance involve long term negative effects that decrease available biodiversity as well as the intrinsic value of the reef, and alter the reef community structure (Smith, 2002). The non-native invasive seaweed species that are most common in Hawai‘i are a result of human introduction. Since the 1950s, there have been an estimated 19 species of macroalgae introduced to the island of O‘ahu. An increase in the carrageenan market in the 1970s encouraged the introduction of several high carrageenan producing species to Hawai‘i. *K. spp.* and *E. spp.* were introduced legally to a northwestern reef on the island of O’ahu for growth studies (Glenn, 1981). Reports of these species rapidly spreading from the area began to come to light in 1996, and confirmation of reef domination and overgrown colonies were confirmed by 2002 (Conklin, Kurihara and Sherwood, 2009). Misidentification has increased confusion about the extent of the species distribution, as well as poor identification without the use of molecular markers.

Currently, several projects to combat these invasive seaweeds showcase different techniques that can be used to eradicate these species. Since 2006, the Super Sucker barge has been operated by the State of Hawai‘i Aquatic Invasive Species Team (AIS), within the Division of Aquatic Resources (DAR) of the Department of Land and Natural Resources (DLNR). In a partnership with the University of Hawai‘i and the Nature Conservancy, this barge is able to target invasive seaweed within Kaneohe Bay as well as the Waikiki area on O’ahu. This is accomplished through the use of a suction generated pump system, led by divers feeding invasive seaweed though a submerged hose. The seaweed is then bagged and distributed to local farmers within the watershed area (DLNR, 2012). An additional, more recent effort to combat these invasive species is the cultivation and “seeding” of native sea urchins, which feed on the invasive seaweed. Small efforts to manually remove seaweed with small volunteer groups have also been effective, however the substantial impact of removal is seen through the pairing of the Super Sucker treatment, followed by urchin seeding (TNC, 2013).

A study in 2011 estimated the total economic value of the coral reef systems in Hawai‘i at 34 billion dollars annually. In addition to keeping this economic resource viable, these invasive seaweed removal efforts also continue to protect the fish and wildlife that reside along the shores (NOAA, 2011).

Species

The foreign seaweeds that have settled along the reefs of Hawai‘i grow and propagate more readily than Hawai‘i’s native seaweeds (Conklin, et. al., 2009). This is most likely because these seaweeds have less natural predators and herbivorous grazers then they would have in their original habitat. They also may have advantage over the native species because of the foreign

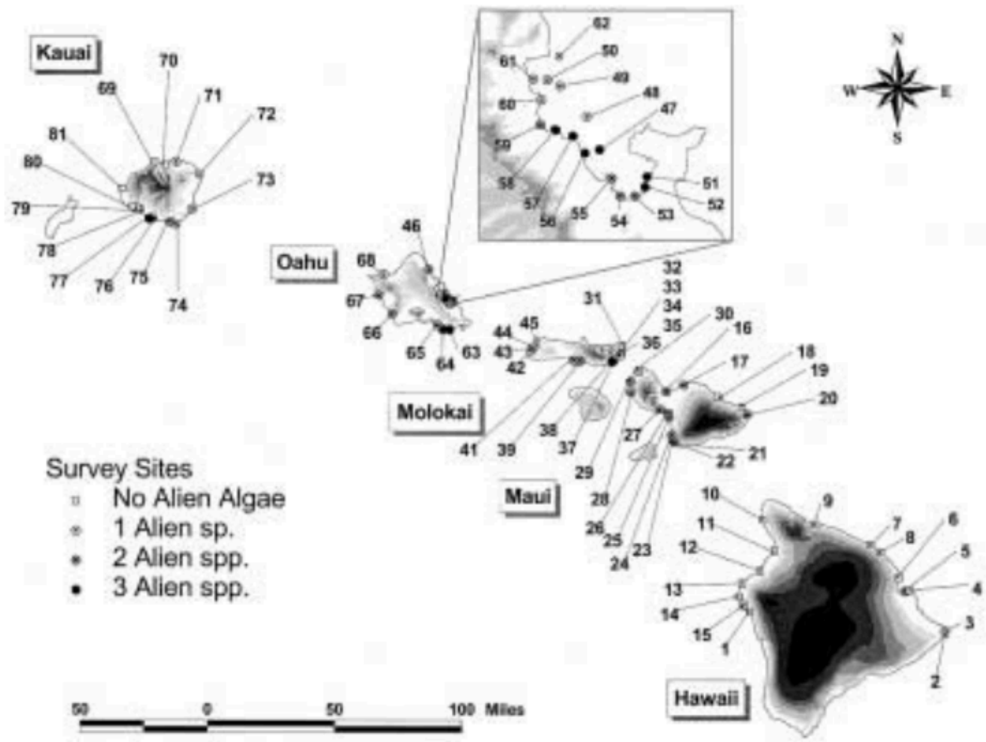

Fig 1.1 Map of all sites surveyed for nonindigenous seaweed in the main Hawai‘ian Islands. Each number represents a particular site and corresponds to the appropriate entry in a table found in (Smith, 2002). Symbols represent the number of nonindigenous seaweed species present

nutrient acquisition strategies, which the native seaweeds find hard to compete with (Williams and Grosholz, 2007). Potential for complete domination by the foreign seaweeds lies in the possibility of a decreased number of herbivorous grazers and the elevated presence nitrogen and phosphorous.

Gracilaria salicornia

Also called "Giant Ogo", this species is one of the most successful species of foreign invasive seaweed in Hawai'i. The distribution spans mostly on O'ahu and Hawai'i Island. *G. salicornia* was first discovered in Hilo Bay on Hawai'i Island, and is believed to have originated somewhere throughout the Indian and Pacific oceans, where it is also commonly found (Smith, 2002). These seaweed are much fit than the native seaweeds and are more flexible to light adjustments, allowing it to be very competitive with the native seaweed. Thick mat form inhibits the growth of other species of seaweed, allowing them to grow very quickly compared to the native species of seaweed (University of Hawaii Mānoa Botany Department, 2001). They propagate both sexually and asexually by cloning through the fragmentation process (Nishimura, 2001).

Kappaphycus spp. (*K. striatum and K. alvarezii*)

Coarse, spiny, invasive seaweed, *K. spp.* is usually dark green in color, but may appear red if shaded. It was first introduced in Kaneohe Bay, O'ahu, in 1979 for experimental aquaculture (Bishop Museum, 2003). This seaweed mostly resides in shallow sub tides on reef flats in Kaneohe Bay, on O'ahu. Due to a thallus with multiple meristems, this branch of seaweeds reproduces very rapidly. Its fast vegetative growth increases with the temperature of the environment (University of Hawaii Mānoa Botany Department, 2001).

Acanthophora spicifera

These 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 towards the brittle nature of the seaweeds, allowing more widespread asexual distribution. The success of these seaweeds has contributed to the displacement of the native species of seaweeds (Bishop Museum, 2003). Evidence of its success in Hawai'i is found in Maui, Moloka'i, Lana'i, Koho'olawe, O'ahu, and Kaua'i (University of Hawaii Mānoa Botany Department, 2001). Its introduction to Hawai'ian reefs was unintentional.

Hypnea musciformis

Most recognized by its broad curls at the ends of some branches, allowing it to twine around other seaweeds, *H. musciformis* seaweeds is usually red in color, it can also be yellowish brown in high light environments or nutrient poor waters (Bishop Museum, 2003). In 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 such as Sargassum, and reproduces by fragmentation. These invasive seaweeds are destructive because they grow much faster than the native seaweed and shade out coral (University of Hawaii Mānoa Botany Department, 2001).

Eucheuma spp. (*E. dentriculatum and E. spp.*)

These species, much like *K. spp.* have 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 species. These species are commonly found on the east shores of the island of O'ahu, as well as the Waikiki area (University of Hawaii Mānoa Botany Department, 2001).

The species that are currently targeted by cleanup efforts on Oahu are, *K. spp., E. spp.,* (DLNR, 2012). These species are predominantly found in Kaneohe bay, and reproduce asexually. *K. spp., E. spp* or *G. salicornia* have not been observed to reproduce sexually in Hawai'i, however still prove very capable of dominating the reefs with fragments as small as .5 cm (Smith, 2002).

The species that was used for the purpose of this project was *E. spp.* due to its nutrient content through dry matter tissue analysis (Table 1.1) and availability due to harvesting.

Plant Requirements

One of the attractive features of the non-native invasive seaweeds that are harvested on O'ahu is the apparent high K content (Table 1-1) in the tissue analysis (Radovich, et al, unpublished data, 2012). Proper plant growth requires adequate nutrient inputs, which are often difficult to produce, in quantity, sustainably. In most plants, Potassium (K) is needed in large quantities in order to regulate the osmotic potential of plant cells. Inadequate K can cause major issues for plants, resulting in poor water uptake, retention, transport, and resistance to pests and diseases (Hue, 2000). K is relatively mobile in the soil, and can be easily leached unless supplemented with organic matter, or in a slow release formulation. K amendments in organic agriculture tend to require additional amounts of amendment more frequently due to the generally low K availability in the amendments (Silva, 2000).

Nitrogen (N) is also generally difficult to acquire in adequate amounts in organic agriculture. N is also needed in larger quantities, and is necessary for supporting metabolic processes such as energy transfer and growth. Previous studies suggest that, N releases more quickly in warmer climates, like Hawaiʻi, therefore increasing the need for a reliable N source (Hue, 2000). While there are many options available, finding resources that can provide adequate amounts of N in one application can be difficult. Rendered meat by-product, or "Tankage" (Island Commodities, Honolulu, HI) is a locally produced fish and meat meal that is available to farmers as a local N source. Originally, the rendered meat by-product was derived from waste from the adjacent slaughterhouse, but as the slaughterhouse began to see less and less use, tankage now consists of 55-60% fish, from the local fishing industry. Tankage is used statewide, and sold wholesale to farmers as a high N organic soil amendment.

Table 1.1- Organic sources in percent dry weight of K for organic amendments.

	N	**P**	**K**
Organic Source (%)			
Bone Meal [b]	3.0	2.0	0.5
Alfalfa Meal [b]	2.7	0.5	2.8
Cattle Manure [b]	2.0	1.0	2.4
Compost [b]	1.0	.08	1.0
Greensand [b]	0.0	0.0	7.0
Cowpea Green Manure [c]	3.6	0.4	3.5
*Tankage [a]	**10**	3.0	.06
****Eucheuma spp.* [a]	.90± .10	.06± .01	**18±2**
***Kappaphycus spp.* [a]	.66±2	.04	22.9
***Aravinvillea amadelphia* [a]	.67	.05	.36
***Gracilaria salicornia* [a]	1.42±2	.11	12.8± .2

[a] Samples were prepared from analysis at the Sustainable and Organic Farming Program (SOAP) at the University of Hawaiʻi at Mānoa, and nutrient content were analyzed at the University of Hawaiʻi Agriculture Diagnostic Services Center (ADSC).

[b] Growing Fruits and Vegetables Organically, © 1994 by Rodale Press, Inc. Permission granted by Rodale, 400 S. 10th St., Emmaus, PA 18098.

[c] Hue, N.V., and I. Amien. 1989. Aluminum detoxification with green manures. Commun. Soil Sci. Plant Anal. 20:1499–1511.

*Tankage and *Eucheuma spp.* are identified in bold as important sources of N and K for this thesis.

** Seaweed collected for analyses were about % 89±2 water, and mass weights were significantly lower after drying. Calculations for a fresh seaweed application should account for % 11±2 mass per percent analyzed nutrient content. Fresh seaweed application calculations should account for the weight difference by dividing application rates by .11± .02.

Soil Characteristics

Hawai‘i is home to ten of the twelve soil orders in the world. Despite the State's small land area (approx. 16,600 km sq.), there are great soil variations within close distances, such as soil weathering, fertility, rainfall, acidity, and many other factors (Ikawa, et al. 1985). A great amount of research by historical agriculture industries in Hawai‘i, such as sugar cane and pineapple, have provided in depth descriptions about the diversity of these soils. While tropical soils are often considered infertile, these past studies have found that, with proper management, these soils can provide high crop yields (Hue, 2002).

Soil K

Plants uptake potassium in the form of K^+ ions, and they are primarily used in regulating the rate of photosynthesis, ATP production, the translocation of sugars, starch production in grains, nitrogen fixation in legumes, and protein synthesis (Korb, et al. 2005). While non-mineral exchangeable K can limit the plants use of other nutrients, K leaching does not pose the same environmental threat as excess nitrogen (N) or phosphorous (P). However, soil samples may not accurately indicate plant available levels of K, as 90-98% of K found in the soil is mineral K, in unweathered rock materials such as feldspars or micas, and is therefore unavailable for plant uptake (Foth et. al., 1997). In addition, extra K is often taken up by plants as luxury consumption, and is mobile in plants, thus the application period is less critical compared to N application period requirements.

Applications of K to soils with soil samples that indicate adequate or high levels of potassium may still be beneficial in a cropping system. Only 1-4% of soil K can be found in the soil solution, on clay humus, or within clay minerals. Exchangeable K can sorb and desorb to negative soil colloid surfaces with a weak electrostatic attraction. Any surplus exchangeable K can bind to clays, and become slowly available over time (McLean, 1978).

The availability depends greatly on the types of K minerals that are found in the soil. Feldspar minerals [$KAlSi_3O_8$], such as Microcline and Orthoclase can resist chemical breakdown and weather more slowly than Mica minerals, such as Muscovite [$K(AlSi_3)Al0_{10}(OH)_2$] and Biotite

$[K(AlSi_3)(Mg,Fe^{2+})_30_{10}(OH)_2]$. These are the major minerals in granite rocks, and bind most of the mineral K found in the soil (McLean, 1978).

