CHARACTERIZING PILIGRASS (HETEROPOGON CONTORTUS) AS LIVING MULCH FOR TROPICAL VEGETABLE CROPS

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MASTER OF SCIENCE
(PLAN B)

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ABSTRACT

An experiment was conducted in Hawai'i during spring 2008 to fall 2009 to examine the response of cabbage (*Brassica oleracea var. capitata*) and zucchini (*Cucurbita pepo* L.) in a native *Heteropogon contortus* (piligrass) living mulch (LM) system and compare it to a conventional bare ground (BG) system. *B. oleracea var.capitata* was planted in two different seasons, fall 2008 and spring 2009. It was rotated with *C. pepo* L. in winter 2008 and summer 2009. The study consisted of field a experiment and laboratory analyses for plant and soil. Data was collected for weed control, insect population, pest and disease damage, crop yield, and soil properties. The results of this study, piligrass LM had: 1) consistently reduced weed biomass up to five times compared to BG, 2) provided habitat for insects, thus it increased total population and biodiversity of insects, and 3) reduced plant and fruit damages due to pests and diseases. Nevertheless, BG yield was five times higher than LM treatment. For the soil analyses, it can be concluded that piligrass as a LM had higher total N (Nitrogen), total C (carbon), and NH_4^+ (ammonium) with similar level of NO_3^- (nitrate) compared to the BG plots. Furthermore, P (phosphorous), K (potassium), Ca (calcium), Mg (magnesium), and pH in both LM and BG plots were not significant different. Analysis of the phytotoxicity of soil from three tests (germination bioassay, charcoal mitigation of inhibitor, and soil phenolic) did not clearly detect any inhibitory substances in the soil. The piligass LM improved the physical quality of soil by increasing WAS (water aggregate stability), maintaining SM (soil moisture) and reducing surface ST (soil temperature). Therefore, improved understanding about the use of piligrass as a LM is important to advance our knowledge of using LM in tropical agricultural systems.

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CHAPTER I
LITERATURE REVIEW

1.1. Introduction

A living mulch system (LM) is a farming system that is used for sustainability of vegetable production and ecological conservation. The living mulch system represents an alternative to low-till/ no-till practices used in agricultural systems (Kuepper, 2001). No-till practices are usually associated with high levels of crop residues left on the soil surface (Baker, Saxton & Ritchie, 1996). Using a LM system has been shown to achieve agro-ecosystem stability in vegetable crop production (Biazzo,& Masiunas, 2000). The LM system is a useful farming practice for improving soil quality, controlling weeds, preventing plant damage by pests and disease (Sainju & Singh, 1997; Hooks & Johnson, 2004) and increasing crop production (Leary, DeFrank & Sipes, 2006). Some previous studies using living mulches have shown increased N availability, organic soil matter, soil structure, water infiltration (decrease water runoff), reduce soil surface temperature and water evaporation, and increase soil productivity (Sainju & Singh, 1997; Hartwig & Ammon, 2002; Leary & DeFrank, 2000; Hooks and Johnson, 2004).

The use of cover crops as a living mulch often pertains to the use legume plants (Fabaceae) because legume can add nitrogen (N) into the soil through nitrogen fixation . However, legume plants also need nutrients to support their life cycle. Previous studies have shown with moderate to high levels of soil N, legumes tend to absorb N from the soil than fix it from the air (Hartwig & Ammon, 2002). Therefore, using other plants as living mulches such as grass species (Poaceae) is an alternative of legume plants. Leary, DeFrank, & Sipes (2006) conducted research in Hawai'i using an African grass, *Cenchrus ciliaris* (Buffelgrass), as a LM. The study showed that Buffelgrass used as a living mulch system was successful at increasing eggplant yield over 100% compared to using a bare–ground system.

Federal and state agencies, research institutions, conservationists and traditional peoples have became aware of the destructive nature of invasive species in Hawai'i due to their displacement of many native Hawaiian plants and the deterioration of ecosystems in

Hawaii. A survey conducted of *H. contortus* (piligrass) on Oahu in 1997 showed that the species was absent in 14 out of 41 study sites due to the invasion of nonnative African grasses (Daehler & Carino, 1998). Currently, the Natural Resources Conservation Service (NRCS) in Hawai'i is attempting to restore some native plants on the island of Kahoolawe (Crago, Puttock & James, 2004), including the restoration of the native piligrass.

Piligrass, a tropical perennial C_4 bunchgrass, is native to Hawaii (Wagner, Herbst & Somer, 1999). It was used in many countries such as Australia, Africa, Southwestern U.S. and India as a valuable fodder for cattle (Shaw & Bisset, 1955; PHPPS, 2008). In Hawaii, *H. contortus* has served as a valuable cultural and natural resource. It was used by ancient Hawaiians for medicinal purposes, as a high quality thatch for building structures, and sometimes used for Hula altars (Bioshop museum, 2008). In Hawai'i, many organizations are trying to conserve the native piligrass by using it for landscaping, restoration and natural conservation projects. Currently, native Hawaiian plants have been successfully used in the Hawaiian Islands for landscaping, phytoremediation, erosion control and soil stabilization (Crago, Puttock & James, 2004).

The native Hawaiian piligrass is important because of its cultural value potential to contribution to indigenous and displacement of fire adapted species (Dahlear & Goergen, 2005). Furthermore, native grasses are highly adaptable to local conditions, drought tolerant, resistant to many insects, pests and pathogens and promote erosion control (Daar & King, 1997; Rorison & Hunt, 1980; Huxtable & Whalley, 1999). Expanding the use of piligrass into commercial agricultural practices will help to sustain its ecological role. Since the native populations of piligrass have become restricted due to the invasion of nonnative species, it should be restored and conserved for sustainable ecological and agricultural purposes.

One potential use of native grasses in farming applications is using them as a ground cover or LM for the integration with vegetable crops. In farming systems, grasses can be used as a living mulch, however, there is very limited information about the use of native grasses as living mulches. Therefore, I propose to characterize the impact of *H. contortus* living mulch for tropical vegetable crops compared it to conventional bare ground farming

systems in Hawai'i. Components objective of this study will include the effect of piligrass as a LM on crop yield, insect population, pest control, and soil properties.

1.2. No-tillage Living Mulch

A living mulch is an established cover crop (CC) and a living ground cover that is interplanted and grown either before or with an annual main crop throughout the growing season (Hartwig & Ammon, 2002; Hooks & Johnson, 2004). Planting vegetable crops in tropical regions poses agricultural problems such as maintaining adequate water supply, pest and disease management, and weed suppression. It has been shown that winter rye planted as cover crop can be integrated in vegetable production systems along with herbicide treatments as a sustainable approach to improve weed management (Walters, Young, & Nolte, 2007). Leary *et al.* (2006) found that eggplant grown in Hawai'i in chemical suppressed Buffelgrass living mulch systems provided much higher yield than conventional bare ground systems. The LM systems are challenging to manage although it can provide a stable habitat for beneficial insects and reduce weed biomass while promoting responsible land stewardship in tropical island ecosystems. Leary *et al*. (2006) also emphasized that suppression of the LM is necessary for successful tropical eggplant production.

According to Peet (2008), CCs can be used in many applications in the vegetable production cycle. First, CCs can be used as a main crop during the primary growing season and as a rotation crop. Second, as a companion crop or living mulch, the cover crop is planted between the rows of the cash crop. Third, CCs can be used as a "catch" crop for nutrients, planted after harvest of the main crop to absorb of nutrients. Finally, as an off-season crop grown to protect the soil during periods when weather conditions prevent more valuable crop production.

There are four important characteristics for choosing a good quality of LM. Those characters are rapid plant establishment to prevent soil erosion and to control weeds; adaptability and persistence is needed to allow for entrance into the field; tolerance of drought and low-fertility soils; and low maintenance budget associated with mowing, fertilizer application, and chemical stunting, (Paine & Harrison, 1993; Arakaki, 2003).

Additionally, LM ground covers can offer a practical and economic management alternative for resource-poor farmers (Hilje & Stansly, 2007). Proper management of LMs is crucial to their successful contribution to crop production.

The application of LM provides several beneficial effects for the abiotic and biotic features in the ecosystem. Living mulches are able to prevent soil erosion, reduce surface water pollution, add organic matter, improve soil quality and productivity, and control weeds (Sainju & Singh, 1997; Hartwig & Ammon, 2002; Hooks & Johnson, 2004; Teasdale, Beste, & Potts, 1991). Living mulches can increase nitrogen levels by 38-220 Kg N/ha from legume plants and 14-90 kg N/ha from non-legume plants (Sainju & Singh, 1997). Living mulch can protect the soil from water erosion by reducing the raindrop impact, reduce soil bulk density, increase total soil porosity, water holding capacity, and soil aggregation (Mulumba & Lal, 2008). In addition, LMs have been shown to depress insect pest populations. In Hawai'i leguminous LMs have been shown to reduce lepidopteran pests and increase the activity of beneficial insect, such as spiders in broccoli (Hooks & Johnson, 2004). Hooks *et al* (1998) found that LMs can be a useful tool in controlling multiple pest complexes in zucchini (Hooks *et al*. 1998). A recent study showed that barrier plants (buckwheat and sun hemp) can protect zucchini from non-persistent viruses (NPVs) (Hooks & Wright, 2008; Manandhar & Hooks, 2008).

However, LMs have also been shown to have negative effects on the main crop similar to weedy species (Teasdale, 1988). Negative impacts of LMs have been reported to be enhancing disease conditions and insect pest and compete for moisture and nutrients (Hooks & Johnson, 2004). In addition, Arakaki (2003) found that crops grown in LM systems resulted in lower yields and later maturity than crops grown conventionally. The lower yield and later maturity of the crop plant was shown to occur because of shading, lower ground temperature, and competition for plant nutrients by the LM plant.

Management of LMs in agricultural crop systems is needed to minimize the negative impacts of the LM. Hartwig & Ammon (2002) suggested highly selective pre-or post-emergence herbicide to overcome the potential problems associated with the use of a LM, while not harming the vegetable crop. It has been shown that competition for N by LM

grasses and crops can be partially overcome with additional nitrogen fertilization (Arakaki, 2003).

Legumes and grasses have both been used successfully as CC. Legumes tend to use soil N rather than fixing their own, if it is available (Hartwig & Ammon, 2002). Elkins *et al.* 1983 described that an experiment comparing grass and legume LMs found that legumes are more difficult to maintain compared to grass LMs when using chemical suppression treatments. Most vegetable crops are broadleaf, thus selective post-emergence herbicide can be used to suppress the grass LM without reducing crop yields (Leary, 1999). In addition, grasses provide better weed control and use less water than legumes generally. Furthermore, grass root penetration can increase water infiltration and limit soil erosion (Leary & DeFrank, 2000). The prevention of soil erosion is a serious obstacle in agricultural systems in Hawai'i where some places are at high risk for soil erosion, thus LMs are a proper application.

1.3. Native plants and *Heteropogon contortus* (piligrass)

A native plant is a plant that grows naturally in a particular area without direct or indirect human intervention (NASS-USDA, 2008). Native plants can have very limited ranges, can be adapted to very harsh climates, or live in diverse habitats (NASS-USDA, 2008). Native species are typically better adapted to local conditions; have greater resistance to pests, insects and pathogens; create better habitat and forage for animals; and are associated with lower maintenance costs for re-seeding, fertilizer and herbicide applications when compared to nonnative plant species (Daar & King, 1997; Rorison & Hunt, 1980; Huxtable & Whalley, 1999). The establishment of native plants in disturbed areas can help exclude the establishment of noxious or invasive species (Landis, Wilkinson, Stainfield & Fekaris, 2005).

When establishing native grasses appropriate site conditions, such as correct rainfall, temperature, soil and microsite characteristics have to be taken into consideration (Huxtable & Whalley, 1999). Adequate rainfall is important for establishment of seeds on a cultivated topsoil (Huxtable & Whalley, 1999). Peterson, Roundy & Bryant (2004) explained that microsites such as soil cracks and depressions, plant litter, gravel, and rock could moderate

soil and air temperatures and be important when establishing native grasses. Conserving soil moisture, increasing water-harvesting capacities, and providing protection from seed predation for native plants should be considered.

In Hawai'i, the protection and conservation of native plants is important concern due to proliferation of invasive species. There are several tasks to protect native Hawaiian plants: 1) eliminate threats to native ecosystems; 2) generate and maintain genetic diversity among species; and 3) replant endangered species in the wild by outplanting (Tamini, 1999). Currently, native Hawaiian plants are mostly used for landscaping, phytoremediation, erosion control, and restoration and conservation applications (Baldos, 2009). They were first initially developed as horticultural ornamentals and for their cultural value (Crago *et al*. (2004). Furthermore, the successfully used native Hawaiian plants for erosion control and soil stabilization on the island of Kaho'olawe and on several riparian zones around O'ahu, Maui and Hawai'I (Crago et al., 2004).

H. contortus (Piligrass) (picture 1.1.), one of 8 Heteropogon species, is a native species to Hawai'i (Wagner et al., 1999; Morden, 2006). *Heteropogon contortus* (L.) P. Beauv. Ex Roem. & Schult., a thick perennial C_4 bunchgrass (tussock grass), is established around tropical and subtropical grasslands of the world (Carino, 1999). *H contortus* is also native to southern Africa, southern Asia, northern Australia, Oceania, the Sonoran desert, and the U.S. in general (IUCN ISSG, 2008; IPC-PHPPS, 2008). *H contortus* has many synonyms and common names, i.e. black speargrass, speargrass (Australia), tanglehead, twisted beardgrass, herbe à moutons (French), and pili grass (Hawai'i) (PHPPS, 2008).