Soils with a low Cation Exchange Capacity (CEC), such as typical highly weathered soils like Oxisols, can bind K. With increasing pH, hydrogen ions (H^+) are removed from cation exchange sites, which can then bind to K, and further decrease plant available K. Soils with high CEC can attract more K, and often show little response to large amounts of K fertilizer. The surplus K weakly binds to clays, and large reserves of fixed K slowly release for plant uptake over time. As plants uptake K from the soil solution, weakly binded K is will desorb into the soil solution (Korb, et al, 2005). High concentrations of calcium (Ca^+), Magnesium (Mg^{+2}), Sodium (Na^+), Ammonium (NH_4^+) and/or Aluminum (Al^{+3}) can compete for exchange sites, altering the concentration of K in the soil solution (Havlin, et. al., 1999).

K is also not incorporated into the plants structure, and therefore not bound in organic forms. In the case of invasive seaweed, these attribute allow any available K held in plant cells to be quickly released for crop use. Most crops will absorb adequate amounts of K early in the growth season, to reach maximum K concentrations. Later growth is not affected by early applications of K, as it is mobile throughout the plants life cycle (Brady et. al., 2002).

Hawai'ian Soil Characteristics

Although soils can diversify within close ranges, generally soils found on the island of Oahu are more highly weathered than soils found on the Big Island of Hawai'i, and are less weathered than soils found on the island of Kauai (Ikawa, et al, 1985). A greater iron oxides content, such as predominant Hematite over Geothite, in Hawai'ian soils, provides a more reddish color in the profile.

Two soil orders are predominantly found at the University of Hawai'i research stations and on historically used agricultural land on the island of Oahu, Oxisol and Mollisol. The Oxisol soil is highly weathered and therefore generally has low fertility. Most of the weatherable silicate clays have been removed, and dominated by insoluble, low CEC oxides of iron and aluminum (Hue, 2000). Macronutrients such as Ca, Mg, and K are often not retained in these soils, and P is easily fixed and immobilized. This soil also contains non-swelling clays, such as kaolinite, with phyllosilicates with a 1:1 ratio of Gibbsite and silicate [SiO_4] tetrahedra. These clays are low activity clays with a pH dependent charge, a relatively low surface area, and non-sticky texture (Hue, 2000). These clays are often associated with nutrient depletion.

Mollisol soil is characterized as a soil with high fertility. Macronutrients such as Ca, Mg and K are retained in these soils, and P is not often fixed. Mollisol soils found in Hawaiʻi can be difficult to cultivate despite their high fertility due to physical soil properties. This soil contains expanding and swelling Smectite clays such as montmorillonite, with phyllosilicates with a 2:1 ratio of Gibbsite and silicate [SiO_4] tetrahedra. This structure allows penetration between silicate layers, and easier cation release to the soil solution. These clays are high activity clays with a permanent negative charge, a high CEC and surface area, a sticky texture, and these soils are often associated with nutrient accumulation (Foth et. al., 1997).

Soil Testing

The soil samples processed for research at the University of Hawaiʻi at Manoa are often handled through the Agricultural Diagnostic Service Center (ADSC) on campus. The process that is used at this service center for extractable cations (Ca, K, Mg) use an Ammonium Acetate extracting solution (1M, pH 7.0). The ration of soil to solution is 1:20. 2g of sifted soil is shaken for 10 minutes, and the cation concentration is measured with an Atomic Absorption (AA) Spectrophotometer (Hue, et al. 2000).

CHAPTER 2: SUMMARY

The potential for Hawai'i's future in sustainable agriculture provides promising opportunities to expand on local markets to support it. Utilizing smart tools to implement a sustainable future of higher food security and lower imports to fuel the local economy is a step in the right direction. A better understanding of the need to control these invasive species and the appropriate methods to combat spread generates a lateral need to address how to process the resulting biomass that is collected from currently used collection methods. Finding a parallel need in our environment that utilizes this waste product promises coexistence between farmers and their crop demands.

In order to proceed with confidence encouraging the use of invasive seaweed in our agriculture system, we must address the following issues. This thesis contains the following studies:

1. Seaweed Viability
   While assessing the use of invasive seaweed as a soil amendment, processing the material becomes an important step towards ensuring safe usage of the products. In response to concerns regarding spreading the invasive seaweed outside of the watershed where they are currently collected, an analysis of viability after various treatments can provide some answers to interests about the responsible usage of this material. If adequate drying treatments are applied to invasive seaweed (*Eucheuma spp.*), reproductive capability and virility can be greatly or successfully compromised.

2. Potassium Leaching
   Understanding the plant availability of these soil amendments can provide a much greater idea for the soil-interaction when used on a larger scale. Starting with small lab experiments to identify soil characteristics can provide an overview of the behavior and break down of these amendments. If increasing applications of seaweed are applied to Hawai'ian soils, increasing nutrient availability can be observed.

3. Glasshouse Trials

   Plants that require higher applications of K can function as a suitable subject when assessing seaweed as a soil amendment. While pot trials do not precisely replicate field conditions, they can demonstrate the plant availability of the available nutrients that were observed in previous research. If glass house and pot grown plants are provided increasing and alternative sources of K, including invasive seaweed (*E.spp.*), increased growth will display a corresponding plant response.

4. Field Trials

   Before recommending soil amendments to local farmers, research needs to verify that high K requiring crops can be grown with invasive seaweed on a large scale. Previous lab and glass house experiments indicated that plant required nutrients are available through applications of seaweed, and a field trial would confirm the supposition. If field grown sweet potato in two Hawaiʻian soils are amended with increasing applications and alternative sources of N and K, these applications will become apparent through plant quality and growth.

CHAPTER 3:SEAWEED VIABILITY

Introduction

Marine non-native invasive seaweed has proven to be very costly to control once established. In addition to developing a threat to marine diversity, invasive seaweeds can negatively impact the commercial value of the area they occupy (Thomsen et. al., 2007).

Some species of invasive seaweed have shown potential for use as an agricultural amendment, thus providing an opportunity to utilize an otherwise ecologically disruptive species. However, due to the invasive nature of these species in Hawai'i, care is needed to ensure they don't spread to unaffected areas of the state. In order to confidently encourage the use of these invasive seaweeds for agricultural use, cost effective and simple methods to make the seaweed non-viable are required (Ahmad et al., unpublished report, 2013).

Large concerns surrounding the use of invasive seaweed as an agricultural amendment, especially when used outside of the watershed of collection, is the invasive nature of these seaweeds. The species used in this viability experiment (*Eucheuma spp.*) have not been observed reproducing sexually in the state (Smith, 2002). Therefore, asexual propagation has proven to be a very successful method of propagation for these species. Fragments as small as 0.5cm long have been observed surviving in lab settings after harvest (Smith, 2002). This resilient asexual propagation technique supports the necessity for investigating successful methods of reducing viability after harvest before use in agriculture.

Previous studies have shown that, Hawai‘ian non-native invasive species show signs of reduced viability when dried at high temperatures in a forced draft oven (Ahmad et al., unpublished report, 2013). This promising lead suggested that, reducing the high water content (85-90%) of these invasive species through heat may provide an answer not only to reducing viability, but also increasing the storage life and transport-ability of these potential soil amendments.

This research project focuses on the drying technique to reduce viability. Investigating different temperatures and durations of drying may provide more insight into future options for dealing with these invasive seaweeds after harvest.

The objective of this experiment is to establish an understanding for the reproductive potential of invasive seaweed (*E. spp.*) after drying treatments. This information can assist in the recommendations for the responsible use of this seaweed as a soil amendment.

Materials and Methods

Invasive seaweed (*E. spp.*) was collected from Kaneohe Bay, with the underwater vacuum "Supersucker", on Jan 2, 2013. The unwashed seaweed was then preweighed and dried at various temperatures for different lengths of time. The dried seaweed was then reintroduced to the ocean in seaweed cages to assess viability after the drying treatment. The location used for this evaluation was the PaePae O He'eia fishpond in He'eia, on O'ahu Island. This experiment was repeated both inside and outside the confines of the fishpond to address the different water qualities.

Inside the fishpond, large rock walls contain young fish, and allow only a small amount of water flow from the ocean. The species of seaweed used in this experiment is not commonly found inside the fishpond. However, outside the fishpond, this species is quite abundant, and dominate much of the flora surrounding the fishpond.

The collected seaweed was transported for drying immediately after collection. Drying treatments for seaweed reintroduced inside the fishpond included: a fresh control (no treatment), drying in a forced draft oven at 65° C for 2 days, 4 days and 8 days. Drying treatments for plants reintroduced outside the fishpond include: a control (no treatment), drying in a forced draft oven at 65° C for 2, 4 and 8 days, and drying at room temperature (18° C) for 6 and 9 days.

After drying, the plants were caged and submerged inside and outside the fishpond for 3 weeks (Figure 3.1). Seaweed cages were made of fine (1mm) polyester mesh to allow water flow in and out of the cages, and also to retain the seaweed for weighing. Bags were weighed and tied to posts outside of the fishpond among wild seaweed of the same species. Each treatment was checked weekly for changes and growth.

After the three-week period, the seaweed was collected. Fresh collection weight and dried weight was recorded. Seaweed was weighed after the three week incubation before and after drying again at 65° C. Both wet weight and dry weights were recorded to determine if mass increased due to growth.

Each treatment had 4 replications and the results were analyzed by an Analysis of Variance (AOV) as a General Linear Model (GLM).

Results and Discussion

Seaweed *E.spp.* was caged and incubated inside the fish pond showed a significant difference from the control treatments (P=.0000). Control mass was weighted (g) at 5.3±1.2, compared to oven dried treatments 2,4 and 8 days, which were 4.95±1, 4.85±1.5, and 4.7±.4, respectively. However, none of the treatments showed mass increase after the incubation period, indicating that the environment was not suitable for seaweed *E.spp.* growth (Table 3.1, Figure 3.2). All treatments showed no signs of persistent cellular structure after three weeks (Figure 3.3).

Seaweed *E.spp.* caged and incubated out side the fish pond, showed significant mass differences after a three week incubation period between the control and drying treatments (P=.0000, .0000). Control mass was weighted (g) at 44.45±2.3, compared to oven dried treatments 2,4 and 8 days and room temperature treatments 6 and 9 days, which were 2.6±.8, .603±.2, and .306±.52, and 5.64±.8, and 3.625±1.2, respectively. In addition to mass difference, physical appearance was also a large differentiating feature between control and drying treatments. While the control treatments showed almost no changes in appearance, drying treatments lost pigment, shape and structure (Figure 3.4).

Significant differences between control treatments and treatments dried in a forced draft oven at 65° C for 2, 4 and 8 days, and dried at room temperature (18° C) for 6 and 9 days were apparent in mass and physical appearance (Table 3.1) Changes in mass may have occurred as a result of decomposition after the seaweed cell structure was damaged due to drying treatments. Control treatments did retain color and structure, indicating that cell structure damage did not occur.

Conclusion

The use of invasive seaweed as a soil amendment outside the watershed where they are currently found can be a cause for concern due to the high efficiency of asexual propagation. Drying treatments at 65° C for 6 days can be a reasonable technique to deal with the reproductive potential.

Although room temperature treatments showed a significant mass difference from control treatments, small fragments still remained (Image 3.5), which may have long term asexual propagation potential. Previous studies from Smith and Smith, (2002), indicted that small fragments of these species are still capable of asexual propagation, and may pose a threat to a new watershed.

For use in local agriculture, as a low cost alternative to imported soil amendments, this product needs to be easily treatable by farmers. Drying the seaweed was chosen as a simple method to remove reproductive potential. Although this analysis was conducted using a forced draft oven at 65° C, in a separate study (Cadby 2013, unpublished data) high temperatures were easily reached using potting benches under a poly ethylene clear sheeting to protect from the rain. Farmers interested in treating invasive seaweed for agricultural use should have easy access to viability reducing methods such as heat.

Alternative treatments may be available if cooperation from State resources or NGO groups take interest in facilitating the use of this resource agriculturally, and a treatment facility is built. In this case, more research surrounding alternative measures to reduce reproductive potential may prove to be highly beneficial. Future studies for recommendations regarding reducing the asexual reproduction of these species would need to encompass a larger species diversity as well as a larger location diversity in order to fully understand the potential of these species.

Figures and Tables

Figure 3.1- Aerial view of the PaePae O He‘eia fishpond in He‘eia, on O‘ahu. Photo is courtesy of PaePae O He‘eia and Martha Chang, 2014

Table 3.1- AOV for all treatments left inside and outside the fishpond. All treatments showed significant difference after a three-week incubation period. Means are described in g.

		Inside the fishpond	65° C outside the fishpond	21° C outside the fishpond
Source	DF	Percent Dry Mass Lost	Percent Dry Mass Lost	Percent Dry Mass Lost
		Means		
Control		5.225	44.45	--
2 days 65°		4.95	2.6	--
4 days 65°		4.85	0.60	--
8 days 65°		4.7	0.31	--
6 days 21°		--	--	5.65
9 days 21°		--	--	3.63
		P val		
Treatment	3	.0000	.0000	.0000
Block	3	.687	.5104	.2015
Error	9			
Total	14			

Figure 3.2- Drying treatments left inside the fishpond after the three-week incubation period showed little to no structure after harvest.

Figure 3.3- Control treatments before and after incubation inside the fishpond.

Figure 3.4- Drying treatments left outside the fishpond for the three-week incubation period. While the control treatments showed almost no changes in appearance, drying treatments lost pigment, shape and structure.

Figure 3.5 -Drying treatments at room temperature for 9 days after the three-week incubation period. Fragments larger than .5 cm still remain, providing the potential for asexual propagation.

CHAPTER 4: POTASSIUM LEACHING

Introduction

Dried seaweed was shown in the previous chapter to be non-viable. The non-viable state implies that residues were no longer contained by cellular membranes and could be readily diffused by the seaweed mass. The rate of diffusion would be dependent upon the size of the mass and the distance to the outside. A measure of this diffusion would be the rate of Potassium (K) leachate when mixed with distilled water. Mixing dried ground seaweed with soil provides an additional factor on potassium leachate rate. Soil columns provide a good indication for the amount of K that is released and available for plant uptake when seaweed is applied at different rates (Kolahchi et. al., 2006). In addition, collecting leachate at different time intervals can provide an understanding of the impact of seaweed decomposition and breakdown on corresponding the breakdown and corresponding K availability (Ahmad et al., unpublished report, 2013).

Different soils may interact differently and provide different responses to the applications of seaweed. This data will provide a better idea as to the free available and slowly available K to the soils. Some of the different characteristics that separate these soils include expectations typical of these two soil types. Mollisol soils contain a higher proportion of high activity, expanding 2:1 clay minerals, such as montmorillonite. Montmorillonite clay increases the likelihood of containing more negatively charged clay mineral surfaces, and can attract and retain cations such as K^+. Oxisol soils, which contain more highly weathered low activity, non-expanding 1:1 clay minerals, have a lower capacity to retain nutrients due to containing less surface area clays such as kaolinite (Brady, 2002)

The objective of this experiment was to establish application rates of invasive seaweed (*Eucheuma* spp.) and subsequent K plant availability in different soil types.

Methods

Soil

Two soils, a Hawai‘ian Mollisol (*Waialua* soil series) pH 5.7, and Oxisol (*Wahiawa* soil series) pH 6.3, were air dried and sifted through a 6 mm screen. Soil columns (Fig. 4.1) were constructed using 8 cm diameter PVC cylinders 30 cm in length. 0.5 mm mesh suspended on a 3.0 cm gravel layer under 12 cm soil layer, and 4 cm soil and algae mixed layer.

Application Rates

Soil columns containing 400g of dry soil were amended with K in the form of dried invasive seaweed *E. spp.* (18% K). The seaweed was dried for 5 days at 65° C before application to ensure a decreased reproductive capability. Application rates included: 0, 67, 134, and 200 kg/ha K. Actual rates applied were: 0, .06557, .13114, and .19671 g.

Measurements

Deionized water added at half pour volume initially to start the incubation process. Also, at every measurement, another half pour volume deionized water was added and collected. Total of 8 leachate samples collected over one month period. Collected subsamples measured for K content using a Horiba Cardy meter (Horiba, 2014). Random subsamples were also submitted to ADSC (Agricultural Diagnostic Service Center) for confirmation and quality assurance.

Results and Discussion

The Oxisol soil showed a significant (.0185) increase in availability of K in the soil solution as seaweed applications increased (Figure 4.1). The Mollisol also showed significant (.0151) increase in K availability with application rates. The total PPM K collected from the Mollisol soil solution was significantly less than was collected in the Oxisol soil.

In both the Oxisol and the Mollisol soils, increasing the application rate of seaweed showed a corresponding K increase in collected leachate (Figure 4.3, 4.4). The availability of K leaching was highest immediately after application and declined after 3 weeks (Figure 4.3). Increased seaweed application increased potassium released into the leachate.

The availability of K from seaweed began to decline after fourteen days from application (Figure 4.3). The decline in K availability occurred in all treatments, with the highest and lowest availability in treatments with rates of 200 and 67 kg/ha K, respectively.

Initial release rate of potassium supports previous findings that K is stored in outer layer of seaweed cells (Ahmad et al., unpublished report, 2013). As this K is released and depleted from the outer layer of the seaweed the rate of release is slower and tied to decomposition. Seaweed decomposition was rapid with little seaweed being visible within a month.

Conclusions

Significant availability of K was found to become available within the first three days after the initial application of invasive seaweed *E. spp*. Applications of seaweed in the field would more likely be effective when used for crops that require a slower release of K availability, and reapplication may also be required. The results suggested that seaweed was a viable source of potassium when added to soil.

Soil characteristics can be attributed to the differences in K availability in these two soil types. Nutrient sorbing characteristics present in Mollisol soils often bind surplus K to soil clays with a weak electrostatic attraction. Soil K does become available over time, however K is slowly and uniformly available. Water retaining characteristics present in a Mollisol would describe the lower availability of K in collected leachate, while the non-swelling clay present in the Oxisol would describe the readily available K in the collected leachate. As water is the primary carrier of K and swelling clays can compact water pathways, the reduced path of K ions can reduce K transportability in the soil. In addition, though the lower (5.7) pH and higher CEC of this soil series would imply that K would not be tightly bound on clay surfaces, adequate water availability can impede K transport. Past studies have indicated that, increasing soil moisture from 10-28% can increase total K transport by 175% (Skogley and Haby, 1981). Future research should account for the water holding capacity of these soils when measuring water input.

Invasive seaweed can be a viable option for small-scale or resource poor farmers in Hawai‘i, and the Pacific islands. Understanding the release rate in different soil types can provide good information pertaining to application rates and timing. With any agricultural amendment, seaweed can be incorporated into a sustainable system when used effectively, but also provides an economical answer to farmers looking to decrease dependence on imported fertilizers.

However, small-scale farmers need to be informed of the potential environmental dangers when using invasive seaweed as a soil amendment, and should take precautions in order to prevent it from spreading to unaffected watersheds. There are small measures that can be taken in order to ensure that invasiveness/potential for propagation is minimized, that also increase the storage-ability and application ease when using this material. Preliminary findings from our research indicate that K is available in the soil with application of *E. spp*. In addition, there are environmental benefits of properly utilizing this invasive by-product that would otherwise be discarded or become a source of nutrient leaching.

Figures and Tables

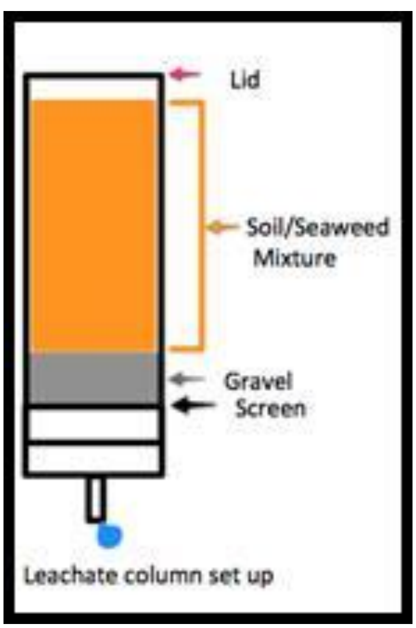

Fig 4.1 Leachate column set up. Soil columns were constructed using 8 cm diameter PVC cylinders 30 cm in length. 0.5 mm mesh suspended on a 1.5 cm gravel layer under 400 g of dried and sifted soil.

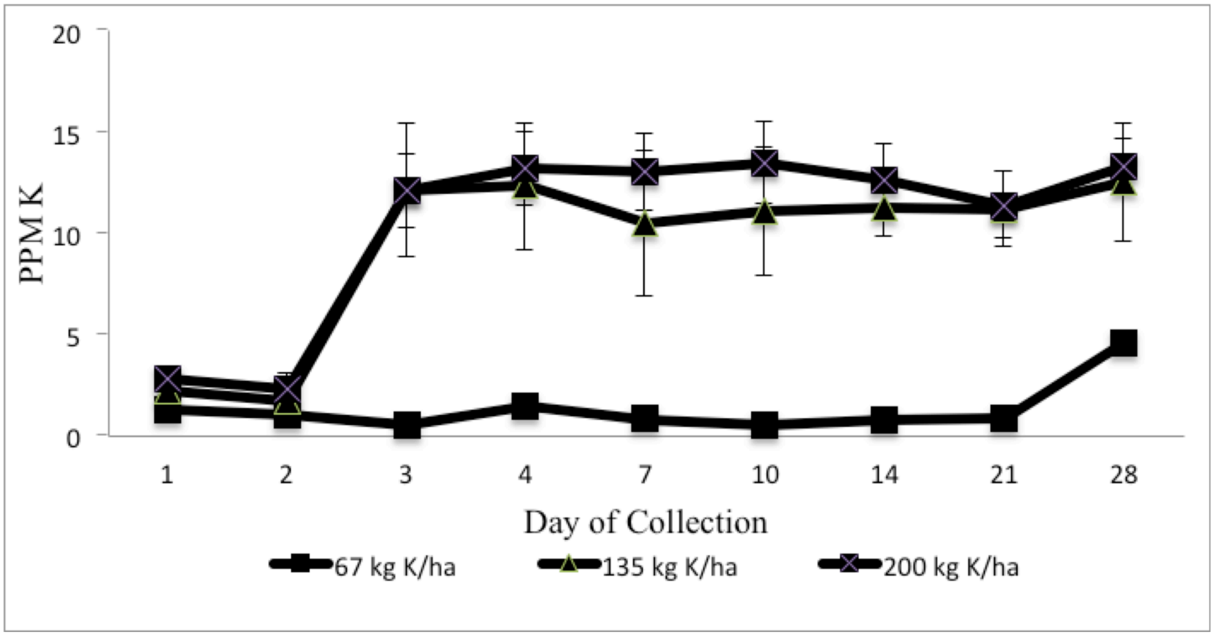

Figure 4.3- K availability over time in PPM for Oxisol soil. Values collected from control (underlying nutrients in soil) were subtracted from all treatments to gather K leached from seaweed.

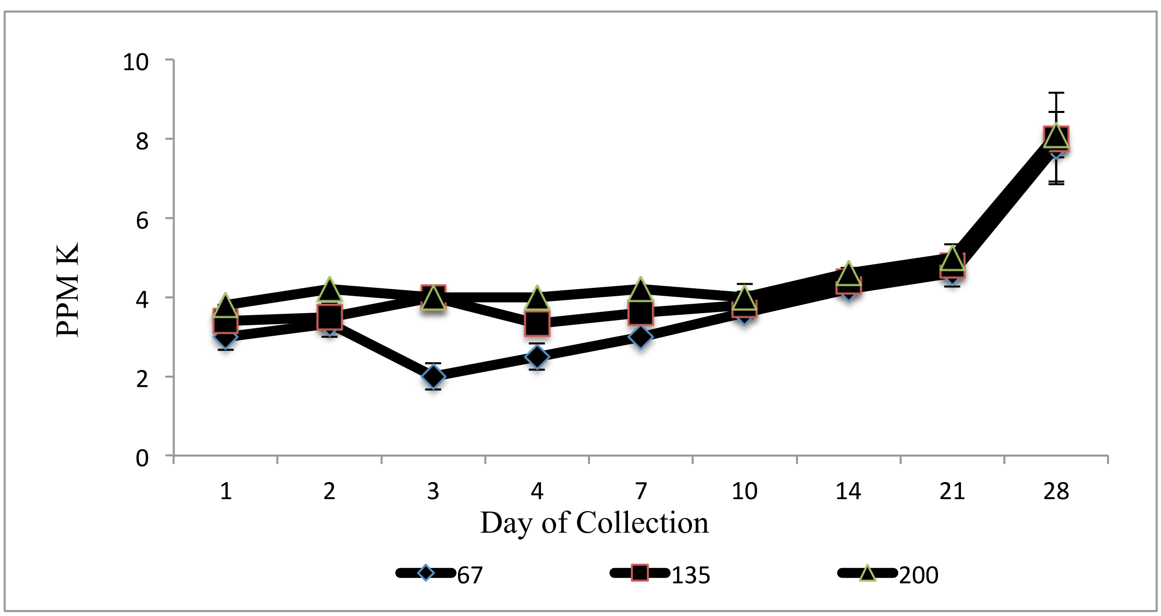

Figure 4.4- K availability over time in PPM for Mollisol soil. Values collected from control (underlying nutrients in soil) were subtracted from all treatments to gather K leached from seaweed.

Table 4.1 AOV for Oxisol and Molliosol soil. Rates were calculated from collected leachate in ppm K^+. Significant readings were made on days 1 and 2 of collection.

Source	**DF**	**Day 1**	**Day 2**	**Day 3**	**Day 4**	**Day 7**	**Day 10**	**Day 14**	**Day 21**	**Day 28**
Oxisol										
	Means									
67 kg/ha K		1.3	1.03	1.47	1.4	0.8	0.5	0.73	0.83	1.57
135 kg/ha K		2.2	1.67	12.1	12.31	10.47	11.03	11.23	11.17	12.5
200 kg/ha K		2.77	2.23	12.07	13.18	13.03	13.43	12.57	11.33	13.3
		P val								
Trt	3	.0185	.0185	.0701	.138	.1377	.4547	.0711	.1061	.3376
Blk	2	.7703	.760	.2441	.670	.6699	.4219	.250	.4219	.2963
Error	6									
Total	11									
Means										
Mollisol										
	Means									
67 kg/ha K		0.3	0.33	0.2	0.25	0.3	0.36	0.42	0.46	0.78
135 kg/ha K		0.34	0.35	0.4	0.33	0.36	0.38	0.44	0.48	0.8
200 kg/ha K		1.38	1.42	1.4	1.4	1.42	1.4	1.46	1.5	1.81
		P val								
Trt	3	.0151	.0220	.0217	.0033	.0212	.0117	.6263	.0922	.088
Blk	2	.2465	.530	.4830	.2106	.6867	.2811	.3200	.1532	.9571

CHAPTER 5: GLASS HOUSE TRIALS

Introduction

The use of sustainable and local soil amendments is increasing world wide, and invasive seaweed (*Eucheuma spp.*) show attractive attributes that may provide some local farmers with a reliable source of Potassium (K) (Radovich, et. al., unpublished data 2013). Although seaweed has been used historically in agriculture for centuries, the species that are found to be invasive in Hawaiʻi were primarily used for carrageenan production, and have not been thoroughly researched for agricultural usage (Smith, et. al, 2002).

Hawaiʻi is home to a great number of soil types, and many of the soils used in agriculture are highly weathered, or were intensively managed requiring additional soil amendments, or organic residues to prevent further soil degradation and increase nutrient retention (Mazzarino, et al. 1997). In addition to its prevalent availability, invasive seaweeds in Hawaiʻi can also provide the organic matter to function as a sustainable soil amendment.

Rendered meat by-product "tankage" is another locally available nutrient source that has promising levels of Nitrogen (N), which may also be available for plant uptake. This local soil amendment is also suitable for Hawaiʻi agriculture, as N is very costly to obtain (Huang, 2009).

Previous studies in the Sustainable Organic Agriculture Program (SOAP), at the University of Hawaiʻi at Mānoa, have indicated that these seaweeds and tankage can provide nutrients that are available for plant growth. This glass house trial aims to assess both of these local soil amendments for plant availability and subsequent plant quality. This information can provide a greater understanding of application rates for a larger field trial.