Piligrass grows rapidly in open areas including agricultural areas, range/grasslands, disturbed areas, and scrublands (IUCN ISSG, 2008). In Hawai'i, it is widespread on all of the main islands on dry rocky cliffs, ledges and slopes exposed to the ocean at elevations of 0-700 m (Wagner et al., 1999). *H. contortus* prefers areas with rainfall less than 800 mm. It is adapted to coarse textured soils with a pH 6-8, drought tolerant, low tolerance for salinity and low fertility, and high temperature (TGS, 2008). It is rarely cultivated, but commonly its propagation is from seeds. *H. contortus* can grow in grasslands that experience seasonal fires because it is fire-resistant and can form savannahs after fire (IUCN ISSG, 2008). Therefore, historically Hawaiians used fire to promote *H. contortus* grasslands (Hoffmann,

2003; Daehler & Goergen, 2005). The optimal germination temperature of *H. contortus* seeds is between 30-35^{o}C, and germination can be inhibited when nighttime temperatures are between 15-20^{o}C (PHPPS, 2008). Seed dormancy can last for about 1 year after seed maturation and seeds are viable for about 1-2 years. *H. contortus* actively grows in spring and summer, but regrowth after harvesting is slow. It has height up to 1.5 m, erect culms, herbaceous stem, and fibrous roots. Leaf blades are 6-24 cm long and 0.4-0.8 cm wide, flat or folded, with a few long hairs near the ligul (PHPPS, 2008).

There are several practical uses of *H. contortus* all over the world. In many countries such as Australia, Africa, Southwestern U.S., and India, the plant has been used as a valuable protein-rich fodder or hay for cattle before inflorescence development and used as a fiber in India (Shaw & Bisset, 1955;PHPPS, 2008). However, it has negative impacts in animal husbandry because of its sharp seeds. In addition, the seeds can also cause similar injuries to dogs with thick undercoats (PHPPS, 2008).

H. contortus can grow in hillsides and lowland. In Hawai'i, before 1970s it has widely covered the Hawaiian Islands. By 1960s in Oa'hu island the *H. contortus* was founded on 41 sites (Kartawinata & Muller-Dombois, 1971), however in 1997 a survey on the same sites with the same method of previous survey found that the community of *H. contortus* only remain 27 of 41 sites. The declining 35% sites of *H. contortus* communities due to displacement by invasive African grasses, such as *Cenchrus ciliaris* (buffel grass), *Pennisetum setaceum* (fountain grass), and *Urochloa maxima* (guinea grass).

In Hawaii, *Heteropogon contortus* is an important cultural and natural resource. It has been shown that piligrass was used by the ancient Hawaiian. The ancient Hawaiians used it for medicine as an ancillary ingredient to treat 'ea [1] and pa'ao'ao[2] (Bishop, 2008; Ulukau, 2008), for building high quality thatch, and sometimes used it for hula altars or *kuahu* (Bishop museum, 2008). Currently, native Hawaiian plants have been successfully utilized for landscaping, phytoremediation, erosion control and soil stabilization in some of the

[1] *'ea* – a general term for infections and infectious diseases; coated tongue, sometimes accompanied by sore throat, the thrush disease of children (Bishop, 2008; Ulukau, 2008)

[2] *pa'ao'ao* – a latent childhood disease, with physical weakening; a general term for ailments (Bishop, 2008; Ulukau, 2008)

Hawaiian islands (Crago et al., 2004). Piligrass has been use for nursery, living mulch for trees, roadside revegetation, and natural conservation (visual observation) (picture 1.2.).

Based on the my literature review, restoration of *H. contortus* is an important area of enthobotanical and ecological research because of its cultural value, rapid population decline, and it being less of a fire hazard compared to the dominant African grasses found in Hawaii (Daehler & Goergen, 2005). Conservation of native grasses can promote floristic biodiversity in Hawaii and therefore, piligrass should be restored and conserved for cultural, agricultural, and ecological reasons.

1.4. Research objective

The main objective of my master's thesis was to evaluate the effects of *H. contortus* as a living mulch system on vegetable crops in two seasons. Using measurements of vegetable crop production, weed control, pests and disease management, and soil properties (chemical and physical soil) as qualitative and quantitative measurements for evaluation of *H. contortus* as a living mulch.

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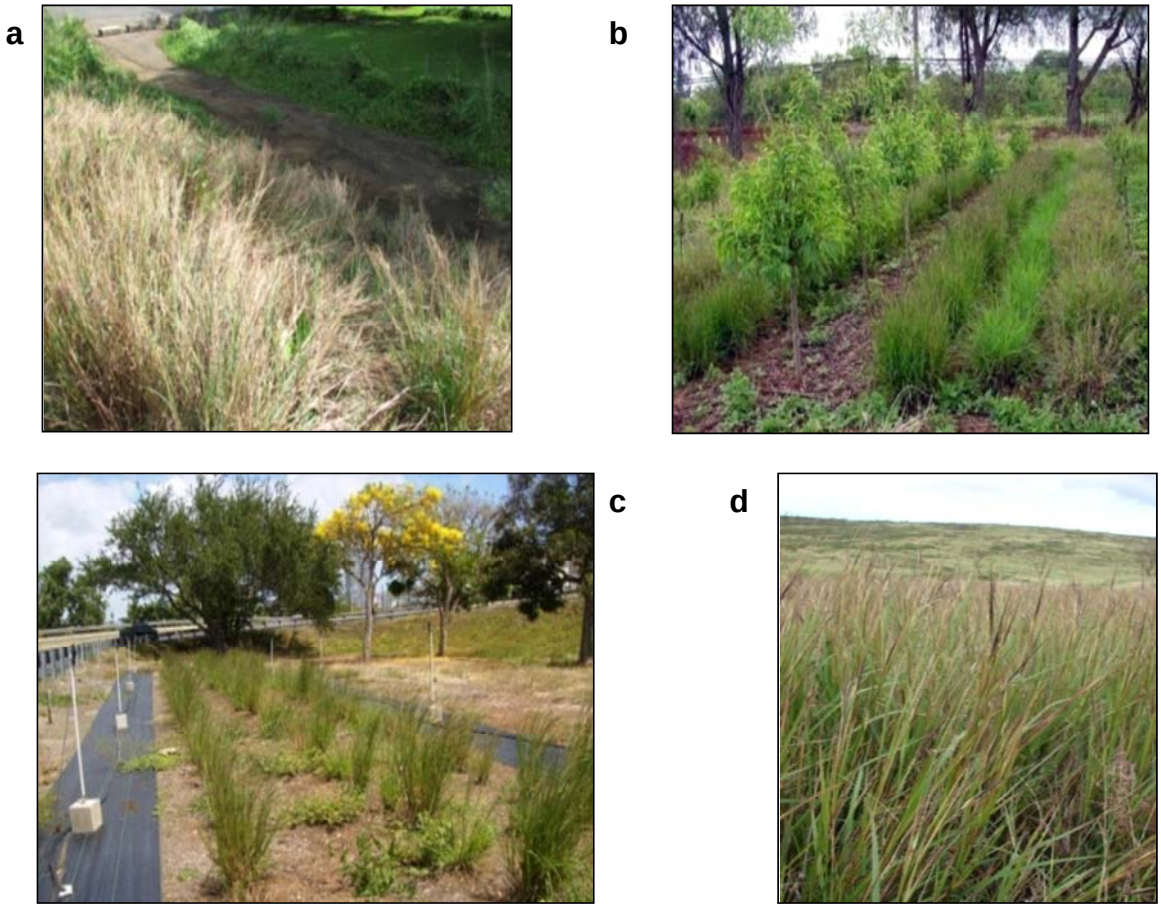
Pictures

Picture 1.1. The individual plant of the *Heteropogon contortus* (piligrass) a perennial C4 tussock grass



Picture1.2. The uses of *H. contortus* (Piligrass) in Hawai'i: a) Landscaping in Kaneohe; b) Living mulch, Poamoho; c) Roadside revegetation, H1; d) Habitat of natural conservation in Kaho'olawe[+] ([+]pic. taken by Forest & Kim Star).

CHAPTER II

THE RESPONSE OF CABBAGE (*BRASSICA OLERACEA VAR. CAPITATA*) AND ZUCCHINI (*CUCURBITA PEPO* L.*)* IN A PILIGRASS LIVING MULCH SYSTEM

2.1. Abstract

An experiment was conducted at the Waimanalo research station on the island of O'ahu, Hawai'i to examine the response of cabbage (*Brassica oleracea var. capitata*) and zucchini (*Cucurbita pepo* L.) to a *Heteropogon contortus* (piligrass) living mulch (LM) system and compare it with a conventional bare ground (BG) system with 4 blocks. *B. oleracea var.capitata* was planted in two different seasons, fall 2008 and spring 2009 and was rotated with *C. pepo* in winter 2008 and summer 2009. During cabbage planting, weed biomass in the LM system was significantly lower both in fall and spring planting. The study found that LM plots had larger populations and greater biodiversity of insects (pests and beneficial insects) than in the BG system for both seasons. During the fall season, both total cabbage plant damage due to pests and head damage due to diseases were significantly higher in the BG system than in LM system. Marketable yield in terms of total weight of cabbage head in fall 2008 was not significantly different between LM and BG systems. However, in spring 2009, cabbage yield in BG plots was significantly higher than in LM. In zucchini crop, weed biomass in the LM system was significantly lower in both winter and spring planting. Piligrass LM plots in winter season contained a higher number of lynx spiders than in BG plots. In summer season, total insect populations and insect biodiversity were not significantly different between the LM and BG systems. Total zucchini plant mortality due to pests and diseases in the winter season was significantly higher in the BG plots compared to the LM plots. In the summer season, zucchini plant damage due to zucchini yellow mosaic virus (ZYMV) in BG plots was significantly higher than LM plots. There was no zucchini harvest in winter season due to plant death caused by pests, diseases and heavy rains. Furthermore, total marketable yield of zucchini in summer season in terms of total weight of fruits in the BG plots was higher than the plots LM. Our study showed that piligrass used as a LM successfully suppressed weed populations, reduced pest and

disease infections, increased insect populations and biodiversity. However, BG treatment has higher crop yields than in LM treatment within two different seasons.

2.2. Introduction

Living mulch (LM) system is an agricultural practice using cover crop where its crop residue was left on the surface soil with low/ no-till application (Baker et al., 1996; Kuepper, 2001). The crop residue from the LM benefits for soil physical quality by increasing soil organic matter, soil structure, water holding capacity, reducing water runoff and soil erosion (Hartwig & Ammon, 2002). Pimental et. al., (1995) reported that the LM system, which is conservation tillage system, can prevent soil loss equivalent to $ 100 $ha^{-1}yr^{-1}$ of economic value. Hence, LM has potential benefits for controlling pests and weeds, preventing soil erosion, and increasing soil quality. In addition, the living mulch also provides habitat for predatory insects (Kuepper, 2001).

On the other hand, the competition between the LM and main crop is an important management concern when applying LM system. LM influences the cash crop by modifying microenvironment and the crop yield due to competition (Hooks and Johnson, 2004) such as for moisture, nutrient, and supporting diseases and pests population (Hartwig & Ammon, 2002). It has been showed that LM has lower yield and later maturity compare to conventional system due to shading, low soil temperature, and competition for nutrients (Arakaki, 2003). However other studies found that broccoli yield in LM and bare ground (BG) plots were comparable (Hooks et al., 2007).

Kuepper (2001) reported that balancing the growth of LM and cash crop can be achieved through selection type of cover crop, living much suppression strategies, arranging a zone of tillage and weed control. Characters of a good living mulch are rapid establishment; tolerance to field traffic, drought, and low fertility; and low maintenance cost (Kuepper, 2001).

A study using *Cenchrus ciliaris* (buffelgrass), a non-native grass, as a LM in Hawai'i provided increasing eggplant yield compare to BG conventional cultivation (Leary et al., 2006). However, there has been no studies investigating the use of a native grass a living mulch for vegetable crops in Hawai'i.

Heteropogon contortus (piligrass), a native Hawaiian grass has potential use as a LM species. Piligrass is a tropical perennial tussock grass (Carino, 1999), native to Hawaii and other tropical countries (Wagner et al, 1999; IUCN ISSG, 2008; PHPPS, 2008). Piligrass is drought tolerant and can be grown in very poor soil (IUCN ISSG, 2008). In Hawaii, native Hawaiian plants have been used for controlling erosion and soil stabilization (Crago et al., 2004). In order to use native perennial grass as LM, piligrass can be maintained year to year by mowing and stunting. Hence, the life cycle of perennial grass can eliminate the need of reseeding every year (Hartwig & Ammon, 2002). Therefore, the aim of this experiment is to determine the response of two sequestration crops of cabbage (*Brassica oleracea var. capitata*) and zucchini (*Cucurbita pepo* L.) in a piligrass LM system.

2.3. Materials sand Methods

2.3.1. Land preparation and establishment of piligrass

Land preparation

This experiment was conducted at the University of Hawaii (UHM) and Waimanalo research station located on the eastern side of O'ahu, from spring 2008 until summer 2009. The Waimanalo research station is found 22^{o}N168^{o}W at 30m elevation with a 2-6% slope and an annual precipitation between 500-1800mm. The soil is Haleiwa type, silty clay with a pH of 6.5-7 and an organic matter content of 1.3-1.8 (Valenzuela, 2008) (picture 2.1.).