Due to high K requirements for growth (Maynard et. al., 2007), both sweet potato and amaranth were used in this study, In addition, both species are locally grown and in demand by consumers. The varieties that were chosen for this study are local favorites, and show great potential for future pairings with these soil amendments.

Two separate greenhouse trials were conducted with sweet potato and amaranth, planted in two soil types and one peat-moss media. Glasshouse trials are a useful first step in determining the efficiency of using invasive seaweed as a soil amendment. These small scale plant conditions can provide a clearer idea for application rates, nutrient availability by soil type and allow small scale comparisons for nutrient sources.

The objective of these pot trials is to discover if applications of invasive seaweed (*Eucheuma spp*.) can generate a response to subsequent K from sweet potato and amaranth grown in a glass house.

Materials and Methods

Soil

Soils used for this experiment include a Mollisol collected from Waialua and an Oxisol collected from Poamoho, Hawai‘i, and a peat moss potting mix, Sunshine Mix # 4. The Mollisol, Waialua series is described as: *Very-fine, mixed, superactive, isohyperthermicPachicHaplustolls* (USDA, 2001). This soil is moderately well drained, has slow to medium runoff, and moderate permeability. The Oxisol, Wahiawa series is described as: *Very-fine, kaolinitic, isohyperthermicRhodicHaplustox* (USDA, 2001). This soil is well drained, with slow to medium runoff and has moderately rapid permeability.

All soils used for this experiment were dried at 30°C for 5 days and sifted through a .6 cm screen.

Fertilizer

Fertilizer applications for sweet potato include application rates of 0, 28, 55, 110, and [(a)] 220 kg Potassium (K) per ha and 155 kg Nitrogen per ha sourced from invasive seaweed (*E. spp.*) and rendered meat by-product, tankage. Phosphorous was supplied at 45 kg per ha P in the form of tankage. [(b)] An additional application of 22 kg K per ha, 155 kg N per ha and 45 kg per ha P was provided with synthetic Potassium Chloride (KCl), Amonium Sulfate $(NH_4^+\text{-}N)_2SO_4$, treble superphosphate (P_20_5) (Table 5.1).

Fertilizer applications for amaranth include application rates of [a] 0, 28, and 55 kg Potassium (K) per ha and 155 kg Nitrogen per ha sourced from invasive seaweed (*E. spp.*) and rendered meat by-product, tankage. Phosphorous was supplied at 45 kg per ha P in the form of tankage. [b]Applications of 155 kg N per ha and 45 kg per ha P 22 kg K per ha were paired with increasing rates of K:0, 28 and 55 kg K per ha, provided with synthetic Potassium Chloride (KCl), Ammonium Sulfate $(NH_4^+-N)_2SO_4$, and treble superphosphate (P_20_5). Lastly, application rates of [c] 0, 28, and 55 kg K and 155 kg N per ha were sourced from Ammonium Sulfate $(NH_4^+-N)_2SO_4$ and invasive seaweed (*E. spp.*) (Table 5.2).

Cultural Practices

Sweet potato cuttings were collected with eight nodes at ten inches long of “Okinowan” variety. Cuttings were planted vertically in one gallon pots in a complete randomized block design. Plants were watered to field capacity through a drip system once a day. Growth parameters relative chlorophyll content, the Minolta SPAD-502 meter, and plant dry weight were collected weekly during and after growth period (110 days), respectively.

Amaranth seedlings, variety “Red Calaloo”, were grown from seed in the glass house. Juvenile plants were transplanted at 12 cm height. The growth parameter plant height and relative chlorophyll content, and the Minolta SPAD-502 readings were collected weekly throughout the growth period (50 days). Dry weight was collected after harvest.

Results and Discussion

Sweet Potato Trials

Dry weight collected from sweet potato pot trials indicated a significant difference in the root weight of plants grown with increasing applications of K in the Mollisol soil (.0264) (Figure 5.1) and the peat moss media (.001) (Figure 5.2), but not in the Oxisol soil (.0754) (Table 5.3).

Dry and fresh weight of roots and biomass collected from plants amended with seaweed and tankage and synthetic K and N displayed no significant difference between the two treatments in both media types and the peat moss media(.3872, .0758, .1109). (Table 5.4)

The growth parameter plant height and relative chlorophyll content, using Minolta SPAD-502 readings indicated no significant difference in any treatments regardless of soil type (Table 5.5).

Amaranth Trials

Dry weight collected from amaranth pot trials indicated no significant difference in the height of plants grown with increasing applications of K in the peat moss media (.5746). (Table 5.6)

Dry and fresh weight of biomass collected from plants amended with seaweed and tankage and synthetic K and N displayed no significant difference in the peat moss media (.0933). (Table 5.6)

The growth parameter plant height and relative chlorophyll content, using Minolta SPAD-502 readings indicated no significant difference in any treatments (Table 5.7).

Conclusions

Sweet potato

The results from the increasing applications of invasive seaweed for K indicated significant results for the peat moss media and the Mollisol soil, however not the Oxisol soil. These results indicated that, K was available for plant uptake in the form of seaweed. However, the results were not apparent in the Oxisol soil, which has a lower water retention capacity than the peat moss media and the Mollisol soil.

Due to the lower nutrient and water retaining capacity of the Oxisol, this soil may have been at a disadvantage when used in a pot trial. A previous meta analysis suggested that, about 65% of experiments conducted do not use sufficient pot size, which can greatly effect the results of the experiment (Poorter et al, 2005). In addition, the short soil profile of the pots may have provided a rapid draining capability, leaching most of the applied nutrients in the Oxisol soil.

All treatments amended with either seaweed paired with tankage or all synthetic K and N did not yield significantly different results. These results indicate that, seaweed paired with tankage is a comparable substitute for conventionally fertilized sweet potato plants.

The use of relative chlorophyll (SPAD) readings as a growth parameter was anticipated to provide insight for plant growth, and not directly indicate K uptake. However as K is a component necessary for photosynthesis to take place, the SPAD readings may have provided valuable insight about the relative growth rate of the plants with increasing applications of K. This was not the case as there were no significant SPAD readings as a result of either increasing application of seaweed or alternative and comparable sources of K.

Future research may need to use more destructive sampling methods to fully determine the uptake of K by sweet potato, such as leaf sampling or plant tissue analysis.

Amaranth

Amaranth plants used in this trial did not show any significant results when growth parameters were compared. These results may indicate that amaranth may not be a suitable crop for K analysis. Alternatively, these results may also suggest that the growth potential was not maximized due to the smaller size of the pots.

In addition, the growth parameters that were used in this trial may not have been adequate for measuring K uptake in amaranth. Future studies may require different techniques for a similar trial.

For the purpose of this glasshouse trial, although seaweed did not appear to provide adequate K to prompt a response in amaranth, synthetic K from conventional fertilizer also did not prompt a response, which indicates a need for improved research methods.

Figures and Tables

Table 5.1- Application rates of increasing treatments of K with invasive seaweed for glass house grown sweet potato.

	Tankage	***Eucheuma spp.***	**NH_4^+-N**	**$P_2 0_5$**	**KCl**
[(a)] 0 kg/ha K	155 kg / ha N, 45 kg/ ha P	--	--	--	--
[(a)] 28 kg /ha K	155 kg / ha N, 45 kg/ ha P	28 kg/ha K	--	--	--
[(a)] 55 kg /ha K	155 kg / ha N, 45 kg/ ha P	55 kg/ha K	--	--	--
[(a)] 110 kg g/ha K	155 kg/ ha N, 45 kg/ ha P	110 kg/ha K	--	--	--
[(a)] 220 kg /ha K	155 kg/ ha N, 45 kg/ ha P	220 kg/ha K	--	--	--
[(b)] 220S kg /ha K	--	--	155 kg/ha N	45 kg/ha P	220 kg/ha K

Table 5.2 Application rates of increasing treatments of K with invasive seaweed for glass house grown amaranth.

	Tankage	***Eucheuma spp.***	**NH_4^+-N**	**P_20_5**	**KCl**
[a] 0 kg/ha K	155 kg/ ha N, 45 kg/ ha P	--	--	--	--
[a] 28 kg/ha K	155 kg/ ha N, 45 kg/ ha P	28 kg/ha K	--	--	--
[a] 55 kg/ha K	155 kg/ ha N, 45 kg/ ha P	55 kg/ha K	--	--	--
[b] 0 /ha K	--	--	155 kg/ ha N	45 kg/ ha P	--
[b] 28 kg/ha K	--	--	155 kg/ ha N	45 kg/ ha P	28 kg/ha K
[b] 55 kg/ha K	--	--	155 kg/ ha N	45 kg/ ha P	55 kg/ha K
[c] 0 kg/ha K	--	--	155 kg/ ha N	45 kg/ ha P	--
[c] 28 kg/ha K	--	28 kg/ha K	155 kg/ ha N	45 kg/ ha P	--
[c] 55 kg/ha K	--	55 kg/ha K	155 kg/ ha N	45 kg/ ha P	--

Key:

DF: Degrees of Freedom

BMFW: Biomass Fresh Weight

RFW: Roots Fresh Weight

BMDW: Biomass Dry Weight

RDW: Roots Dry Weight

Table 5.3-An AOV indicated a significant difference in the root weight (g) of sweet potato plants grown with increasing applications of K in the Mollisol soil and the peat moss media, but not in the Oxisol soil.

	DF	BMFW	BMDW	RFW	RDW
	Media				
	Means				
[a] 0 /ha K		64.2	14.4	35.45	5.7
[a] 28 kg/ha K		36.85	8.075	46.95	8.02
[a] 55 kg/ha K		43.175	9.675	51.15	9.65
[a] 110 kg/ha K		32.825	7.25	51.3	10.6
[a] 220 kg/ha K		59.9	12.2	57.55	11.77
	P val				
Block	3	.0682	.2491	.1160	.0911
Treatment	4	.0633	.5576	.0001	.0000
Error	12				
Total	19				
	Oxisol				
	Means				
[a] 0 /ha K		28.025	6.325	22.8	5.425
[a] 28 kg/ha K		29.875	6.675	26.25	5.2
[a] 55 kg/ha K		24.15	4.95	18.75	2.875
[a] 110 kg/ha K		25.9	5.225	15.775	2.6
[a] 220 kg/ha K		32.7	6.925	18.375	3.425
	P val				
Block		.2827	.4200	.1748	.1552
Treatment		.0941	.1774	.0754	.7334
	Mollisol				
	Means				
[a] 0 /ha K		33.8	6.225	21.05	3.1
[a] 28 kg/ha K		32.45	5.6	27.2	3.8
[a] 55 kg/ha K		27.2	5.225	32.45	4.15
[a] 110 kg/ha K		21.025	3.725	33.8	4.35
[a] 220 kg/ha K		24.8	4.26	34.8	5.12
	P val				
Block		.4436	.0736	.5763	.2763
Treatment		.3060	.6504	.0264	.0081

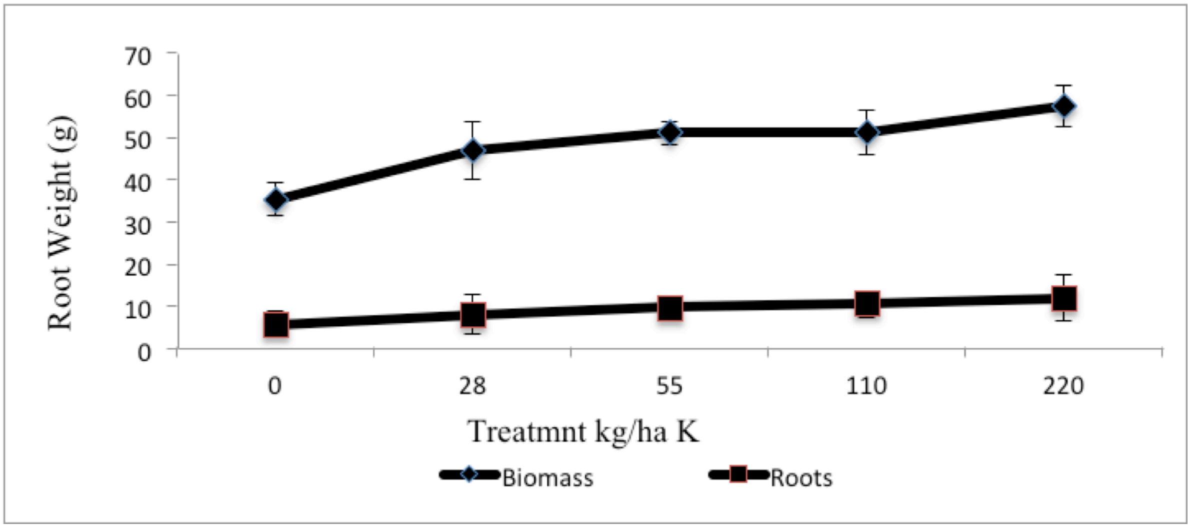

Figure 5.1- An AOV indicated a significant difference in the root weight of plants grown with increasing applications of K in the Mollisol soil.

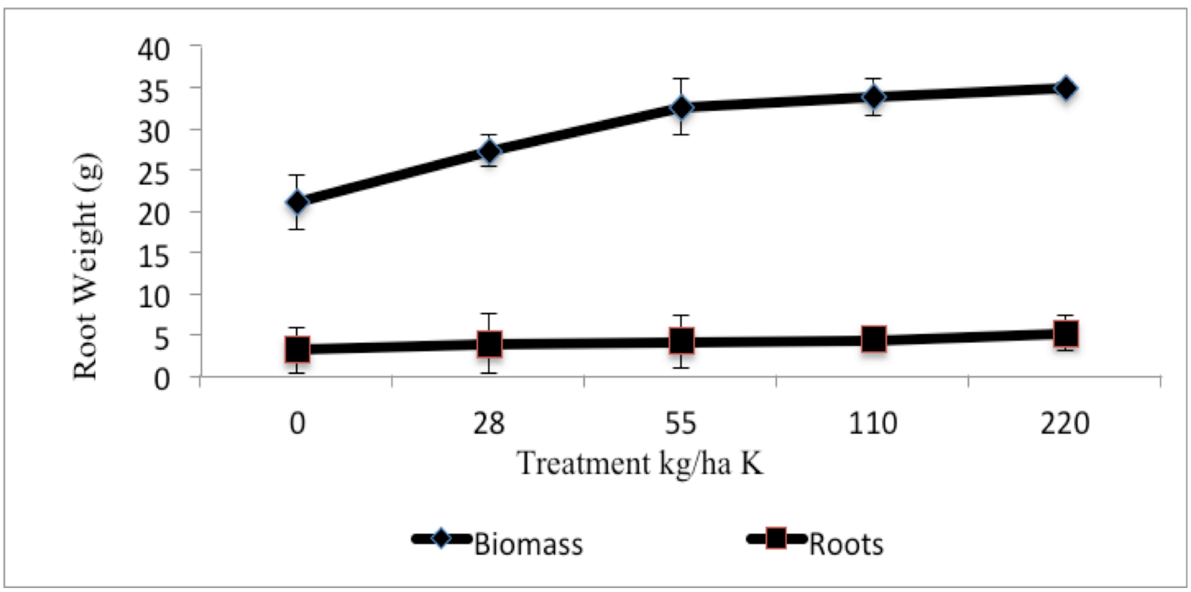

Figure 5.2-An AOV indicated a significant difference in the root weight of plants grown with increasing applications of K in the peat moss media.

Table 5.4- Sweet potato amended with seaweed and tankage and synthetic K and N displayed no significant difference between the two treatments in both media types and the peat moss media.

	DF	BMFW	BMDW	RFW	RDW
	Media				
		Means			
(a) 220 kg /ha K		59.9	12.2	57.55	9
(b) 220S kg /ha K		45.7	10.525	56.3	10.675
	P val				
Block	3	.7841	.2584	.9589	.8493
Treatment	4	.5174	.4299	.1122	.3872
Error	12				
Total	19				
	Oxisol				
		Means			
(a) 220 kg /ha K		32.7	6.925	18.375	3.425
(b) 220S kg /ha K		25.775	5.325	17.675	5.35
	P val				
Block	3	.4096	.6528	.1552	.0768
Treatment	4	.9145	.5199	.7334	.0758
	Mollisol				
		Means			
(a) 220 kg /ha K		24.8	4.26	11.56	3.3
(b) 220S kg /ha K		28.5	5.625	14.47	4.125
	P val				
Block	3	.4436	.0745	.3574	.6762
Treatment	4	.3060	.0511	.2335	.1109

Table 5.5- The growth parameter relative chlorophyll content, using Minolta SPAD-502 readings for sweet potato indicated no significant difference in any treatments, regardless of soil type treatments.

	DF	1/24/14	1/31/14	2/7/14	2/14/14	2/21/14	2/28/14	3/7/14	3/14/14
		Media							
		Means							
[a] 0 /ha K		22.375	24.82	25.7	23.17	24.9	31.63	26.6	24.34
[a] 28 kg/ha K		29.9	24.5	28.15	24.25	25.87	32.67	30.4	26.4
[a] 55 kg/ha K		27.65	27.47	27.37	24.29	25.9	32.91	31.27	26.88
[a] 110 kg/ha K		27.75	26.82	28.42	24.92	26.6	34.51	33.04	25.01
[a] 220 kg/ha K		32.87	28.2	28.3	31.02	30.4	39.07	33.12	27.87
	P val								
Block	4	.3036	.1804	.0932	.3422	.1084	.2399	.7495	.3036
Treatment	3	.1493	.0949	.0655	.1927	.1189	.0775	.0944	.1493
Error	12								
Total	19								
		Oxisol							
		Means							
[a] 0 /ha K		34.12	32.05	30.95	31.2	32.25	30.31	31.12	28.77
[a] 28 kg/ha K		29.37	33.27	31.65	32.4	32.25	32.39	30.24	27.6
[a] 55 kg/ha K		30.3	34.22	36.0	28.67	33.55	33.875	32.4	29.4
[a] 110 kg/ha K		32.3	35.42	34.72	30.95	33.52	33.65	34.89	28.93
[a] 220 kg/ha K		32.7	37.3	31.97	33.05	37.4	34.931	34.91	30.11
	P val								
Block	4	.3351	.8744	.7738	.4387	.3011	.9410	.0686	.3351
Treatment	3	.9189	.0796	.0643	.6640	.9670	.0934	.0921	.9189

Table continued on next page.

Table 5.5- continued.

	DF	1/24/14	1/31/14	2/7/14	2/14/14	2/21/14	2/28/14	3/7/14	3/14/14
		Mollisol							
		Means							
[a] 0 /ha K		30.625	33.55	29.9	31.15	33	31.90	30.54	27.01
[a] 28 kg/ha K		35.325	41.5	35.62	33.62	30.65	35.35	31.29	25.44
[a] 55 kg/ha K		34.05	27.2	34.62	36.2	34.17	33.05	30.22	30.21
[a] 110 kg/ha K		33.925	29.42	36.02	30.45	40.9	34.2	27.05	30.05
[a] 220 kg/ha K		29.65	40.25	35.8	34.25	33	36.76	28.25	31.2
	P val								
Block	4	.7793	.0989	.6670	.7793	.7893	.9410	.9858	.7793
Treatment	3	.2375	.3775	.0883	.2375	.4033	.0934	.2513	.2375

Table 5.6-An AOV indicated no significant difference in the height or dry weight of amaranth grown with increasing applications of K

	DF	BDW	Height
		Means	
[a] 0 kg/ha K		25	8.5
[a] 28 kg/ha K		23.75	7
[a] 55 kg/ha K		25	8
[a] 155 kg/ha K		26.25	7.75
	P val		
Block	3	.3557	.4623
Treatment	4	.0933	.5746
Error	12		
Total	19		
		Means	
[b] 0 /ha K		27.5	8.75
[b] 28 kg/ha K		27.5	9.75
[b] 55 kg/ha K		26.25	9.25
[b] 155 kg/ha K		27.5	9.25
[c] 0 kg/ha K		28.75	8.75
[c] 28 kg/ha K		27.5	9.25
[c] 55 kg/ha K		28	9
[c] 155 kg/ha K		28	9.5
	P val		
Block	3	.6674	.8569
Treatment	4	.3291	.5461
Error	12		
Total	19		

Table 5.7- Relative chlorophyll readings collected from amaranth amended with seaweed and tankage and synthetic K and N displayed no significant difference between the two treatments in the peat moss media.

	DF	7/22/14	7/29/14	8/5/14	8/12/14	8/19/14	8/26/14	9/2/14	9/9/14
(a) 0 kg/ha K		17.1	16	16.5	18.7	20.25	16	16.6	12.6
(a) 28 kg/ha K		18.7	18.7	17.7	19.6	22.9	18.12	22.18	14.04
(a) 55 kg/ha K		22.2	16.7	19.1	15.7	17.15	22.09	21.15	17.19
(b) 0 /ha K		18.3	12	17.5	12	13.17	17.34	19.56	15.71
(b) 28 kg/ha K		15.28	16.29	17.09	16.15	22.12	19.05	18.17	13.17
(b) 55 kg/ha K		21.19	20.11	22.01	22.14	21.16	21.22	23.6	13.07
(c) 0 kg/ha K		17.24	18.93	18.45	19.11	15.15	19.43	14.17	12.18
(c) 28 kg/ha K		16.40	21.25	18.19	22.56	18.22	22.03	21.06	13.61
(c) 55 kg/ha K		20.1	19.22	21.17	18.03	20.15	22.13	22.89	16.31
		P val							
Block		.8903	.6877	.3342	.9304	.5902	.3840	4830.	.1822
Treatment		.0933	.6704	.9503	.4204	.5912	.3902	.3949	.4950
Error									
Total									

CHAPTER 6: FIELD TRIAL

Introduction

As the state of Hawai‘i strives to reduce dependence on imported food, increasing local food supplies is dependent on the availability of soil amendments to replace imported fertilizers. This key concern is crucial to supplement local agriculture growth. Locally available soil amendments would reduce the cost of shipping and handling for farmers, but also decrease the carbon footprint from long distance transportation. Some locally available soil amendments may need to be sourced from creative resources that might otherwise be considered waste.

Materials such as rendered meat by-product, “tankage” (Island Commodities, Kapolei, HI) and non-native invasive seaweed both show potential for use as locally available soil amendments. Both products could be obtained at low cost by local farmers. Worldwide, many seaweed species are used for agriculture (fertilizer or animal feed), including species that are found in Hawai‘i (Zemke-White, Ohno, 1999).

Recent studies have highlighted the need to produce local fertilizers in Hawai‘i. Local actions include Korean Natural Farming (KNF) techniques and Effective Microorganism (EM) cultivation, both require local inputs and increased soil organic matter. In addition, consumers increasingly demand sustainably produced products and take interest in food miles, origin, and quality (HDOA, 2008). Previous studies have shown that, organic wastes increase soil organic matter as well as supply plant nutrients (Harts et al., 1996; Smith et al., 1992; Shankls and Gouin, 1989). Similarly, studies also show that, composted organic material can increase soil organic matter, provide nutrients for plant growth, alleviate aluminum toxicity, and render phosphorus more available to crops (Beltran et al., 2002, Hue, 1992).

Currently, much of the invasive seaweed collected from Kaneohe and Maunalua Bay is applied within the watershed for agricultural use. Although there is farmer demand for this soil amendment, not much is understood about application rates and effective treatments to reduce the reproductive potential of these invasive seaweeds. These invasive seaweed species are observed to contain high levels of potassium (Ahmad et al., unpublished data, 2012).

Sweet potato is a locally produced crop with local demand and a high potassium (K^+) requirement. Investigating the effect of the invasive seaweed (*Eucheuma spp.*) and tankage on sweet potato growth can provide a clearer understanding of the nutrient availability provided by these locally available products.

The objective of these field trials is to determine if increasing applications of invasive seaweed (*Eucheuma spp*.) can generate a growth response to subsequent K from sweet potato as well as alternative sources of N (in the form of tankage) in two soil types.

Materials and Methods

Soil

Two field experiments were conducted, on the North Shore of O‘ahu , for the purpose of this study. The first site was located in Waialua on the Pioneer Hi-Bred farm. The elevation at this site is 35 m above sea level. This soil is a Mollisol, ‘Waialua' series. This soil is described as: *Very-fine, mixed, superactive, isohyperthermicPachicHaplustolls* (USDA, 2001). This soil is moderately well drained, has slow to medium runoff, and moderate permeability. Total % N, and extractable PPM P and K was 137, 54, 782, respectively. pH was measured at 5.7.

The Waialua series mollisol is described as slightly acidic to neutral, and generally found with soil temperatures 22° C annually. The soils are slightly acid or neutral. 5-30% by volume contains rocks .2-6.4 cm, and it contains fine black concretions throughout.

The second site, on the University of Hawai‘i at Mānoa CTAHR Poamoho Agricultural Research Station, was an Oxisol, ‘Wahiawa' series. The elevation at this site is 230 m above sea level. This soil is described as: *Very-fine, kaolinitic, isohyperthermicRhodicHaplustox* (USDA, 2001). This soil is well drained, with slow to medium runoff and has moderately rapid permeability. Total % N, and extractable PPM P and K was 13, 24, 256, respectively. pH was measured at 6.3.

The Wahiawa series Oxisol is generally found with soil temperatures 22° C annually. This soil contains black concretions and basalt that is highly weathered, up to 2 meters deep.

Fertilizer Treatments

The trials were composed of 72 plots, arranged in a complete randomized block design with four replications. Six treatments were distributed randomly in each block. The treatments were provided with one or more of the following materials:

Nitrogen was supplied at 155 kg/ ha N as either Ammonium Sulfate $(NH_4^+\text{-}N)_2SO_4$ or rendered meat by-product, "tankage". Tankage is comprised of high levels of N (Table 1.1). Phosphorous was supplied at 45 kg/ ha P in the form of tankage or treble superphosphate (P_20_5). Potassium was applied at varying rates (Table 6.1) with either potassium chloride (KCl) or dried invasive seaweed (*Eucheuma spp.*).

The fertilizer regimes represent the range of K sources that were applied in this experiment. The control treatment was comprised of 155 kg/ ha N and 45 kg/ha P supplied by tankage, with no K via seaweed application (0 kg/ ha K). Increasing levels of K were applied (55, 110 and 220 kg/ ha K) in the form of dried invasive seaweed.

The second component, comparing sources of N, P and K, include applications of N, P and K with synthetic fertilizer, a combination of chemical fertilizers and dried invasive seaweed, or a combination of tankage and seaweed (Table 6.1).

Soil samples were taken before planting, and after harvest (110 days after planting) at 30 cm depth. The field was ploughed and divided into uniform rows. All fertilizer was applied by hand and incorporated into the soil directly prior to planting.

Cultural Practice

Sweet potato "Okinowan" variety cuttings were obtained from Wayne Ogasawara at the Mililani Agriculture Park. Each cutting had eight nodes and ten inches long. Cuttings were planted at the beginning of the summer season on May 5, 2014. The field was divided into 18 ridges (20-35 cm height), 45 cm wide, with random arrangement (6 treatments, 2 buffer rows per treatment with 4 replications). Each treatment had 40 plants (total 10 plants per row which is an equivalent of approximately 32,000 plants/ha).

Plots were hand weeded, and vines were “turned” in order to reduce rooting in adjacent treatment blocks. Repeated leaf measurements of the sixth leaf from the tip (Maynard, et. al., 2006) taken over time (3 months) of mature, undamaged leaves to indicate nutrient uptake volume with chlorophyll meter.

Data Collection

The following data was collected weekly during the growth (110 days) for leaf area, node density, canopy growth rate, and relative chlorophyll content using Minolta SPAD-502. All leaf measurements were taken using the sixth leaf from the vine tip. At harvest time, fresh weight, dry weight and marketable root number was counted. Fresh weight was collected after harvest, and subsequent dry weight was collected after roots and biomass were dried for 5 days at 65°C, or until compete drying had taken place.