The experimental design was a randomized complete block design with two treatments and four blocks. Treatments consisted of piligrass living mulch and conventional bare ground systems. Each living mulch plot was 4.5 m x 7.2 m with 4 crop rows and 8 piligrass rows.

On April 25, 2008, two months prior to planting piligrass the field was prepared (picture 2.2.a.). An overhead irrigation system was installed to supply the entire experiment area with adequate water to promote weed seed growth (picture 2.2.b.). On June 4, 2008 pre- and post-emergence were applied using goalTender 4F® (oxyflourfen 0.89 kg a.i./ha) and Roundup® (glyphosate 0.15 kg/ha) mixed with MSO (methylated seed oil 0.12 kg a.i./ha). The herbicides application used a backpack with a 12-volt battery powered sprayer equipped with a hand three-nozzle wand and Teejet 8004 LP nozzle tips (picture 2.2.c.).

Establishment of piligrass

From February 2008 until June 2008, piligrass seeds were established at Magoon green house of UHM. On February 2008, the piligrass was grown from the seeds and germinated in vermiculate media in 25 trays (picture 2.3.a.). One month later, the seeds were transplanted to tubes in media mixed Promix (pro micoriza), lime, and 81 kg N/ha as 21-14-11 fertilizer. Prior to transplanting piligrass to the field, 30 cm of top growth were cut off to reduce transpiration during early establishment (picture 2.3.b).

On June 12, 2008 the piligrass was transplanted to the field (picture 2.3.c). The piligrass was planted with space 0.6 m x 0.6 m within row and 0.6 m x 1.2 m between rows. There were 8 rows of piligrass per plot where two piligrass rows were between one crop row, the design of piligrass planting can be seen at picture (2.3.f). Hence, total piligrass per plot was 64 plants or 256 plants for 4 blocks. Immediately after transplanting the piligrass, 112 kg N/ha, 93 kg K/ha as 18-0-18 fertilizer was broadcasted to entire experiment (picture 2.3.d). One week after transplant piligrass, a second round of pre-emergence herbicide was sprayed again using goalTender 4F® (oxyflourfen 0.45 kg a.i./ha) a half rate of previous application (picture 2.3.e).

Piligrass LM treatment was maintained by mowing and herbicide application to reduce competitive of plants. Prior to planting the cash crop, piligrass was mowed twice at 47 and 68 DAT using a sickle bar mower at 30 cm of plant height (Picture 2.4.a). The piligrass biomass was laid down on the ground to cover the entire soil surface in LM plots (picture 2.4.b). One week later, the piligrass plants were stunted using FusiladeDx® (fluazifop 0.14 kg a.i./ha) with a hand pump sprayer with single nozzle hallow cone tip (picture 2.4.c). A symptom of piligrass response to herbicide application was purple color of leaves (picture 2.4.d).

2.3.2. Cabbage growing season in fall 2008

Cabbage establishment

On July 30, 2008 cabbage (cultivar KK cross) was germinated in a media of promix and a 21-4-11 fertilizer. At 7 days after planting (DAP), the seeds were transplanted to cell trays. One week later, the cabbage was transplanted to the field. The cabbage transplants

had to be replanted three times due to ant, snail, and slug damage especially in LM plots. A total 480 cabbage plants were planted with 1.8 m between rows and 0.3 m apart within rows. Irrigation was supplied to the crop rows through drip lines everyday for 15 to 20 minutes at 8.00 am at a rate of 21,056 L/ha. At 34 DAT (days after transplant) of cabbage, the plants were fertilized with 90 kg N/ha, 40 kg P/ha, and 74 kg K/ha as 19-19-19 fertilizer within the drip irrigation using Dosatron International DI 16 injection (picture 2.5.).

At 7 DAT of cabbage, metaldehyde granules (2,4,6,8-tetramethyl-1,3,5,7,-tetra oxycyclo-octane) were applied 1.34 kg a.i./ha to control slugs and snails. Also at 17 DAT of cabbage, diazinon 4-E [O,O-diethyl o-(2isopropyl-6-methyl-4-pyrimidinyl) phosphorothioate] was applied at rate 5.25 kg a.i./ha to control ants. At 34 DAT of cabbage, malathion 25W (0.8 kg a.i/ha) was sprayed to control cabbage looper, cabbageworm, whitefly, and aphids. Pesticide spraying was done using a backpack hand pump sprayer with a single nozzle hallow cone tip.

Data collection

a. Weed data

Hand weeding was performed for both LM and BG treatments. Time data was recorded to determine return to weed free status and dry weed biomass for each plot at 10 DPT (days prior to transplanting) and 15 DAT of cabbage was recorded. Weed biomass was dried in an oven at 48^{o}C until get stable.

b. Insects population

Insects were collected using insect sweep net. At 48 DAT of cabbage, insects were collected during an average time of 50 seconds per plot when walking (picture 2.6.a). Insects counts in the net was recorded for each species. The data of insect species were recorded to determine total number of insect and total number of species per plot.

c. Pests and diseases damage

During early establishment of cabbage, plant damage due to ants, snails, and slugs occurred largely in LM block I due to *Leucaena leucocephala* shading nearby the plot.

Therefore, after growing the cabbage the *L. leucocephala* trees were cut along the eastside of area plot. At 55 DAT of cabbage, plant damage due to pests, which are looper and cabbageworm, was recorded by visual observation with symptoms such as holes in leaves, multiple growing plants and malformation of cabbage (picture 2.7.). Head cabbage damage was also recorded due to disease infection with symptoms: rotten and splits (picture 2.8.).

d. Yield

Cabbage harvesting was done at 55 DAT (picture 2.9). Marketable yield data was collected based on minimum head size greater or equal to 13 cm of diameter and no signs of pest or disease injury. The yield was collected only from sampled row (two middle crop rows) which was 10 plants/row. Total number of heads per plot, total weight of head per plot, the average weight per head, and average diameter per head were recorded.

2.3.3. Zucchini growing season in winter 2008

Zucchini establishment

On October 25, 2008 zucchini (cv. commander) was directly sowed into cell trays in the same media used for cabbage. At 14 DPT (days prior to transplanting) of zucchini to the field, piligrass was mowed using a sickle bar mowed. One week later, the piligrass was sprayed with FusiladeDx® (fluazifop 0.14 kg a.i./ha) with a hand pump sprayer single nozzle hallow cone tip to suppress the piligrass LM. At 12 DAS (days after seeding) of zucchini, a total 160 zucchini plants were planted with 1.8 m between rows and 0.9 m apart within rows. Transplants were fertilized twice using the same fertilizer of 90 kgN/ha as 19-19-19 within the same system of drip irrigation. The drip irrigation was also set up with the same time and amount of water to the previous cabbage crop.

At 0 and 7 DAT of zucchini, application of metaldehyde granules to control slugs and snails was done with same rate 1.34 kg a.i./ha as the cabbage crop. Moreover, at 30 DAT, malathion 25W was also sprayed at a rate 0.8 kg a.i./ha to control aphids, leafhoppers, and cucumber beetles using a backpack hand pump sprayer with as single nozzle hallow cone tip.

Data collection

a. Weed data

Hand weeding was conducted within all plots for both LM and BG treatments. At 7 DPT and 28 DAT of zucchini time data was collected for a return to weed free status and dry weed biomass for each plot.

b. Insects population

At 15 DAT of zucchini usual counts were used to record the Lynx spider level (a beneficial insect) (picture 2.10).

c. Pests and diseases damage

At 28 DAT of zucchini, plant mortality due to pests and diseases infection was recorded (picture 2.11).

d. Yield

The winter season in 2008 had rainy weather that contributed to total loss of the crops. No yield data was recorded.

2.3.4. Cabbage growing season in spring 2009

Cabbage establishment

During this growing season, piligrass was mowed three times: at 14 DPT, 42 and 69 DAT of cabbage (picture 2.12). The piligrass plant was mowed to a height of 30 cm. At 7 days after mowing first, piligrass regrowth was stunted with FusiladeDx® (fluazifop 0.14 kg a.i./ha).

On January 20, 2009, germination of cabbage (cv. KK Cross) was carried out at the Magoon of UHM using the same media as the first series of cabbage and zucchini. Six days later, the seeding was transplanted to cell trays. On February 6, 2009 (at 9 DAS), the cabbage was transplanted to the field. The transplants were fertilized two times at 0 and 33 DAT of amount 90 kg N/ha as 19-19-19 fertilizer within the drip irrigation system.

At 7 DAT of cabbage, metaldehyde granules were applied again at the same rate 1.34 kg a.i./ha to control slugs and snails. At 12 DAT, insecticide Radiant® (spinetoram 0.09 kg a.i./ha) was sprayed and followed by sprays Avaunt® (indoxacarb 0.08 kg a.i./ha) at 38 DAT using backpack hand pump sprayer with a single nozzle hallow cone tip.

Spinetoram and indoxcarb were applied to control cabbage looper (*Trichoplusia ni*), diamondback moth (*Plutella xylostella*) and cabbageworm (*Pieris rapae*).

Data collection

a. Weed data

Hand weeding was done twice at 7 DPT and 33 DAT of cabbage (picture 2.13). Weed data includes time to return weed free status and weed biomass.

b. Insects population

Insect data collection was completed during the growing season using three methods: sticky traps, insect sweep net, and visual counts. At 21 DAT of cabbage, 4 sticky traps, 13 x 7.5 cm^2 wide, were placed each plot in crop and non-crop rows in LM and BG plots (picture 2.14.a). At 33 DAT of cabbage, insects were caught by insect sweep net to all plots of LM and BG treatments with an average collection time of 50 seconds walking per plot. At 56 DAT of cabbage, Lynx spider webs were counted (picture 2.14b).

c. Pests and diseases damage

Cabbage head damage due to insect and diseases were quietly reduced compared to the fall 2008 crop, thus data for plant injury due to these factors was not recorded.

d. Yield

Cabbage harvesting was performed at three times: 56, 62, and 68 DAT. Marketable yield data based on head size was collected from two middle crop rows. Marketable cabbage head diameter had to be greater or equal to 13 cm and not contain signs of pests and disease damage (picture 2.15). The total number of heads, total head weight, the average weight of all heads, and the average diameter of all cabbage heads was recorded.

2.3.5. Zucchini growing season in summer 2009

Zucchini establishment

After planting cabbage in spring 2009, the field was cleaned to prepare for planting zucchini. At 18 DPT and 52 DAT, the piligrass was mowed using a sickle bar mower to a height of 30 cm. One week later, the piligrass was sprayed with fluazifop 0.14 kg a.i./ha.

Zucchini (cv. commander) seeds were produced in the same methods as previously described. At 10 DAS on April 27, 2009, the zucchini plants were transplanted to the field. The transplants were fertilized three times at 0, 7 and 23 DAT of zucchini with 90 kg N/ha as 19-19-19 fertilizer within the drip irrigation. Also at plating (0 DAT), malathion at rate 0.8 kg a.i./ha was applied to control aphids, leafhoppers, and cucumber beetles. At 7 DAT of zucchini, Sniper® (bifenthrin 0.13 kga.i./ha) was sprayed to control aphids. At 14 DAT Metarex® (metaldehyde 0.91 kg a.i./ha) was broadcasted to control snails and slugs. At 23 DAT of zucchini, Radiant® (spinetoram 0.09 kg a.i./ha) mixed with Sniper® (bifenthrin 0.13 kg a.i./ha) were sprayed again to control aphids and pickleworm. Insecticide spraying was conducted with a backpack hand pump sprayer with a single nozzle hallow cone tip.

Data collection

a. Weed data

Hand weeding was conducted within all plots for both LM and BG treatments as needed. At 55 DAT, time data to return plots to a weed free status and weed biomass for each plot were collected.

b. Insects population

Insect collection was recorded during growing season using insect sweep net at 52 DAT with an average time collection of 50 seconds per plot.

c. Pests and diseases damage

Total zucchini plant damage due to zucchini yellow mosaic viruses (ZYMV) (picture 2.16) was recorded at 30, 35, 39, 45, and 52 DAT zucchini. At the last

observation time, percentage of infected plants and plant mortality data were also recorded.

d. Yield

Zucchini yield was collected 5 times at 30, 35, 39, 45, and 52 DAT (picture 2.17). Marketable fruit was based on size where the length was equal or greater than 13 cm and free of pest damage. Marketable zucchini yield included total fruits, total weight, average weight/ fruit, and average length of fruit. Yield data was collected from two middle row (5 plants/row) and total yield from the four crop rows include marketable and non-marketable yield.

2.3.6. Data collection and statistical analysis

Data collected consisted of marketable yield, weeding time and biomass control, insect counts, and plant injury due to disease. Marketable yield included total number of fruit, total weight of fruit, average weight per fruit and average head cabbage diameter or zucchini fruit length were measured. Weed control included time to return weed free status and weed biomass. Insect, pest and disease control included total number of insects and degree of plant damage due to pest and disease damage.

Analysis of variance was conducted using Statistic 9 software (Analytical Software, Tallahasee, FL).

2.4. Results

2.4.1. Cabbage growing season in fall 2008 and spring 2009

Marketable yield

Marketable yield of cabbage for both fall 2008 and spring 2009 in BG plots were higher than in LM plots. In the fall season 2008, marketable cabbage yield in terms of total heads of cabbage, total weight, and diameter of heads in LM and BG plots were not significantly different, although numerically BG had higher yield than the LM plots (table

2.1). However in terms of average weight per head of cabbage in BG plots (0.8 kg/head) was significantly heavier than in LM plots (0.5 kg/head) (table 2.1).