Leaf area was recorded with photographs and analyzed with ImageJ. These measurements were taken of the 6^{th} leaf from the growing tip, as suggested by Knotts Handbook for Vegetable Growers (Maynard et. al., 2006).

Results and Discussion

Treatments were broken up into two groups in order to assess a) the effectiveness of invasive seaweed (*Eucheuma spp.*) when used as a soil amendment at increasing increments, and b) the effectiveness of tankage as a Nitrogen source and invasive seaweed as a Potassium source separately.

Increasing Applications of K

Treatments 0, 55, 110, 220 kg K/ha and 155 kg N/ha through tankage and invasive seaweed (*Eucheuma spp.*):

Plants grown in Poamoho (Oxisol) soil showed significant influence due to increasing application rates in root fresh weight, root dry weight and leaf area (Table 6.1, Figure 6.1). Both biomass and root weight increased significantly with increasing applications of K with invasive seaweed (*Eucheuma spp.*).

Plants grown in Waialua (Mollisol) soil showed significant influence due to application rates in both the fresh weigh of collected roots as well as the dry weight of collected roots, but not in leaf area (Table 6.2, Figure 6.2).

Plants grown in Poamoho (Oxisol) soil showed significant influence due to comparative N and K application rates in biomass fresh weight, biomass dry weight, root fresh weight, root dry weight, leaf area and marketable root number (Table 6.3, Figure 6.3). Both biomass and root weight increased with increasing applications of K with invasive seaweed (*Eucheuma spp.*).

Plants grown in Waialua (Mollisol) soil showed significant influence due to application rates in biomass fresh weight, root fresh weight, and root dry weight (Table 6.4, Figure 6.4). Both biomass and root weight increased significantly with increasing applications of K with invasive seaweed (*Eucheuma spp.*), but not significantly in marketable root number or leaf area.

Comparing K Sources

Treatments amended with invasive seaweed and tankage[a] compared synthetic N and invasive seaweed[c] grown in Poamoho (Oxisol) soil also indicated a significant difference when biomass dry weight, root dry weight, leaf area and marketable root numbers were compared (Table 6.5).

Treatments amended with synthetic K and N[b] were comparable to treatments amended with synthetic N and invasive seaweed[c], showing no significant difference in leaf area or marketable root number. However, there was a significant difference in root and biomass fresh and dry weight (P= .005, .001, .0118, and .0000 respectively), with the treatment synthetic N and invasive seaweed[c], yielding significantly more root weight (Table 6.6)

Site Comparison

In general, sweet potato plants grown in the Oxisol soil yielded significantly higher numbers of harvestable roots (Table 6.2). In addition, leaf area due to increased seaweed application rates also had significant results. By comparison, the Mollisol soil showed significant results only with fresh and dry root weights.

Soil Sample Collection

Soil samples collected after harvest were submitted to the ADSC for analysis. Soil samples for increased seaweed applications collected after harvest indicated no significant difference in pH, or applied P, Ca, Mg or N. Significant difference was shown in colleced K for both locations.

Soil samples for comparing nutrient sources collected after harvest indicated no significant difference in pH, or applied P, K, Ca, Mg or N for both locations.

Conclusion

Sweet potato provides a suitable subject for K fertilizer trials due to its high K requirement. However, in order to answer questions about the impact of seaweed as a soil amendment, a number of different field crops can provide a wider variety of results. When looking at only sweet potato amended with invasive seaweed, we can conclude that plant growth was comparable to conventionally amended plants.

When paired with Tankage, it appears that, a significant difference can be found when increasing application rates of K are added with invasive seaweed *Eucheuma spp.*. In addition, when grown in an Oxisol soil, applications of invasive seaweed *E.spp.* paired with synthetic N (ammonium) does show a significant growth response, measured by root yield. Conversely, the same treatments were not significant when grown in a Mollisol soil. This discrepancy may be due to the high K retaining capabilities, typical of a Mollisol, which can contain a higher proportion of non expanded 2:1 clay minerals, such as montmorillonite, which increases the likelihood of containing negatively charged clay mineral surfaces, and can attract and retain cations such as K^+. On the other hand Oxisol soils, which contain more highly weathered low activity clays have a lower capacity to retain nutrients due to containing lower surface area clays like kaolinite (Brady, 2002).

An interesting significant growth parameter, relative chlorophyll content, using the Minolta SPAD-502 meter, indicated significant growth as a response to increased K application. K will regulate the rate of photosynthesis and the translocation of the photosynthesis products. While K may not provide a direct response on SPAD readings, it can be used as a measurement for growth. These readings were consistent with the readings gathered from the both sites, indicating that the initial response in growth can be paired to K applications.

In the circumstance of the Mollisol soil, more research would provide answers as to the amount of K in the form of invasive seaweed *E.spp.* paired with synthetic N (ammonium) would be required in order to gain the desired plant response. Contrariwise, in the circumstance of the Oxisol soil, enough evidence is provided to suggest that, adequate applications of invasive seaweed *E.spp.* paired with synthetic N (ammonium) can provide the basic nutrients that sweet potato would require for adequate growth. However, high NH_4^+ availability has been shown to increase K concentrations in the soil solution, which could describe the plant growth response to increasing K applications for root growth and not leaf area in the Mollisol soil (Foth et. al., 1997).

Tables and Figures:

Table 6.1-Treatments were supplied with alternative sources of N, P and K. Increasing applications of K were amended with seaweed and tankage, and comparison application were amended with both seaweed and chemical N, seaweed and tankage or chemical N, P and K

	Tankage	***Eucheuma spp.***	**$(NH_4^+\text{-}N)_2SO_4$**	**P_20_5**	**KCL**
0 kg/ha K	155 kg/ha N, 45 kg/ha P	--	--	--	--
55 kg/ha K	155 kg/ha N, 45 kg/ha P	55 kg/ha K	--	--	--
110 kg/ha K	155 kg/ha N, 45 kg/ha P	110 kg/ha K	--	--	--
[(a)]220 kg/ha K	155 kg/ha N, 45 kg/ha P	220 kg/ha K	--	--	--
[(b)]220S kg/ha K	--	--	155 kg/ha N	45 kg/ha P	220 kg/ha K
[(c)]220SL kg/ha K	--	220 kg/ha K	155 kg/ha N	45 kg/ha P	--

Key:

BMFW: Biomass Fresh Weight RFW: Roots Fresh Weight BMDW: Biomass Dry Weight RDW: Roots Dry Weight

LA: Leaf Area MR: Marketable Root # NPI: Nodes Per Inch P Val: probability

Table 6.2- AOV for treatments 0, 55, 110, 220 kg K/ha and 155 kg N/ha through tankage and invasive seaweed (*Eucheuma spp.*), amended with increasing rates.

	DF	BMFW	BMDW	RFW	RDW	LA (Cm^2)	MR	NPI
	Oxisol							
		Means						
Mean [(a)]0 kg/ha K		403	60	351.75	118.75	6.65	4	1.01
Mean [(a)]55 kg/ha K		450.75	100.75	450.75	140.5	6.7	6.5	0.77
Mean [(a)]110 kg/ha K		461.3	100.75	454.25	191.5	6.75	7	0.89
Mean [(a)]220 kg/ha K		450.5	94.75	488.75	246.1	6.8	9.75	.83
	P val							
Block	3	.5907	.3204	.9655	.7386	.1322	.4396	.5111
Treatment	3	.4727	.1762	.0267	.0000	.0001	.2471	.1942
Error	73							
Total	79							
	Mollisol							
		Means						
Mean [(a)]0 kg/ha K		543.15	65	172.7	64	11.44	1.25	.74
Mean [(a)]55 kg/ha K		601.75	132.25	289	105.25	11.44	3	.90
Mean [(a)]110 kg/ha K		631	139.75	339.5	133.5	11.61	3.5	.70
Mean [(a)]220 kg/ha K		647	153.5	580.25	213.3	12.21	6.5	.93
	P val							
Block	3	.8924	.1101	.3524	.7448	.9374	.0693	.6592
Treatment	3	.4377	.0460	.0000	.0000	.7424	.0873	.6662

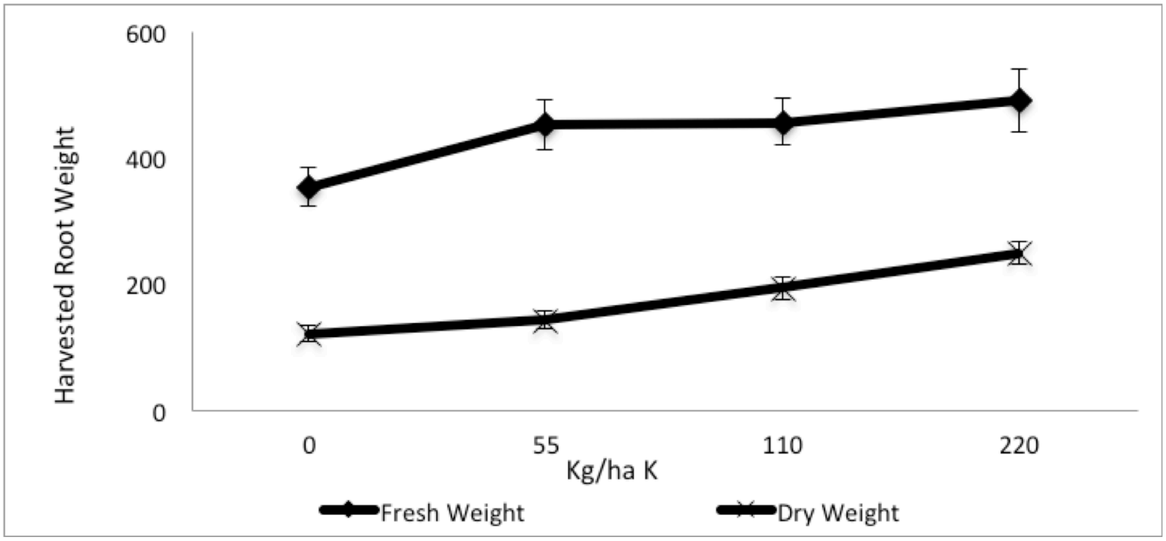

Figure 6.1-Harvested fresh and dried root weight from Oxisol soil. Increasing applications of K with seaweed show significant results.

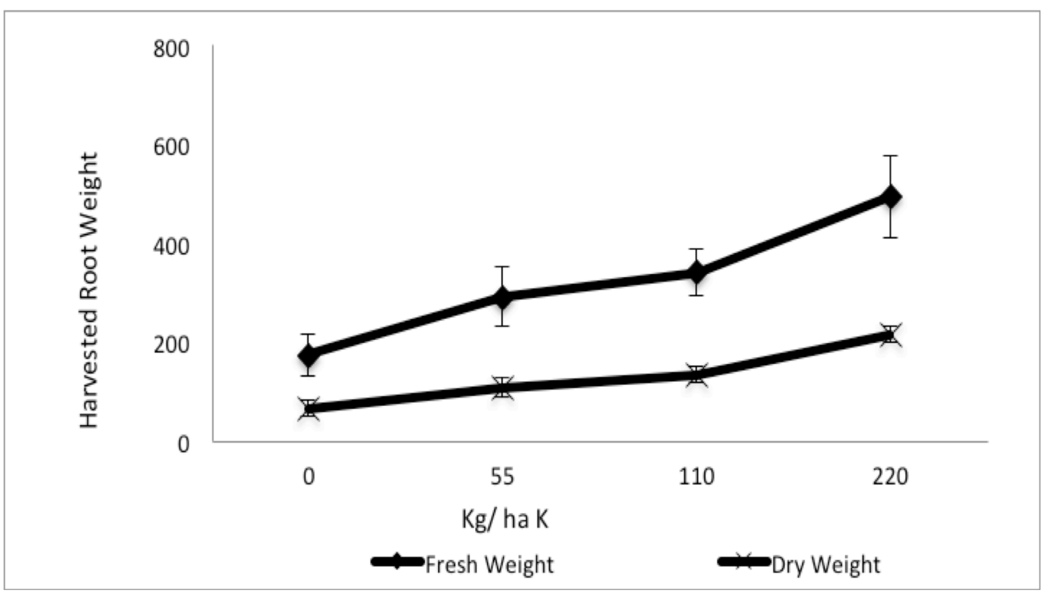

Figure 6.2-Harvested fresh and dried root weight from Mollisol soil. Increasing applications of K with seaweed show significant results.

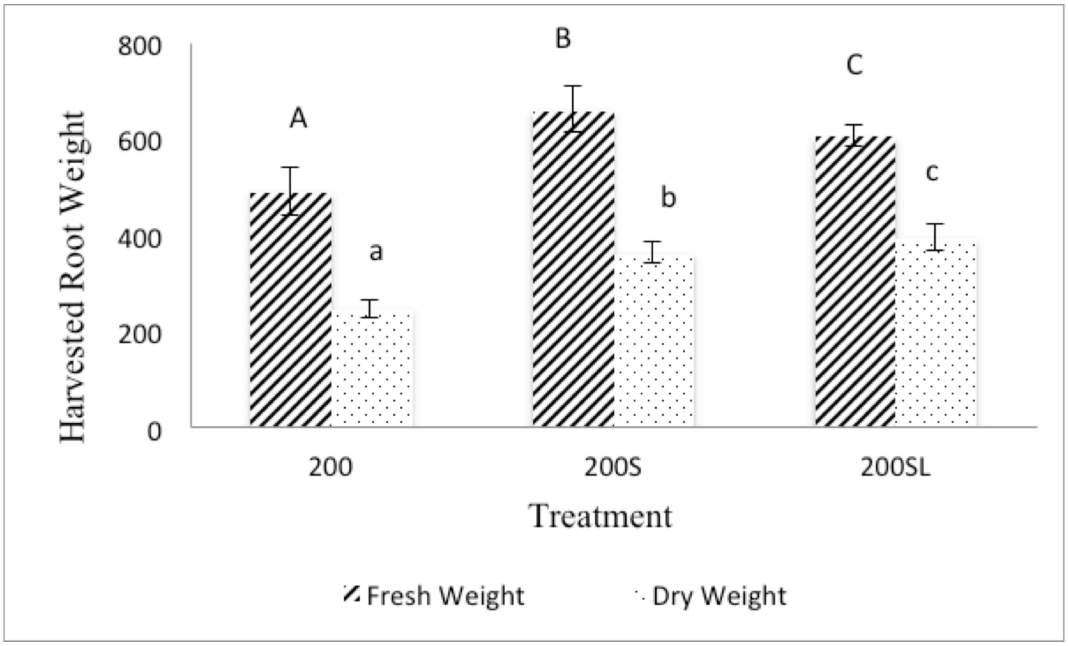

Figure 6.3-Harvested fresh and dried root weight from Oxisol soil. Applications with comparative sources of N and K show significant results.