In the spring season 2009, the heads of cabbage harvested was 3 times (picture 2.15). Total number of head cabbage in BG plot was significantly higher (18'353 total heads/ha) than in LM (8'320 total heads/ha) (table 2.1). In addition, total weight and diameter of heads of cabbage in the BG plots were significantly higher (16'767 kg/ha with diameter 17.4 cm/head) than in LM plots (4'796 kg/ha with diameter 15.2 cm/head) (table 2.1). In spring 2009 for the first harvest date (at 56 DAT) the total number of heads and total weight of heads were significantly higher in BG plots than in LM (table 2.2). Meanwhile, for other harvest dates, the cabbage yields were not significantly different between LM and BG plots (table 2.2). Cabbage yield in spring 2009 in BG was three times higher than LM.

Weed control

In fall 2008, at 15 DAT of cabbage, weed biomass in the LM treatment was significantly lower (215 gram/plot) than the BG treatment (767 gram/plot) (table 2.5) Time to return weed free status in both LM and BG plots was not significantly difference (table 2.5). Both treatments had similar time requirements for weeding, but the weed population varied between treatments. The LM plots had small weeds that took extensive time to remove compare to large weed in BG plots. In spring 2009, at 33 DAT of cabbage, weed biomass in LM plots was significantly lower (275 grams/plot) compared to BG plots (1'387 grams/plot) (table 2.5.).There was not significant difference between LM and BG plots for time to return weed free status (table 2.5.). Overall BG plots had five times more weed biomass than the LM plots.

Insect population

During the cabbage crop of fall 2008 and spring 2009, total insect counts in the two treatments were not significantly different. In fall 2008 at 48 DAT of cabbage, there were four dominant insects caught by sweep net in the plots including two beneficial insects: lynx spider (*Oxyopes salticus*; order Araneae) and ground beetle (*Carabits* sp.; order

Coleoptera); and two pests: grasshoppers (*Katydids* sp. order; Orthoptera) and cabbageworm (*Pieris rapae*; order Lepidoptera) (table 2.7.). In general, the piligrass LM treatment had numerically higher counts of insects than in the BG treatment (figure 2.1). Counts of Lynx spider and cabbageworm adults were not significantly different in the LM and BG treatments, however, the LM treatment had significantly higher ground beetle and grasshopper counts (figure 2.1.). Overall, total insect counts in LM treatment was significantly higher (23 insects/plot) than in the BG treatment (3 insects/plot) (table 2.8.). Total number of species was not significantly difference in the LM and BG plots (table 2.8).

In spring 2009 at 21 DAT of cabbage, there were 11 main insect species from sticky traps in crop row. They are ants (order Hymenoptera), cabbage root manggot (order Diptera), *Ceroxys latiusculus* (order Diptera), *Chaetopsis* sp.(order Diptera), Flea beetles (order Celeoptera), grasshopper (order Orthoptera), Hairy maggot blowfly (order Diptera), Lygus bug (order Hemiptera), lynx spider (order Araneae), whiteflies (order Homoptera) and cabbageworm adult (order Lepidoptera) (table 2.9). The number of insect within each species (figure 2.2) and total number of insects per plot were not significantly different in both LM and BG plots (table 2.10). The total number of species in LM treatment was significantly higher (10 species/plot) compare to BG (8 species/plot) (table 2.10). At 33 DAT of cabbage, insects were collected using the sweep net. Collected insects were similar to previous sticky traps except cabbage root manggot, Lygus bug, ants, and *Ceroxys latiusculus* but adding cabbageworm adult (white butterfly). In general the number of insect within species was not significantly different with the exception of grasshoppers that were higher in the LM treatment (Figure 2.3). LM plots has significantly higher total number of insect (23 insects/plot) and total number of species (8 species/ plot) than BG plots (11 insects of 4 species/ plot) (table 2.10). Moreover, at 56 DAT of cabbage, the number of plant with Lynx spider webs (picture 2.22) was not significant difference (figure 2.4).

Pest and disease damage

In fall 2008 at 55 DAT of cabbage, visual observation was used to record foliar and head damage. Total plant damage due to pests with symptoms: unformed leaf, and multiple

heads in BG plot was significantly higher than in LM plots (table 2.14; picture 2.7). Head cabbage damage due to diseases with symptoms of rots and cracks in BG plot was significantly higher than in LM plots (table 2.14; picture 2.8).

Meanwhile, in spring 2009 there was not serious problem of foliar and head cabbage damage. Therefore, plant and head damage data were not recorded.

In addition, visual observation on plant growth and yield was conducted. Cabbage in LM plots in spring 2009 showed stunted plant, purple leaves, light green color of leaf and delayed maturity (picture 2.13). However, numerical data of these growths attributes did not numerically recorded.

2.4.2. Zucchini growing season in winter 2008 and summer 2009

Marketable yield

Harvesting zucchini in the winter season 2008 was not possible due to plant collapse from heavy rains. In summer 2009, zucchini yield was harvested five times at 30, 35, 39, 45, and 52 DAT from the two middle rows (picture 2.17). Marketable yield at each harvest date was not significantly different between LM and BG plots (table 2.3.a). However, total marketable yield from 5 harvests showed the BG treatment to be significantly higher for number of fruits per ha and total weight (kg/ha) compared to the LM plots (table 2.4). Table 2.3.b. shows that total number of non-marketable fruits and its total weight were not significant different between LM and BG. Meanwhile picture 2.17, table 2.3.c and table 2.3.d. shows that BG has greater total zucchini fruit and total weight of fruits from four crop rows include marketable and non-marketable yields.

Weed control

In winter season 2008, weed biomass in LM was significantly lower (57.3 gram/plot) than in BG (340.5 gram/plot). In summer 2009, weed biomass was also significantly lower (400 gram/plot) compare to BG plot (1’630 gram/plot) (table 2.6). The time to return weed free status in both seasons were not significantly different between the LM and BG plots (table 2.6). Overall, BG had 5 times weed biomass than LM.

Insect population

In winter 2008, observational data was collected on plants with spiders at 15 DAT before heavy rainfall. Total plants with lynx spiders in the LM plots were significantly higher than in the BG plots (table 2.11). Furthermore, in the summer season at 52 DAT, insects were collected using a sweep net. There were three dominant insects: lynx spider (order Aranaea), squash vine borer (order Lepidoptera), and squash bag (order Hemiptera) (table 2.12). Total number of insect within each species was not significant different (figure 2.5). Total number of dominant insects and total number of insect species were not significantly different between LM and BG plots, although numerically higher in BG plots (table 2.12).

Pest and disease damage

At 28 DAT of zucchini in winter 2008, plant mortality due to pest and diseases was recorded (picture 2.11). Total number of dead plants in BG plots was significantly higher (15 plants/plot) than in LM plots (3 plant/plot) (table 2.15). At 39 DAT, BG plants had more damage due to heavy rainy, while plants in the LM plots were still growing normally (picture 2.11). In the summer of 2009, plant damage due to ZYMV was observed regularly at 30, 35, 39, 45, and 52 DAT. At 30 and 35 DAT, total plants infected by ZYMV were not significantly different between LM and BG treatments. Meanwhile at 39, 45, and 52 DAT, BG plots had significantly more plant damage than in the LM plot (figure 2.6). In general, BG plots had higher total plant damage than LM plots (figure 2.6.). At 39 DAT in the BG plots, several symptoms appeared on plants: yellow mosaic, malformation, blisters, necrosis, and plant stunting. Zucchini fruits in the BG plots also showed signs of distortion, deformation, and blistering problems (picture 2.16). In the LM plots, there was similar symptoms, but not to the same extent as in the BG plots. At 52 DAT, total plant mortality and percentage of infected plants were investigated. Total plant mortality due to virus was not significantly different between LM and BG plots. The percentage of plants showing viral symptoms (e.g., mosaic leaves, distorted and/or mottled fruit) was recorded at 52

DAT. Data showed that infected plants in the BG treatment were significantly higher (100%) than in the LM treatment (78.75%) (table 2.16).

2.5. Discussion

We analyzed the benefits of the integration perennial *Heteropogon contortus* (piligrass) as a living mulch (LM) with vegetable crops based on the following parameters: crop yield, weed control, insect population control, pest and disease control. Cabbage (*Brassica oleracea var. capitata*) represents the brassica family, the common leaf vegetable for tropical areas. As well as zucchini (*Cucurbita pepo* L.) represents the cucurbita family, a tropical fruit vegetable. Cabbage was selected for the first growing season because the pre-emergence herbicide (Oxyflurfen) could be used with cabbage to establish piligrass. In this experiment, piligrass LM was maintained from summer 2008 by mowing and herbicide application to diminish growth and reduce competition with the main crops.

Crop yield

The piligrass LM reduced cabbage and zucchini yields in all growing seasons. This same result seen in a study in Illinois, crop yields were reduced by all treatments with four perennial LM covers: white clover (*Trifolium rapens*), red clover (*T. pratencis*), perennial ryegrass (*Lolium pratense*) and canola (*Brassica napus*) (Biazzo & Masiunas, 2000). In this experiment, the reduction of cabbage and zucchini yields recorded in the LM plots occurred due to deficiency of nutrients during the establishment phase. In this experiment, several symptoms of nutrient deficiency occurred in both cabbage and zucchini plants during the establishment phase of growth such as stunting, chlorosis, purple leaf of cabbage, and late maturity (picture 2.13.). Although, 90 kg N/ha, 40 kg P/ha, and 74 kg K/ha as 19-19-19 fertilizer was directly applied to the crop rows, the fertilizer was not enough to support plant growth of crops in LM plots. In our experiments, N fertilizer may have not been supplied frequently enough to support crop growth and high yield in LM plots. In contrast, the BG crops grew well and had higher yields than LM plots because of adequate N supply. In the BG plots, crops showed symptoms that they were receiving enough N with plants having dark green leaves and vigorous growth for both cabbage and zucchini (visual

observation, picture 2.13). In addition, a previous study on broccoli transplants was shown to be very sensitive to nutrient competition with the LM plants during the early establishment phase of the crop cycle (Leary, 1999). Thus, it can be suggested that in this experiment, the cabbage and zucchini transplants in the LM plots suffered from nutrient deficiency in the early establishment and growth phases due to competition with piligrass plants. A detailed advanced study and discussion about nutrients deficiency in LM plots compare to BG plots can be seen at next chapter (chapter III).

Weed control

The piligrass LM treatment successfully suppressed weeds compared to the conventional BG treatment. Previous studies have shown that LM biomass can reduce weed suppression (Sainju & Singh, 1997; Hartwig & Ammon, 2002; Hooks & Johnson, 2004; Teasdale, Beste, & Potts, 1991). The piligrass mulch completely covered the ground around and was able to suppress weed growth. In addition, the LM displaced weeds by competing for moisture, nutrients, light, and by modifying the microenvironment (Biazzo & Masiunas, 2000). In the BG plots, weeds covered the entire experimental area, while, weeds in the LM plots were small and were mostly concentrated in crop rows due to water supplied by the drip irrigation system. However, both plots required similar time to remove weeds.

Insect population

The piligrass LM system provided habitat for insects including pests and beneficial insects. The piligrass LM had a higher counts and number of species for cabbage and zucchini growing in both wet and dry seasons. There were 15 dominant insects consisting of 2 beneficial insects and 13 pests in LM and BG plots. The beneficial insects were lynx spider (*Aranae*) and ground beetle (*Carabidae*) (Hartwig & Ammon, 2002; Hooks & Johnson, 2004). Lynx spider was a predator for cabbageworm and winged-fly bug (Chaetopsis sp.) (Hartwig & Ammon, 2001; visual observation) (picture 2.10). Furthermore, ground beetle is a predator for caterpillars and cabbage maggot (Schooley, 2005; Finch & Collier, 2007.). Others have reported higher numbers of beneficial insects in LM plots (Hartwig & Ammon, 2002, Kuepper, G., 2001). Most of the pests found were

within the Diptera order which are mostly flies found in grass fields. It can be concluded that piligrass recruited flies, but also natural enemies.

Pest and disease damage

The piligrass used as a LM system successfully reduced plant damage, fruit damage, and plant mortality of cabbage and zucchini caused by pests, diseases, and rainy weather. Exposed soil surfaces in the BG conventional plots promoted the spread of viruses by pest vector from one plant to another. Pests such as a cabbage worm, cabbage looper, diamondback and zucchini pests were serious problems for young transplants of both crops. The piligrass LM protected these young transplants by acting as a barrier plant that successfully protected the main crops from the spread of pests and diseases. A study in Hawai'i showed that LMs can be a useful tool in controlling multiple pest complexes in zucchini, as barriers for non-persistent viruses (NPVs) (Hooks *et al*. 1998; Hooks & Wright, 2008; Manandhar & Hooks, 2008). Living mulches have also been shown to prevent the induction of disease due to soil splash from the ground (Leary & DeFrank, 2000). In this experiment, based on visual observation, LMs also prevented plant damage caused by soil erosion. Living mulch protects the soil from soil erosion by reducing the rain drop impact (Mulumba & Lal, 2008).

Other affecting factors

In addition, a recent study on winter rye LMs found that the growth and productivity of zucchini squash was reduced most likely from the effects of allelopathy (Walters & Young, 2008). Therefore, the evaluation the effects of allelopathy from piligrass LM and BG plots had been done in this experiment to try to elucidate why there was a reduction in plant growth and yield in the LM plots. The study results and discussion can be seen in the next chapter (chapter III).

The reduction of crop yields in the LM plots may also have been due to the effects of shading during the establishment phase of crop growth. The crops that experienced the effects of shading had similar symptoms as the crops grown with the LM such as stunting and lighter leaf color, thus it could be assumed that the crops were suffering due to

competition for light. A previous study found that the reduction of broccoli yield in a LM treatment was caused by the shading of young plants by *Cenchrus ciliaris* (buffelgrass) (Leary, 1999). During the vegetative growth phase, young plants need sufficient solar radiation for the processes of carbon assimilation and photosynthesis (Leary, 1999). Hartwig & Ammon, (2002) found that the mechanical mowing or spray applications to the LM will physically block photosynthesis and reduce LM growth. Maintaining a minimum height of the LM is important to minimize competition for light between the LM and crop plants. Even though, piligrass was mowed and stunted 2 to 3 times during each growing season of our experiment, competition for light was still an obstacle for crops. On the other hand, piligrass mulch can prevent evapotranspiration at early transplanting stages and keep soil moisture high. Finally, it can be suggested that cabbage and zucchini plant growth in the LM system was inhibited by the effects of shading, producing late maturity in crops. Therefore, evaluation of soil moisture and soil temperature in piligrass LM and BG treatments had been recorded during growing seasons. The study results and discussions about physical soil can be seen at chapter III.

2.6. Conclusions and recommendations

After conducting experiments using piligrass as a LM for tropical vegetable crops, the experiments showed that piligrass as a LM provided both advantages and disadvantages to tropical vegetable crops. In summary, the advantages of piligrass as a LM were: 1) piligrass LM consistently reduced weed biomass, 2) piligrass LM provided habitat for insects, thus it increased total population and biodiversity of insects, and 3) piligrass LM reduced plant and fruit damage due to pests, diseases, and heavy rainy. Nevertheless, BG system had higher yield for all crops both growing seasons.

Thus, piligrass could be used as a LM because it was successful for weed, pest, and disease control and supports integrated pest management (IPM) practices in tropical vegetable crops. Developing piligrass in an agriculture system in Hawaii is a way to conserve a native plant. However, understanding the dynamic interactions of piligrass as a companion plant with tropical crops should be considered since it significantly reduced crop yield.

In the following chapter III discuss: what factors are contributing to the crop yield reduction in piligrass LM. The six factors studied were 1) nutrient deficiency; 2) water competition; 3) soil physical properties; 4) soil temperature; 5) substances that inhibit plant growth in the soil; or 6) combinations of 1 through 5.

2.7. Literature citations

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Tables

A. Marketable yield

Cabbage growing season in fall 2008 and spring 2009

Table 2.1. The marketable yield of cabbage in fall 2008 and spring 2009 in the piligrass living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant difference (P<0.05) between means of treatments.

Treatments	Total head (per ha)		Total weight (kg/ha)		Average Weight/head (kg)		Av. Diameter of head (cm)	
	Fall 2008	Spring 2009 [np)]	Fall 2008	Spring 2009	Fall 2008	Spring 2009	Fall 2008	Spring 2009
LM	14 027	8 320	7 048	4 796	0.5	0.6	14.0	15.2
BG	14 682	18 353 *	11 286	16 767 *	0.8 *	0.9	14.7	17.4 *

[np)] non-parametric analysis.

Table 2.2. Total marketable cabbage yield per plot in spring 2009 occurred three harvest dates in the piligrass living mulch (LM) and bare ground (BG) treatments. Yield data was collected from the two middle rows (10 plants/row). Symbol (*) indicates a significant difference (P<0.05), (**) highly significant difference (P<0.01) between means of treatments.

Treatment	Harvest I (56 DAT)		Harvest II (62 DAT)		Harvest III (68 DAT)	
	Total head/ plot	Total head weight (kg/plot)	Total head/ plot	Total head weight (kg/plot)	Total head/ plot	Total head weight (kg/plot)
LM	2	1.0	3	1.9	4	1.9
BG	15 **	14.6 *	3	1.9	1	0.5

Zucchini growing season in summer 2009

Table 2.3.a. **Marketable yield** of zucchini at five harvest dates in summer 2009 in the piligrass living mulch (LM) and bare ground (BG) treatments. Yield data was collected from the two middle rows (5 plants/row). No significant difference between treatments.

Trt.	30 DAT		35 DAT		39 DAT		45 DAT		52 DAT	
	Total fruits/ plot	Total weight kg/plot	Total fruits/ plot	Total weight kg/ plot	Total fruits/ plot	Total weight kg/plot	Total fruits/ plot	Total weight kg/ plot	Total fruits/ plot	Total weight kg/ plot
LM	2	0.5	2	0.4	0	0	1	0.1	0	0
BG	5	2	3	2	0	0	0	0	0	0

Table 2.3.b. **Non-marketable** yield of zucchini at five harvest dates in summer 2009 in the piligrass living mulch (LM) and bare ground (BG) treatments. Yield data was collected from the two middle rows (5 plants/row). No significant difference between treatments.

Trt.	30 DAT		35 DAT		39 DAT		45 DAT		52 DAT	
	Total fruits/ plot	Total weight kg/plot	Total fruits/ plot	Total weight kg/ plot	Total fruits/ plot	Total weight kg/plot	Total fruits/ plot	Total weight kg/ plot	Total fruits/ plot	Total weight kg/ plot
LM	0	0	2	0.4	1	0.2	1	0.3	3	0.4
BG	2	0.5	1	0.5	1	0.3	2	0.7	2	0.7

Table 2.3.c. **Total number of zucchini fruits** at five harvest dates in summer 2009 in the piligrass living mulch (LM) and bare ground (BG) treatments. Yield data was collected from the **four rows** (5 plants/row) include marketable (M) and non-marketable (NM) yields.

Trt.	Harvest I		Harvest II		Harvest III		Harvest IV		Harvest V		Total
	M	NM	M	NM	M	NM	M	NM	M	NM	
LM	5	0	4	4	1	2	2	2	0	5	25
BG	7	3	6	4	1	5	0	4	0	4	34

Table 2.3.d. **Total weight in kg** of zucchini fruits at five harvest dates in summer 2009 in the piligrass living mulch (LM) and bare ground (BG) treatments. Yield data was collected from the **four rows** (5 plants/row).

Trt.	Harvest I		Harvest II		Harvest III		Harvest IV		Harvest V		Total
	M	NM	M	NM	M	NM	M	NM	M	NM	
LM	1.1	0.1	0.7	1.1	0.1	0.3	0.2	0.7	0	1.1	5.4
BG	3.9	0.5	3.6	1	0.1	1.3	0.01	1	0	1.1	12.51

Table 2.4. Total marketable yield of zucchini in summer 2009 in the living mulch (LM) and bare ground (BG) treatments. Total fruit and total fruit weight were significantly higher then in BG treatment. Yield data was collected from the two middle rows (5 plants/row).

Treatments	Total fruit (per ha)	Total fruit weight (kg/ha)	Average weight/ fruit (kg)	Av. length of fruit (cm)
LM	2 936	930	0.3	20.2
BG	6 607 *	3 768 *	0.6	20.6

B. Weed control

Table 2.5. Weed control during **cabbage** growing season in fall 2008 and spring 2009 within the living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant difference (P<0.05), (**) highly significant difference (P<0.01) between means of treatments.

Treatments	Time to return weed free status (hour/ha)		Weed biomass (gram/plot)	
	Fall 2008 (15 DAT)	Spring 2009 (33 DAT)	Fall 2008 (15 DAT)	Spring 2009 [t)] (33 DAT)
LM	29.7	36	215	275
BG	20.3	81.3	767 *	1 387 **

[t)] transformation data

Table 2.6. Weed control during **zucchini** growing season in winter 2008 and summer 2009 within the living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant difference (P<0.05), (**) highly significant difference (P<0.01) between means of treatments.

Treatments	Time to return weed free status (hour/ha)		Weed biomass (gram/plot)	
	Winter 2008 (28 DAT)	Summer 2009 (55 DAT)	Winter 2008 biomass (28 DAT)	Summer 2009 (55 DAT)
LM	13.4	74.1	57.3	400
BG	22.4	156.8	340.5 *	1630 **

C. Insect collections

Insects collection during cabbage growing season in fall 2008

Table 2.7. Description of dominant insects collected by net at 48 DAT of cabbage during cabbage growing season in fall 2008 in the piligrass living mulch (LM) and bare ground (BG) treatments

Common name	Order	Family	Scientific name
Lynx spider	Araneae	Oxyopidae	*Oxyopes salticus*
Ground beetle	Coleoptera	Carabidae	*Carabids spp.*
Grasshoppers	Orthoptera	Tettigoniidae	*Katydids spp.*
Cabbageworm adult (butterfly)	Lepidoptera	Pieridae	*Pieris rapae*

Table 2.8. Dominant insects collected by net at 48 DAT of cabbage in fall 2008 in the piligrass living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant difference ($P<0.05$) between means of treatments.

Treatment	Total number of insects/plot	Total number of insect species/plot
LM	23 *	4
BG	3	2

Insect collection during cabbage in spring 2009

Table 2.9. Description of dominant insects collected by sticky traps and net during cabbage growing season in spring 2009 within piligrass living mulch and bare ground treatments

Common name	**Order**	**Family**
Ants	Hymenoptera	Formicidae
Cabbage root maggot	Diptera	Anthomyiidae
Ceroxys latiusculus	Diptera	Ulidiidae
Chaetopsis	Diptera	Ulidiidae
Flea beetles	Coleoptera	Chrysomelidae
Grasshopper	Orthoptera	Tettigoniidae
Hairy maggot blowfly	Diptera	Calliphoridae
Lygus bug	Hemiptera	Miridae
Lynx spider	Araneae	Oxyopidae
Whiteflies	Homoptera	Aleyrodidae
White butterfly	Lepidoptera	Pieridae

Table 2.10. Dominant insects collected by sticky traps and net during cabbage growing season in spring 2009 within piligrass living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant difference (P<0.05), (**) highly significant difference (P<0.01) between means of treatments.

Treatments	Total number of insects/ plot		Total number of insect species/ plot	
	Sticky traps (21 DAT)	Net (33DAT)	Sticky traps (21 DAT)	Net (33DAT)
LM	203.4	23 *	10 *	8 **
BG	226.8	11	8	4

Insect observation during zucchini growing season in winter 2008

Table 2.11. Total zucchini plants with Lynx spiders at 15 DAT of zucchini in winter 2008 in the piligrass living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant difference ($P<0.05$) between means of treatments.

Treatment	Total number of plant with spider per plot
LM	14 *
BG	2

Insect collection during zucchini growing season in summer 2009

Table 2.12. Description of dominant insects collected by net at 52 DAT of zucchini in summer 2009 in the piligrass living mulch and bare ground treatments.

Common name	Order	Family
Lynx spider	Araneae	Oxyopidae
Squash vine borer	Lepidoptera	Sesiidae
Squash bug	Hemiptera	Coreidae

Table 2.13. Dominant insects collected by net at 52 DAT of zucchini in summer 2009 in the piligrass living mulch (LM) and bare ground (BG) treatments. No significant difference between treatments.

Treatment	Total number of insects/plot	Total number of insect species/plot
LM	13	4
BG	5	2

D. Pest and disease damage

Table 2.14. Total number of plant damage due to insects and head damage of cabbage due to diseases at 55 DAT of cabbage in fall 2008 in the piligrass living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant difference ($P<0.05$) between means of treatments.

Treatment	Total cabbage plant damage/ plot	Total head cabbage damage/ plot
LM	2	0
BG	8 *	6 *

Table 2.15. Total number of dead plant of zucchini due to pests and disease at 28 DAT of zucchini in winter 2008 in the piligrass living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant difference ($P<0.05$) between means of treatments.

Treatments	Total number of dead plant per plot
LM	3
BG	15 *

Table 2.16. Total number of dead plant and percentage of infected zucchini plants per plot at 52 DAT of zucchini in summer 2009 in the piligrass living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant difference ($P<0.05$) between means of treatments.