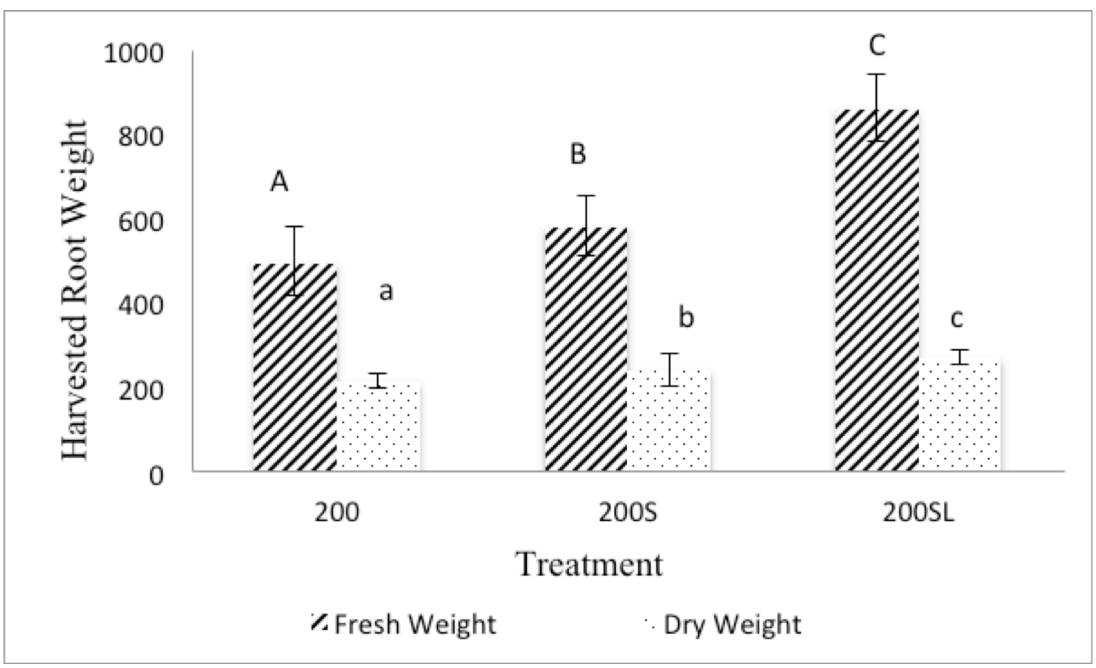

Figure 6.4-Harvested fresh and dried root weight from Mollisol soil. Applications with comparative sources of N and K show significant results.

Table 6.3- Treatments (200, 200S, 200SL) Harvested fresh and dried root weight from the Oxisol and Mollisol soil. Applications with comparative sources of N and K show significant results.

	DF	BMFW	BMDW	RFW	RDW	LA	MR	NPI
		Oxisol						
		Means						
Mean [a]220 kg/ha K		450.5	94.75	454.3	246.1	6.79	9.75	0.831
Mean [b]220S kg/ha K		658.3	144.3	658.3	360.8	12.25	19	.625
Mean [c]220SL kg/ha K		604	116.3	604	391.5	10.14	21.75	0.783
	P val							
Block	3	.8324	.2622	.3765	.7448	.5758	.3969	.3274
Treatment	2	.0008	.0000	.0034	.0000	.0153	.0084	.0982
Error	54							
Total	119							
		Mollisol						
		Means						
Mean [a]220 kg/ha K		647	153.5	494.3	213.3	12.20	6.5	.926
Mean [b]220S kg/ha K		895.3	164.5	580.3	240.2	12.35	6.75	.584
Mean [c]220SL kg/ha K		685.25	159.8	859.8	268.3	12.25	7.0	.784
	P val							
Block	3	.13610	.5382	.6469	.0003	.9419	.0925	.8061
Treatment	2	.0099	.8627	.0014	.0000	.9613	.9779	.1606

Table 6.5- Treatments in Oxisol (200S and 200SL) had comparable results for fresh and dry biomass and root weight for treatments amended with [b]chemical fertilizer and [c]seaweed and chemical fertilizer. Compared to Waialua had no comparable results for fresh and dry biomass and root weight for treatments amended with [b]chemical fertilizer and [c]seaweed and chemical fertilizer

	DF	BMFW	BMDW	RFW	RDW	LA	MR	NPI
	Oxisol							
		Means						
Mean [b]220S kg/ha K		658.3	144.3	658.3	360.8	12.25	19	0.625
Mean [c]220SL kg/ha K		604	116.3	604	391.5	10.14	21.75	0.783
	P val							
Block	3	.7281	.4322	.0731	.0003	.6668	.1048	.8791
Treatment	1	.0005	.0001	.0118	.0000	.1873	.1672	.0690
Error	35							
Total	39							
	Mollisol							
		Means						
Mean [b]220S kg/ha K		895.3	164.5	580.3	240.2	12.35	6.75	.584
Mean [c]220SL kg/ha K		685.25	159.8	859.8	268.3	12.25	7	.784
	P val							
Block	3	.3646	.6884	.7059	.3899	.5592	.2144	.7018
Treatment	1	.001	.8186	.0149	.6831	.9505	.9234	.4202

Table 6.6- Collected SPAD readings for the Oxisol soil indicate significant difference in readings in early growth, but not in late growth. No significant difference was found in the Mollisol soil.

	DF	7/2/14	7/9/14	7/16/14	7/23/14	7/30/14	8/6/14	8/13/14	8/20/14	8/27/14	9/3/14
		Oxisol									
Block	3	.0791	.4715	.0791	.1927	.3476	.1734	.0944	.5736	.2034	.1625
Treatment	3	.0133	.0022	.0042	.0017	.0283	.0842	.3436	.5030	.1177	.3429
Error	21										
Total	31										
Mean [a] 0 /ha K		36.08	35.80	36.08	37.20	38.33	39.58	40.44	41.30	36.13	35.70
Mean [a] 55 kg/ha K		39.33	36.63	39.33	39.08	38.83	44.15	43.21	42.28	36.23	34.78
Mean [a] 110 kg/ha K		37.93	41.38	37.93	40.31	42.70	40.43	41.36	42.30	37.33	36.70
Mean [a] 220 kg/ha K		43.18	43.58	43.18	44.11	45.05	45.20	45.08	44.95	40.00	40.35
		Mollisol									
Block	3	0.7974	0.8741	0.5598	0.1806	0.2464	0.7694	0.9098	0.2405	0.1845	0.6880
Treatment	3	0.5598	0.0832	0.7974	0.2337	0.5992	0.5402	0.9098	0.481	0.1183	0.5612
Error	21										
Total	31										

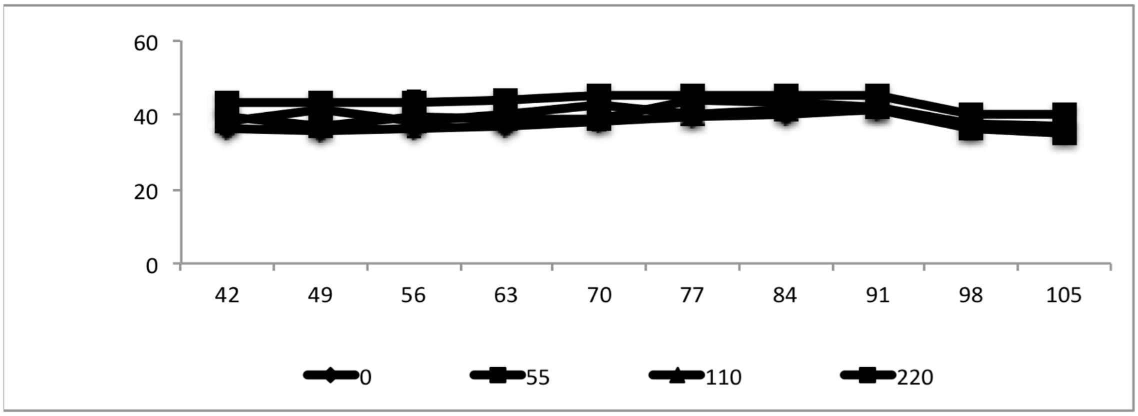

Fig 6.5 SPAD Readings for Oxisol soil fertilized with Tankage for N and increasing applications of seaweed for K. Increasing applications consistently yielded higher relative chlorophyll readings, significant in early growth, but not in later growth.

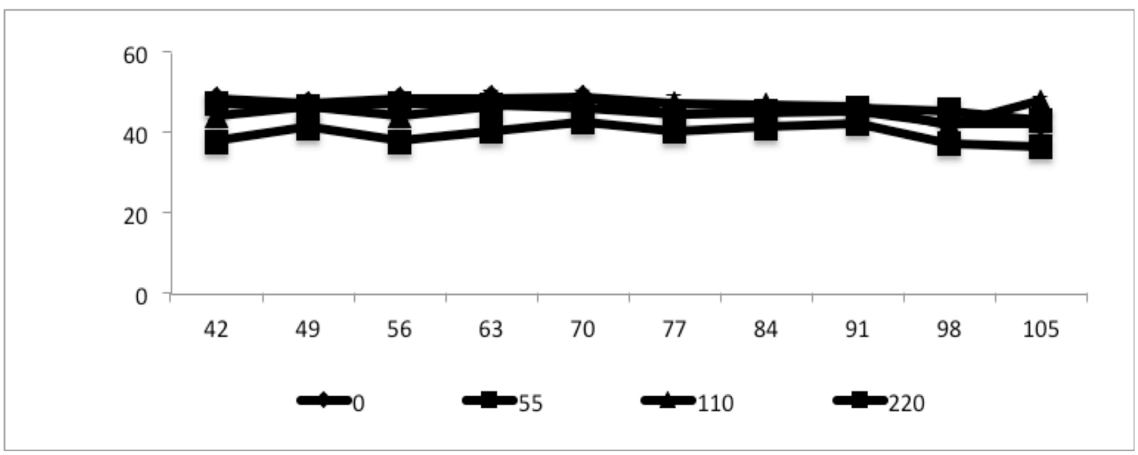

Fig 6.6 SPAD Readings for Mollisol soil fertilized with Tankage for N and increasing applications of seaweed for K. Increasing applications had no significant difference in reading.

Table 6.6- Collected SPAD readings comparing K and N sources. No significant difference was found in either the Oxisol or Mollisol soil.

	DF	7/2/14	7/9/14	7/16/14	7/23/14	7/30/14	8/6/14	8/13/14	8/20/14	8/27/14	9/3/14
		Oxisol									
Block	3	.4485	.3591	.4485	.4413	.1988	.2493	.7146	.8867	.6801	.1625
Treatment	3	.3612	.1231	.3612	.2820	.1020	.1633	.3092	.7041	.1757	.3429
Error	21										
Total	31										
		Mollisol									
Block	3	.8338	.6305	.4840	.7633	.7669	.9469	.9845	.5570	.4507	.3114
Treatment	3	.4840	.2512	.8338	.1992	.2957	.3431	.6163	.7947	.4112	.1612
Error	21										
Total	31										

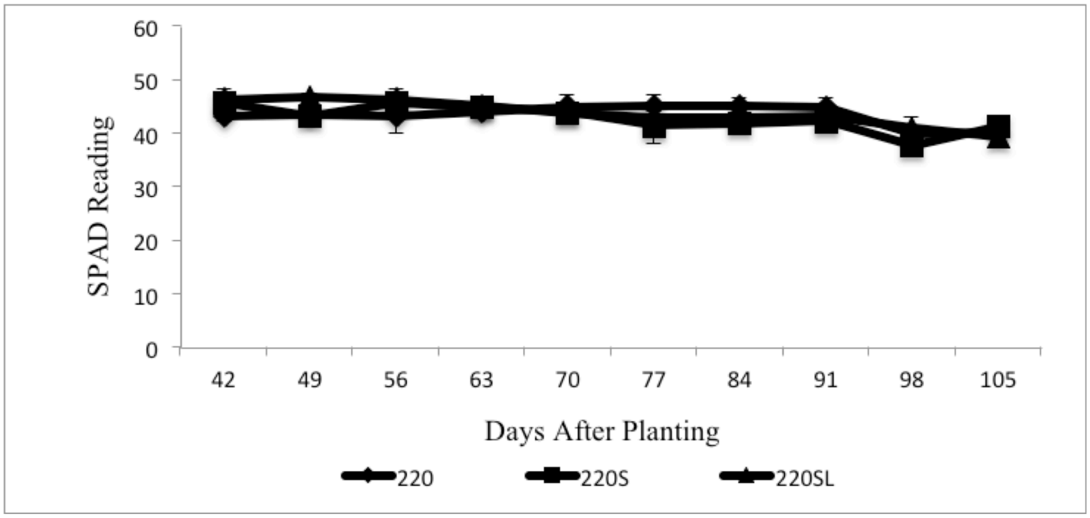

Figure 6.7- No significant difference was found in SPAD readings from the plants grown in the Oxisol soil when amended with seaweed and tankage (220), seaweed and synthetic N (220S), or synthetic N and seaweed (220SL).