Treatments	Number of plant-mortality due to virus per plot	% Infected plant per plot
LM	0	78.75
BG	3	100 *

Figures

Insect collection during cabbage growing season in fall 2008

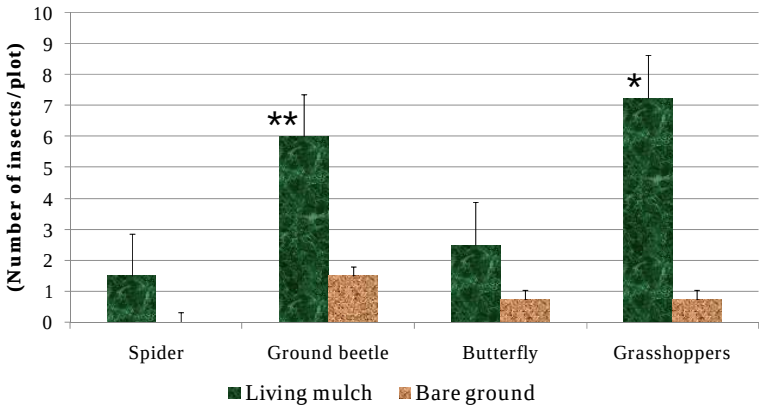


Figure 2.1. Total insects of four dominant insect species per plot collected by net at 48 DAT of cabbage in fall 2008 from entire the piligrass living mulch (LM) and bare ground (BG). Symbol (*) indicates a significant different (P<0.05) and (**) highly significant difference (P<0.01) between mean of treatments

Insect collected during cabbage growing season in spring 2009

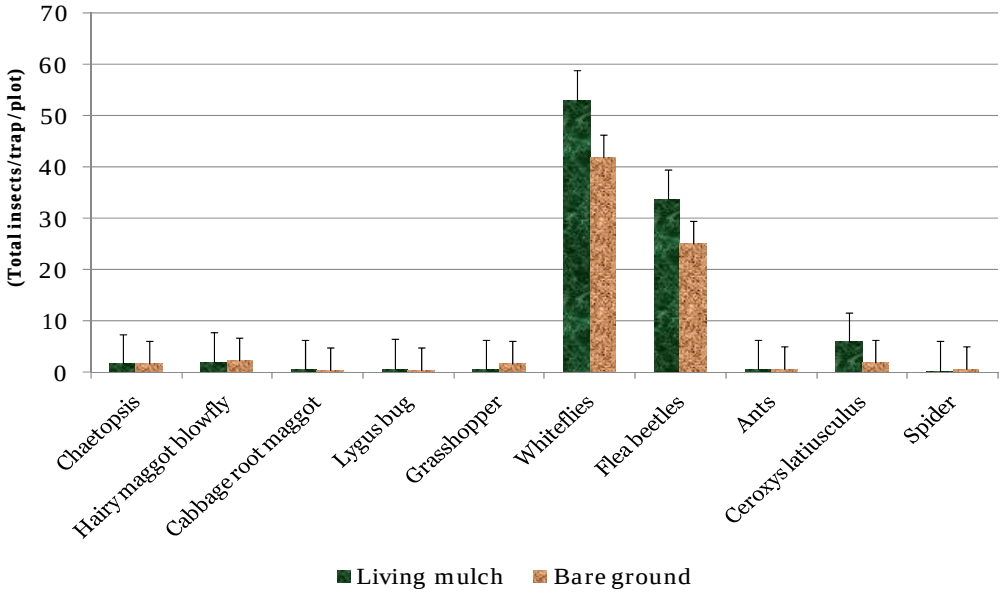


Figure 2.2. Total population of ten dominant insects collected by sticky traps (97.5 cm^2) in crop rows at 21 DAT of cabbage in spring 2009. Mean of insect per trap each plot no significant

difference between piligrass living mulch (LM) and bare ground (BG) treatments (transformation data).

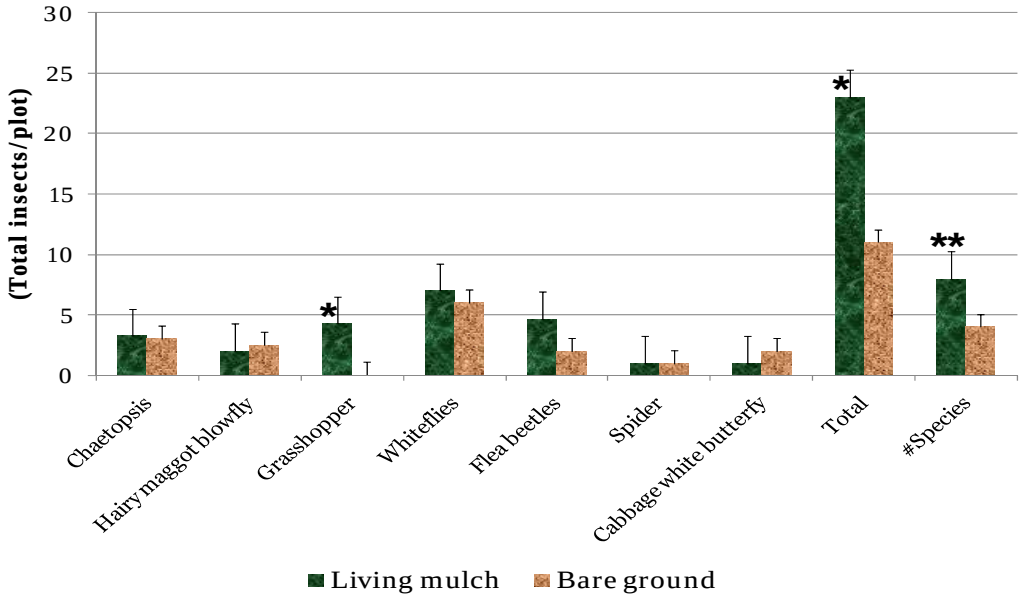


Figure 2.3. Total insect population of 7 dominant insect species collected by net at 33 DAT of cabbage in spring 2009 from entire piligrass living mulch (LM) and bare ground (BG) treatments. Symbol (*) indicates a significant different (P<0.05) and (**) highly significant difference (P<0.01) between mean of treatments (transformation data).

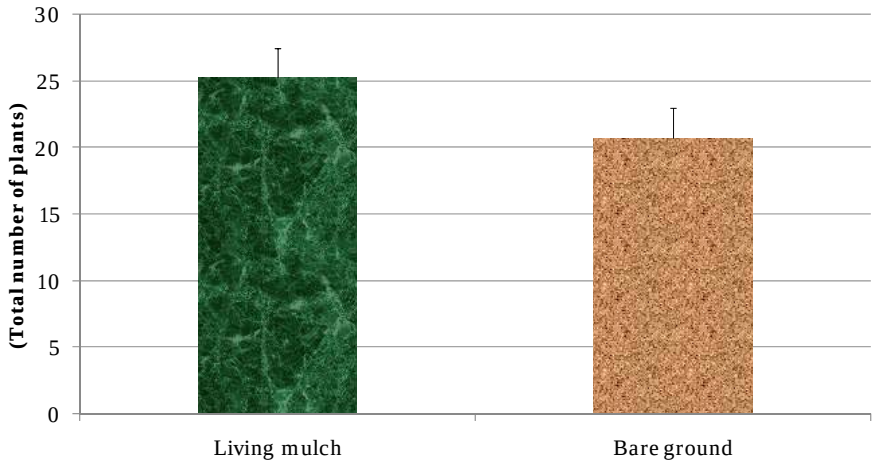


Figure 2.4. Total number of plants with spider webs at 56 DAT of cabbage in spring 2009.

Insect collected during zucchini growing season in summer 2009

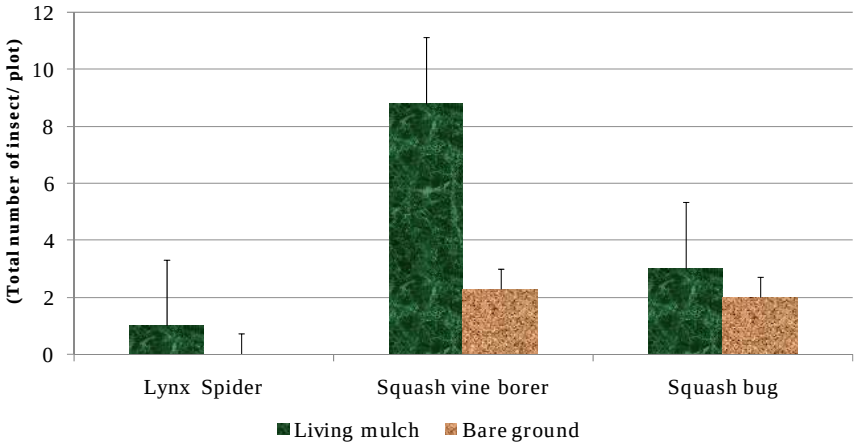


Figure 2.5. Total insect of three dominant insect species collected by net at 52 DAT of zucchini in summer 2009 from entire piligrass living mulch (LM) and bare ground (BG) treatments. Data reported no significant different.

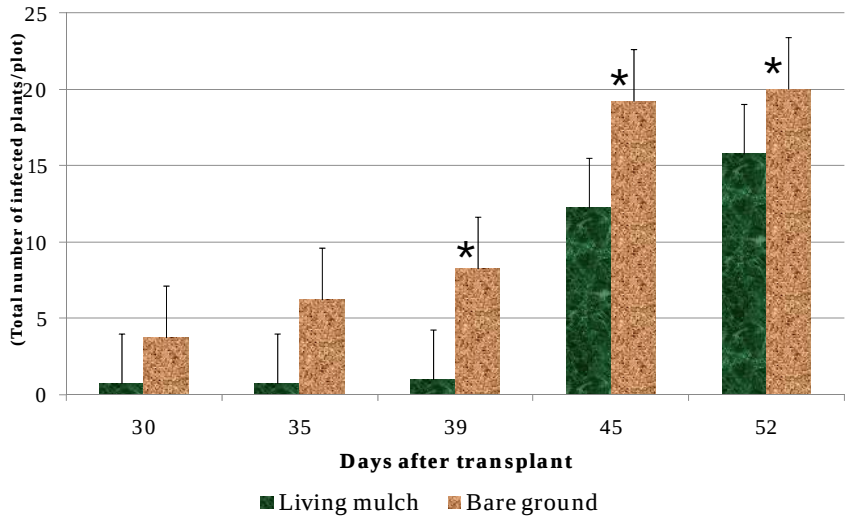
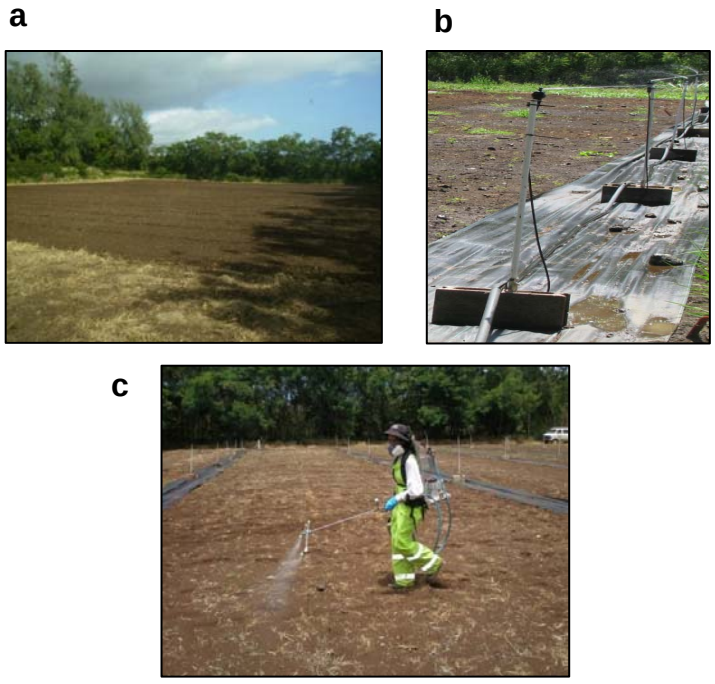


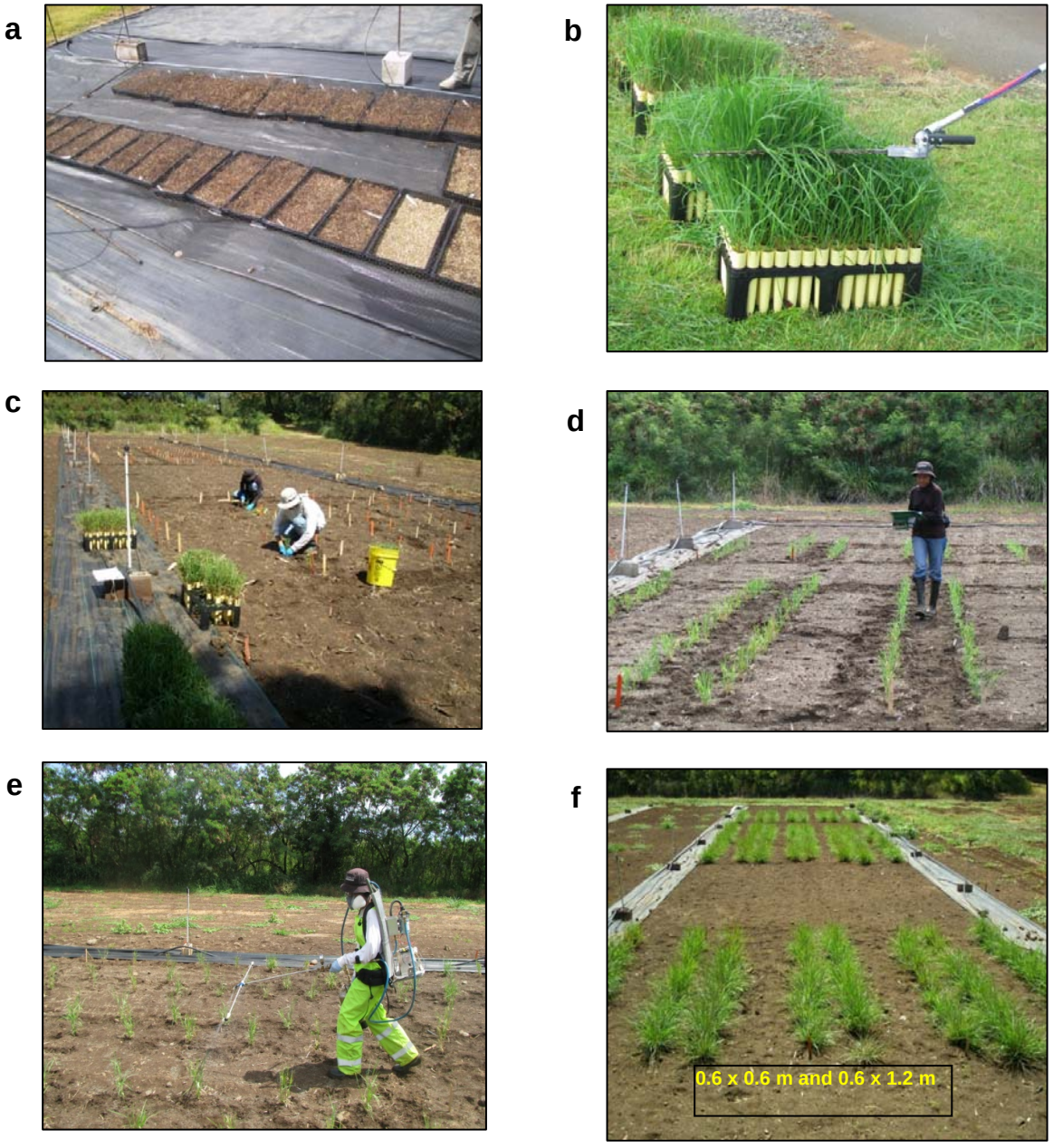
Figure 2.6. Total zucchini plant damage due to zucchini yellow mosaic virus (ZYMV) in summer 2009. Symbol (*) indicates a significant different ($P<0.05$) between mean of treatments.

Pictures

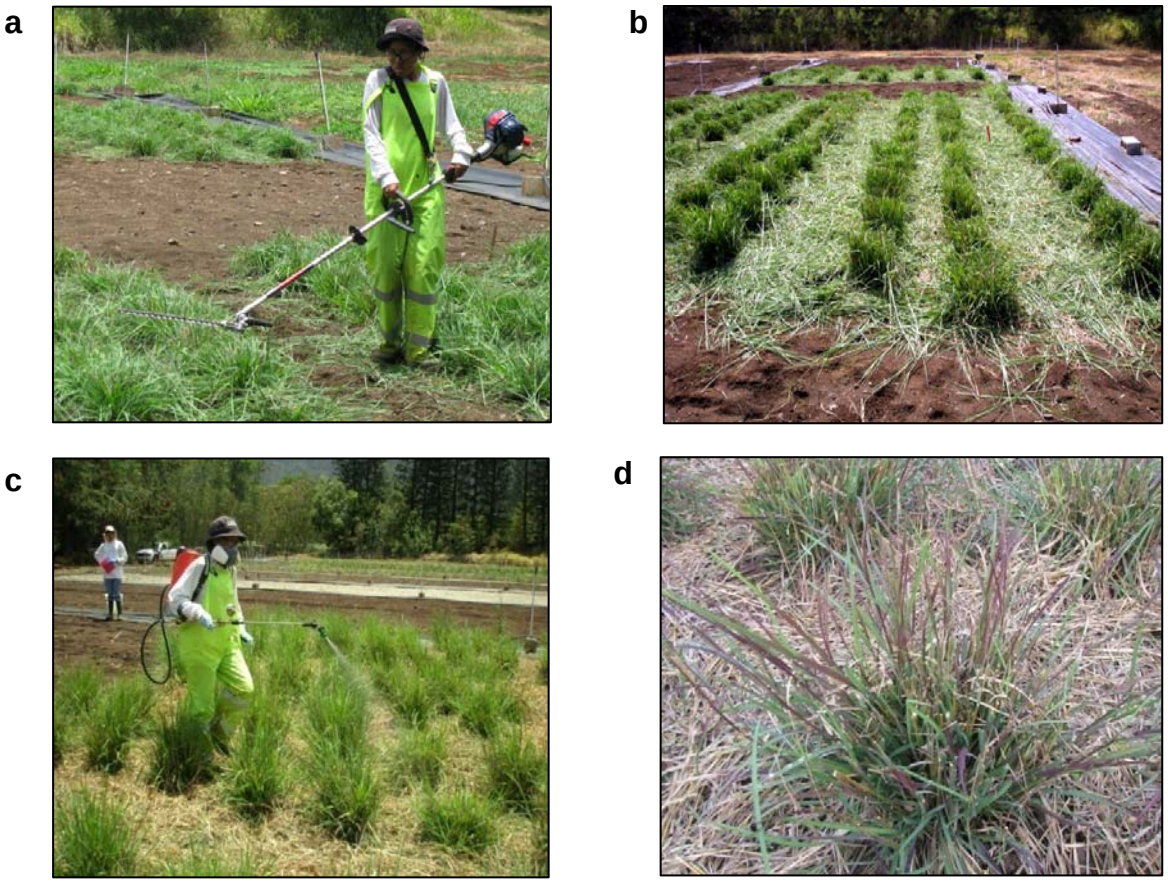
Picture 2.1. The location of field experiment in Waimanalo research station, CTAHR, Univ. of Hawaii at Manoa. The experimental site has Heleiwa silty clay (fine, mixed, isoperthermic Typic Haplustoll).



Picture 2.2. Field preparation activities at 2 months prior to planting piligrass living mulch: a) cleaning the field; b) Installed overhead irrigation; c) spraying pre-and pos-emergence herbicides.



Picture 2.3. Piligrass planting and establishment in the field (February to June 2008): a) seeds germination in trays at Magoon-UHM; b) cutting upper leaves of piligrass prior to transplanting; c) transplanting piligrass to the field; d) fertilizing 112 kgN/ha as 18-0-18; e) spraying pre-emergence oxyflourfen 0.45 kg a.i./ha 1 week after transplanting; f) growing the piligrass with space 0.6 x 0.6 m within rows and 0.6 x1.2 m between rows.



Picture 2.4. Piligrass living mulch management including: a) mowing using sickle bar mower; b) the piligrass biomass laid down on the ground to cover the soil surface; c) stunting the piligrass using fusiladeDx® (fluazifop 0.14 kg a.i./ha); d) the purple leaves and stunted plant of piligrass caused by fluazifop reaction.

Picture 2.5. Injection fertilizer 90 kg N/ha as 19-19-19 within the drip irrigation Dosatron International DI 16 injection

Picture 2.6. Collecting insects by net at 48 DAT of cabbage in fall 2009 with time 50 sec. walking/plot

Picture 2.7. Cabbage plant damage due to pests: looper and cabbage worm in fall 2008

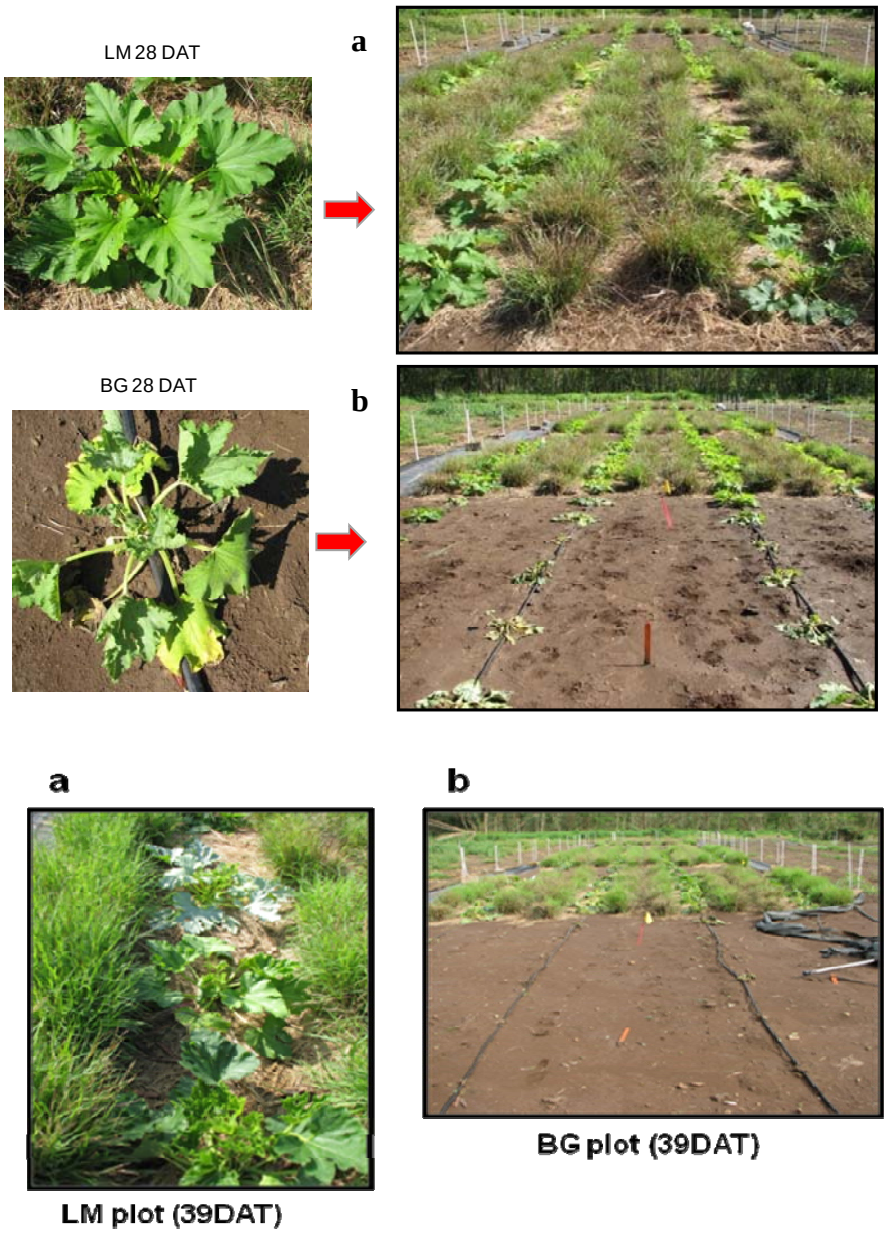
Picture 2.8. Head cabbage damage due to diseases in fall 2008

a. Living mulch plot

b. Bare ground

Picture 2.9. Total yield of cabbage at 55 DAT in fall 2008, a) representative cabbage yield from piligrass living mulch. Total yield treatment block IV with better quality of head, b) representative cabbage yield from bare ground treatment block IV with head damage.

Picture 2.10. Beneficial insect, Lynx spider (*Oxyopes salticus*) catching a winged-fly bug (*Chaetopsis*) on zucchini leaf



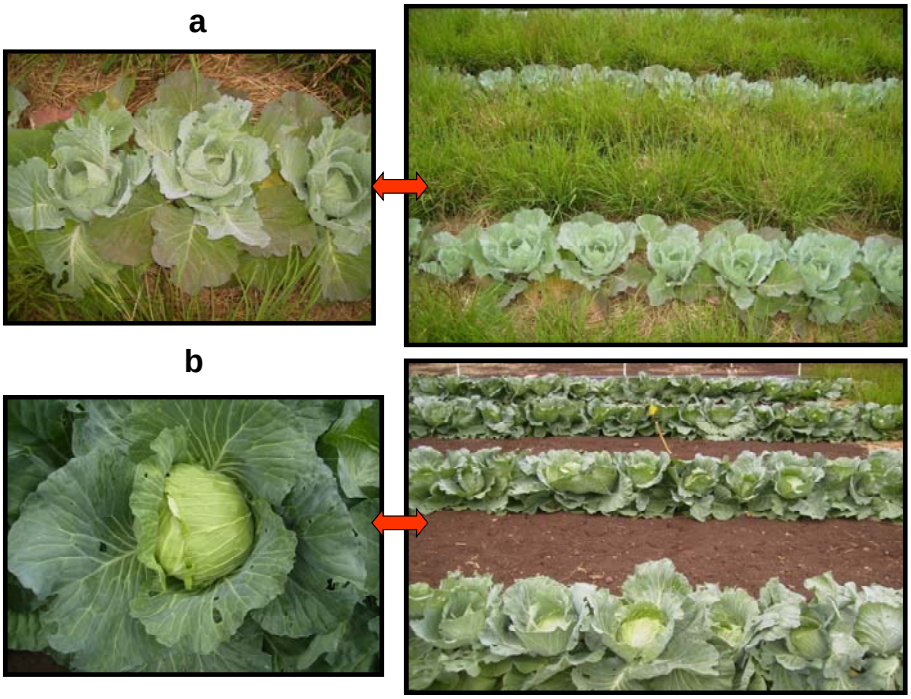
Picture 2.11. The condition of Zucchini in LM and BG plots at 28 and 39 DAT of zucchini in winter 2008; a) zucchini growth normally in piligrass living mulch treatment, b) zucchini plant damage in bare ground treatment due to pests and disease in heavy rainy weather

Weeding, 33 DAT

Mowing II 56 DAM1 (42 DAT)

Mowing III, 27 DAM2 = 69 DAT

Picture 2.12. Hand weeding, and mowing the piligrass during cabbage growing season in spring 2009



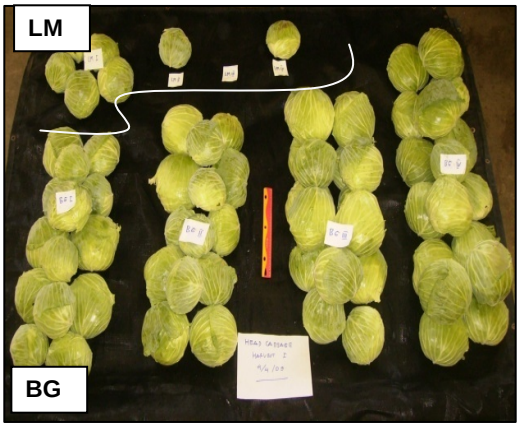
Picture 2.13. The condition of cabbage in LM and BG plots at 56 DAT of cabbage in spring 2009. a) Stunted plant, purple and light green color of cabbage leaves in piligrass living mulch treatment, b) vigorous plant and dark green color of cabbage in bare ground treatment.

a

b

Picture. 2.14. a) Insect collected by sticky trap (13 x 7.5 cm) at 21 DAT of cabbage in spring 2009; b) Lynx spider (*Oxyopes salticus* and its web when observation at 56 DAT of cabbage in spring 2009

Measuring marketable yield
Diameter ≥ 13 cm



Harvest I

Harvest II

Harvest III

Picture 2.15. Marketable yield of cabbage in spring 2009. Marketable yields have diameter greater or equal to 13 cm. In harvest dates I (56 DAT), II (62 DAT), and III (68 DAT) cabbage yield in piligrass living mulch (LM) treatment lower than in bare ground (BG) conventional treatment. Cabbage growth in piligrass LM had delay maturity. Yield data was collected from the two middle rows (10 plants/row).