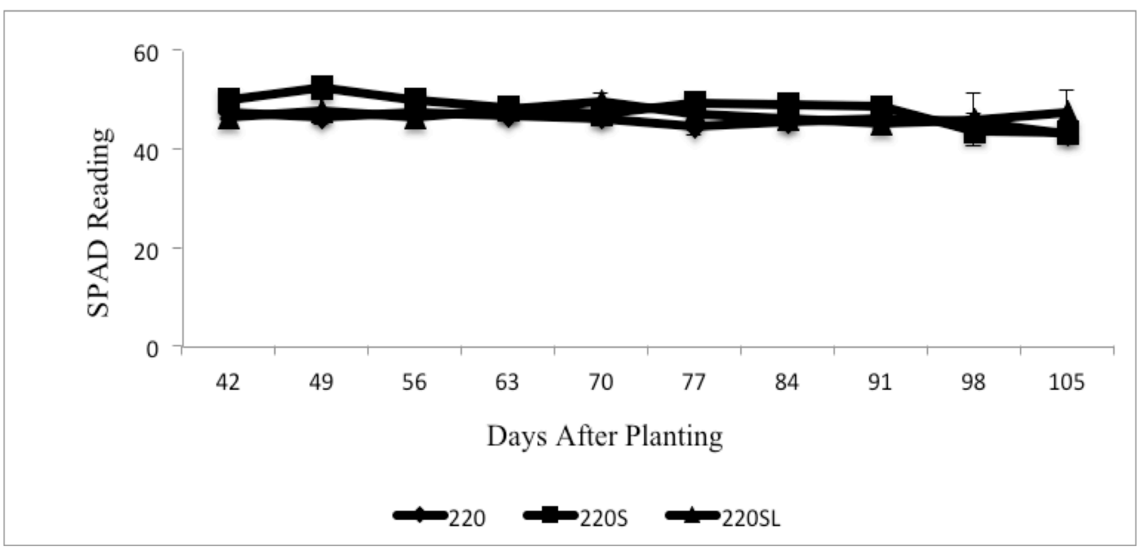

Figure 6.8- No significant difference was found in SPAD readings from the plants grown in the Mollisol soil when amended with seaweed and tankage (220), seaweed and synthetic N (220S), or synthetic N and seaweed (220SL).

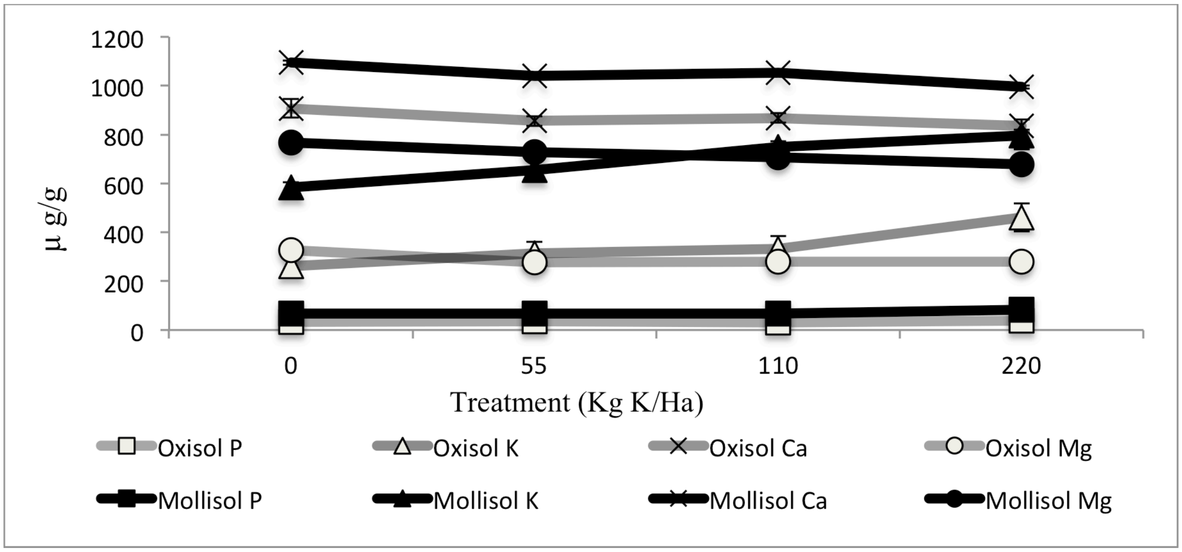

Figure 6.9- Soil samples for increased seaweed applications collected after harvest indicated no significant difference in pH, or applied P, Ca, Mg or N. Significant difference was shown in colleced K for both locations.

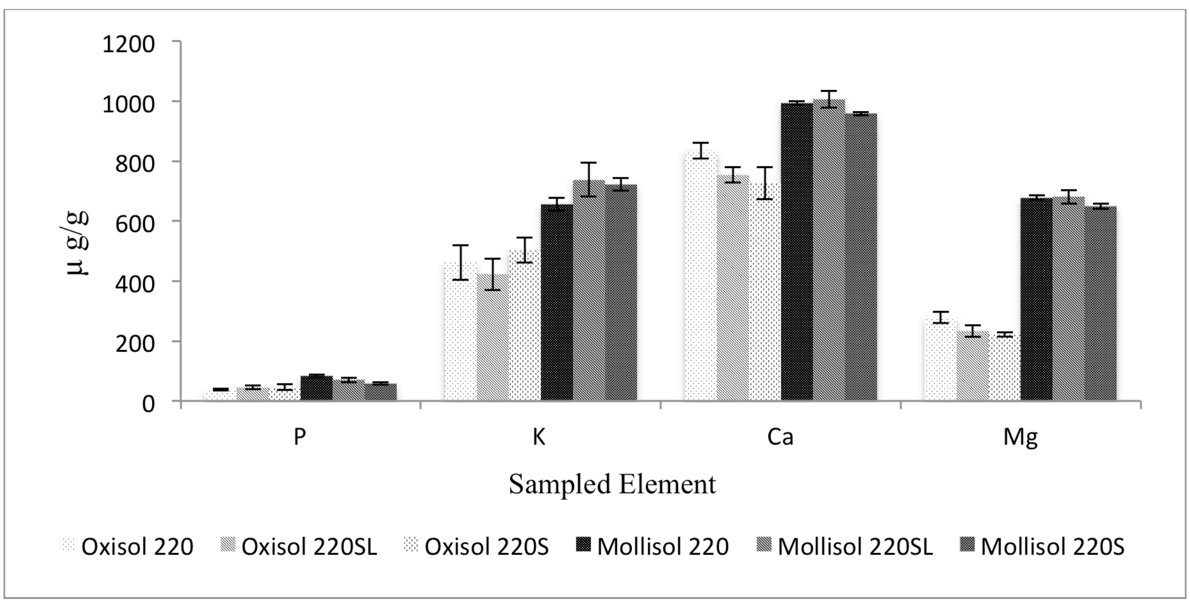

Figure 6.10 - Soil samples for comparing nutrient sources collected after harvest indicated no significant difference in pH, or applied P, Ca, Mg or N. Significant difference was shown in colleced K for both locations.

Table 6.7 -Soil samples for increased seaweed applications collected after harvest indicated no significant difference in pH, or applied P, Ca, Mg or N. Significant difference was shown in colleced K for both locations.

			←--------------µg/g--------------→				%
	DF	**pH**	**P**	**K**	**Ca**	**Mg**	**N**
	Oxisol						
		Means					
Mean [(a)]0 kg/ha K		6.1	33.1	260.6	906.8	326.5	0.1143
Mean [(a)]55 kg/ha K		6.1	33.5	314	855.5	276.1	0.0858
Mean [(a)]110 kg/ha K		6	32	333	868	280	0.0826
Mean [(a)]220 kg/ha K		6.1	35.3	461.4	834.8	278.7	0.0872
	P val						
Block	3	0.8787	0.3031	0.7503	0.3531	0.6052	0.1911
Treatment	3	0.6695	0.5979	0.0433	0.4874	0.2824	0.4666
Error	9						
Total	15						
	Mollisol						
		Means					
Mean [(a)]0 kg/ha K		5.9	66.5	583.8	1095.0	766.2	0.1030
Mean [(a)]55 kg/ha K		5.7	66.1	749.2	1040.3	728.7	0.1224
Mean [(a)]110 kg/ha K		5.8	67.4	797.2	1053.8	707.5	0.1243
Mean [(a)]220 kg/ha K		5.7	83.6	655.4	994.3	678.2	0.1216
	P val						
Block	3	0.1020	0.4238	0.3781	0.4363	0.7824	0.9665
Treatment	3	0.0573	0.0896	0.0272	0.0878	.0.2229	0.8306

Table 6.8 - Soil samples for comparing nutrient sources collected after harvest indicated no significant difference in pH, or applied P, K, Ca, Mg or N.

			←---μg/g---→				%
	DF	**pH**	**P**	**K**	**Ca**	**Mg**	**N**
		Oxisol					
		Means					
Mean [a]220 kg/ha K		6.1	38.3	461.4	834.8	278.7	0.0872
Mean [b]220S kg/ha K		5.7	45.5	503.0	726.4	222.3	0.0671
Mean [c]220SL kg/ha K		5.8	45.2	422.9	754.5	233.6	0.1013
	P val						
Block	3	0.1773	0.1448	0.6253	0.666	0.2223	0.9958
Treatment	2	0.0649	0.5971	.05574	0.6107	0.0657	0.6482
Error	6						
Total	11						
		Mollisol					
		Means					
Mean [a]220 kg/ha K		5.7	83.6	655.4	994.3	678.2	0.1216
Mean [b]220S kg/ha K		5.7	58.6	722.5	958.7	649.1	0.1110
Mean [c]220SL kg/ha K		5.8	70.0	722.2	1006.5	681.0	0.0974
	P val						
Block	3	0.3422	0.0693	0.1019	0.4464	0.6594	0.9105
Treatment	2	0.0601	0.0644	0.3283	0.3122	0.3444	0.7474

CHAPTER 7: CONCLUSION

As the State of Hawai'i moves towards a future of food security and environmental stewardship, utilizing local wastes as agricultural resources can provide a sustainable resource. While re-purposing wastes has long been an idea of the past, responsible and safe usage of these products needs to be incorporated into the future with the inclusion of invasive seaweed.

The research described in this thesis supports the use of invasive seaweed for agricultural purposes. For the efficient use of agricultural resources, while reducing the human spread of invasive species through agriculture, these first steps towards responsible resource usage.

Viability of the seaweed

The species that are currently being investigated for use in agriculture can be found on many of the main Hawai'ian islands (see Figure 1.1). While removal and use are currently concentrated to the watersheds that they are currently found in, increased removal efforts may encourage use outside of those areas. In response to concerns regarding spreading the invasive seaweed outside of the watershed where they are currently collected, an analysis of viability after various treatments provides some answers about the responsible usage of this material. Invasive seaweed (*Eucheuma spp.*), shows dramatically reduced reproductive capability and virility when dried for six days at 65° C. While shorter treatments also provided reduced growth potential, more research is needed for a definite verification of the reproductive potential of this species.

Nutrient leaching in Hawai'ian soils

Soil columns for lab studies can provide an idea for the K availability from increasing applications of seaweed. Understanding reliable application rates not only improves the efficiency of application, but also reduces the probability of nutrient leaching and loss to the environment. Increasing application rates can provide a model for the K leaching rate for different Hawai'ian soils. In two soil types observed, significant availability of K was found to become available within the first three days after the initial application of invasive seaweed *Eucheuma spp*. Higher K release from the Oxisol soil indicates that K may be more easily leached from soils with a lower water retention capability. While not analyzed, the rate of leaching at each sampling was noticeably slower in the Mollisol soil. This trial shows that applications of seaweed can provide adequate K in soil, however water application rates may affect plant uptake.

Small-scale pot trials

Increasing applications of invasive seaweed to sweet potato for K yielded significant results for the peat moss media and the Mollisol soil, however not the Oxisol soil. K was available for plant uptake in the form of seaweed, however, not out rightly apparent in the Oxisol soil, which has a lower water retention capacity than the peat moss media and the Mollisol soil. However, all treatments amended with either seaweed paired with tankage or all synthetic K and N did not yield significantly different results, therefore seaweed paired with tankage is a comparable substitute for conventionally fertilized sweet potato plants. Amaranth plants used in this trial did not show any significant results when growth parameters were compared, and amaranth may not be a suitable crop for K analysis.

Larger scale field trials

Sweet potato plants in two Hawaiʻian soils amended with invasive seaweed showed adequate nutrient availability due to increasing applications of seaweed. In addition, comparable K sources did provide adequate evidence that invasive seaweed could provide sufficient support when compared to conventional synthetic fertilizers. However more investigations into application of invasive seaweed on different Hawaiʻian soils can provide a clearer idea for more efficient application rates, a K from seaweed availability timeline, and any potential nutrient loss. In the meantime, applications of dried invasive seaweed can be used as a suitable soil amendment on sweet potato crops.

As research refines the potential of invasive seaweed to be used as a local soil amendment, treating the collected seaweed to reduce reproductive potential on a larger or consistent scale may be an issue that needs to be addressed. Some possibilities include, researching a simple, more effective means to reduce invasive seaweed viability, or creating a treatment facility to process the seaweed product before distribution out side of the watershed. No matter what method is used to treat this issue, the importance should not be lessened. Although removal efforts are improving, there is little to no barrier keeping these species from spreading to the northeastern tip of Oahu, where the seaweed could become impossible to control.

Lastly, the research that is presented only describes one species of invasive seaweed, the potential to expand the use of other collected invasive seaweeds is available as well. As long term efforts towards removing invasive seaweed from Hawai‘i’s shores take effect, the availability of invasive seaweed as a waste product will be reduced. Looking to these future goals, the possibility of cultivating native seaweeds for agricultural may become an option. For example, the native seaweed *Ulva spp.* has been identified as a possible source of plant nutrients, and can be easily cultivated without the potential of becoming invasive in Hawai‘i. Some of the advantages of using cultivated native algae include: low competition with land based food production systems, low freshwater usage, low fertilizer applications, and high yields per species.

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