Picture 2.16.The condition of zucchini in living mulch (LM) and bare ground (BG) treatments at 39 DAT of zucchini in summer 2009. a) Zucchini in BG treatment suffered due to Zucchini Yellow Mosaic Viruses (ZYMV); b) zucchini growth normally in LM with not much damage; c) The symptoms of ZYMV for plant: yellow mosaic, malformation, necrosis, and plant stunting; and for fruits: distortion, deformation and blistering.

Picture 2.17. Total Zucchini yield in living mulch (LM) and bare ground (BG) treatments in summer 2009. The yield picture were taken for all yields from the four crop rows (5 plants/row) include (marketable and non marketable yield) with fruit length $\geq$ 13 cm. Zucchini yield in BG plots was higher than in LM plots. Fruits damage occurred in both LM and BG treatments.

CHAPTER III

THE EFFECT OF PILIGRASS (*HETEROPON CONTORTUS*) LIVING MULCH SYSTEM ON CHEMICAL AND PHYSICAL PROPERTIES OF SOIL

3.1. Abstract

A study examining the effects of piligrass as a living mulch (LM) on the chemical and physical properties of soil was conducted at Magoon greenhouse and St. John laboratories at the University of Hawaii at Manoa from fall 2008 to fall 2009. Field research was conducted to characterize crop, weed, and pest response to piligrass living mulch (LM) and conventional bare ground (BG) cultivation systems with four blocks. After one year, piligrass LM soil had significantly higher levels of total N (nitrogen) and NH_4^+ (ammonium) with similar levels of $NO3^-$ (nitrate). However, the N of zucchini plant tissues in LM was significantly lower than in BG plots. Total C (carbon) in LM soils was significantly higher than BG soil at a 0-2 cm depth in crop rows. Nutrients (P (phosphor), K (potassium), Ca (calcium), and Mg (magnesium) and pH were similar in both LM and BG soils at 0-2 cm depth. The seed germination bioassay with 3 plant species did not detect any inhibitory substance in the LM and BG plots. A physical attribute of soil, water stable aggregates, was significantly higher in LM plots than in BG plots at 0-2 cm. Soil moisture was not significantly different in both LM and BG plots. The piligrass LM had reduced soil temperature compared to the BG conventional plots over 9 months of monitoring. Thus, piligrass LM had increased total carbon, total N, $NH4^+$, and soil aggregate stability. On the other hand, piligass LM inhibited crop growth and reduced crop yields due to N-immobilization and cooler soil temperature.

3.2. Introduction

Living mulch is a cover crop that grows directly with the vegetable crops in a reduced tillage system. Competition for nutrients, water, and light between the LM and the main crop is a serious problem in agricultural systems because it can reduce the growth and yield of vegetable crops (Biazzo & Masiunas, 2000). Our field experiment found that cabbage and zucchini yields in the piligrass LM plots were lower compared to the BG plots. On the

other hand, Blanco-Canqui & Lal (2007) indicated that crop residue retention is important for sequestering soil organic carbon (SOC), controlling soil erosion, and improving soil quality. Long-term (10-years) study on straw mulching increased SOC concentration and improved near-surface soil aggregate properties.

H. contortus (Piligrass), is a perennial tussock grass commonly found in tropical and subtropical areas (Carino, 1999). The tussock grasses play important roles in the capture and control of scarce stability of soil at a large spatial scale (Northup, et al., 1999). The perennial LMs have benefits for soil attributes such as erosion control, soil structure environment and maintenance, organic matter augmentation, carbon dioxide sequestration, and rhizosphere development (Hartwig & Ammon, 2002; Leary & DeFrank, 2000).

Soil temperature, soil moisture and aeration influence N availability in the soil in terms of microorganism activities during the decomposition process (Cook & Ellis, 1987). Hartwig and Ammon (2002) explained that LM increased soil organic matter and N availability in soils. However, immobilization of N occurs when NH_4^+ and NO_3^- present in the soil is used by the growing microbes to build proteins and break down soil organic matter (SOM) to release available N (Hazelton & Murphy, 2007).

In addition, the visual symptoms of poor plant health might be associated with growth suppression due to allelochemicals (Inderjit & Weiner, 2001). In agricultural weed management, exploiting allelophaty can help to reduce weeds and other pests by direct interactions or through the use of natural herbicides (Inderjit & Mukerji, 2006; Walters & Young, 2008). Allelophaty is defined as a plant chemical interference from of one species to another by releasing a toxic substance to the environment (Inderjit & Mukerji, 2006). The toxicity from the LM plant could influence weed abundance, but also have negative impacts on the cash crops. Allelopathy has agricultural implications because it can reduce plant growth and crop productivity. Phenolic compounds are important intermediates in the formation of humus and responsible for stabilizing nitrogen in organic forms in soils (Whitehead et al., 1982). However, some monomeric phenolics are toxic to seed germination and inhibit microorganism growth (Whitehead et al., 1982; Trifonova et al., 2008). Inderjit & Weiner, (2001) explained in detailed that phenolics inhibit nitrification (oxidation of NH_4^+ to NO_2^- (nitrite)) influencing a plant access to soil nutrients.

There are several methods to examine the phytotoxity in the soil. Bioassay is a simple seed germination to test the toxicity of soils and plant extracts. Incorporating activated charcoal is also used to examine inhibitory compound in the soil (Callaway & Ashehough, 2000). Phenolic analysis has been used to examine growth suppression attributed to the decomposition of plant tissues. Phytotoxic Phenolic compounds in plant tissues have been identified as 2-methoxyphenol, 2,6-dimethoxyphenol, 2-furaldehyde (furfural), pyrrole-2-carboxaldehyde and furan-2-methanol (Trifonova et al., 2008). Phenolic compounds released to the soil during decomposition include p-hydroxybenzioc, vanillic, p-coumaric and ferulic acids (Chandramohan et al., 1973; Whitehead et al., 1982). Inderjit & Weiner, (2001) showed that the phytotoxicity of phenolic acid compounds was influenced by pH, mineral nutrition, C-sources present, light and temperature.

Aggregate stability is the resistance of soil aggregates to breakdown when water and mechanical manipulation are applied. The stability of aggregates is influenced by soil texture, type of clay, extractable iron, extractable cations, the amount and type of organic matter present, and the type and size of the microbial population (USDA –NRCS, 1996). Stable aggregates are critical to erosion resistance, water availability, and root growth. Soils with stable aggregates at the soil surface are more resistant to water erosion than other soils. This is due to soil particles being less likely to detach and the higher rate of water infiltration (USDA-NRCS, 2001). If the bare soil had been exposed to rain, any disintegration of aggregates can be used as an indication of the stability of soil structure. The structure value is related to SOM, soil consistency, concentration of calcium in solution, the residual effect of grass, and crop yield (Betay, 2000). Brady and Weil (1996) reported that soil temperature is influenced by soil cover and especially by organic residues or other type of mulch placed on the soil surface. In periods of hot weather, the mulches keep the surface soil cooler than where no cover is present. In contrast, during cold weather the mulches moderate rapid temperature declines. Mulches tend to buffer extremes in soil temperature fluctuations.

This study aims to determine the influence of piligrass as a LM on the chemical and physical properties of soil in relation to crop growth and yield. Continuous reduction of crop yields in fall-winter and spring-summer seasons prompted hypotheses about the

effects of piligrass on the chemical and physical properties of soil. There are: 1) nutrient deficiency (N-immobilization), 2) water competition, 3) changes in the physical properties of the soil, 4) lower soil temperature, 5) an increase in secondary substances that inhibit plant growth in the soil, or 6) combinations of point 1 through 5.

3.3. Materials and methods

3.3.1. Soil sampling

Laboratory analyzes were conducted to determine changes of chemical and physical properties of soil in piligrass LM and BG plots. Soil samples were taken four times during the growing seasons in 2008 and 2009. On September 9, 2008, at 102 DAT of piligrass (12 DAT cabbage fall 2008), soil samples were collected from the field at 0-2 cm and 3-10 cm depth both crop and non-crop rows using a trowel. Half of the soil samples were put in plastic bags and kept in a cool room before analyzing for total C concentration. The other samples were analyzed for WAS (water aggregate stability) and SM (soil moisture). On October 10, 2008, approximately 125 DAT of piligrass, eight data loggers were put in the soil at a depth of 10 cm within crop and non-crop rows to record soil temperature in degree Celsius (^{o}C). Each sensor was put in small plastic bags 5 cm wide and left in the soil for approximately 9 months. On June 26, 2009, the data loggers were removed from the field at 386 DAT of piligrass.

On April 26, 2009 approximately 325 DAT of piligrass (after growing cabbage spring 2009), soil samples were taken again at a depth of 0-2 cm from the crop rows using a trowel. The soil samples were immediately analyzed in the lab to determine soil nutrients such as total N, C, P, K, Ca, Mg, pH, and subjected to seed germination bioassay tests. On June 12, 2009 at 46 DAT of zucchini in summer 2009, soil samples were taken from depths of 0-5 cm and 15 cm away from drip irrigation tubing using a soil core sampler to determine the ability of activated charcoal to mitigate inhibitory soil properties. Four sub samples were taken for each block (figure 3.1).

In addition, on July 1, 2009 at 390 DAT of piligrass (after growing zucchini in summer 2009), the last round of soil samples were taken from crop rows at depths of 0-2

and 3-10 cm using a soil core sampler. The soil samples were used to analyze WAS, SM, phenolics, NH_4^+, and NO_3^- in crop row. The soil samples were taken from every plot on piligrass LM and BG treatment, 4 subsamples per plot. Soils were kept in plastic bags and stored in either a dry or cool room depending on type of analyzes being performed.

3.3.2. Plant sampling

Plant tissue of piligrass was collected at 68 DAT of piligrass to determine plant tissue nutrient composition. About ten plants of piligrass were cut at 30 cm along the length of the shoot with samples composed of both leaf and stem tissues, and stored in brown paper bags. Immediately after cutting the grass from the field, the samples were sent to Agriculture Diagnostic Service (ADS) center at the College of Tropical Agriculture and Human Resources (CTAHR) at the University of Hawaii at Manoa. ADS (plant diagnostic lab.) analysis determined plant tissue for essential nutritional components such as N, P, K, C, Ca, Mg, Na, Fe, Mn, Zn, Cu, and B of the piligrass. In addition, piligrass aboveground biomass was collected twice to measure dry biomass at 102 DAT of piligrass (after the 2^{nd} mowing) and 378 DAT of piligrass (after the 7^{th} mowing). Fresh piligrass biomass was collected from a square 0.09-m2 area in the field. Four sub samples of piligrass were taken for every plot and dried in an oven at 48^oC for 5-6 days.

At 46 DAT of zucchini in summer 2009, zucchini leaves were collected for plant tissue analysis of N levels. Zucchini leaves of similar maturity were cut from the midsection of plant. The leaves were kept in clean plastic bags before analyzing at ADS (plant diagnostic lab.) (picture 3.2).

3.3.3. Chemical properties of soil

a. Soil nutrients analysis

   Total soil nutrient concentrations of N, NH_4^+, NO_3^-, C, P, K, Ca, Mg and soil pH were analyzed at ADS (soil diagnostic lab.) in June 2009 to determine nutrient composition of the soil. Total C concentration was examined twice at 102 and 325 DAT of piligrass. Total N, P, K, Ca, Mg concentrations and pH were evaluated at 325 DAT of piligrass.

In addition, NH_4^+ and NO_3^- were determined at 390 DAT of piligrass at the end of the field experiment. ADS described the chemical analyses for soil extraction that used 2 M KCl to analyze NH_4^+ and NO_3^-; 1N NH_4OAc, pH 7.00 to analyze K, Ca, and Mg; and modified Truog 0.20N H_2SO_4, pH 2.02 to analyze P. Total N and C concentrations were determined by dry combustion using a LECO TrueSpec CN analyzer. Ammnoium and nitrate (NH_4^+ and $NO_{3)}^-$ levels were determined using a colorimetric analyzer (Easychem Plus discrete analyzer). Phosphorus (P) analysis also used the colorimetric analyzer and was performed using the Mo-Blue method. K, Ca, and Mg analyses were performed using ICP-OES (Perkin-Elmer Optima 7000 Dv). In addition, pH soil measurement used saturated paste and a pH meter (Fisher Accumet 805 MP). All values of measurements are expressed on an oven dried soil basis.

b. Bioassay test

A seed germination bioassay was conducted in a growth chamber. Bioassay was used to detect phytotoxic compounds soil from experimental plots. A randomized complete block design was used for the bioassay experiment. There were four blocks with three treatments: soil from LM plots, BG plots, and distilled water and moistened filtered paper. Blocking was used to reduce variation within the growth chamber. This bioassay used three plants i.e rye grass (*Secale cereale* L.), Manoa lettuce (*Lactuca sativa*), and cress (*Lepidium sativum*) (picture). Soils from the field were taken from a depth of 0-2 cm in crop row. Soil was sieved to remove rocks, roots and debris. Ten grams of 1-2 mm of soil was placed in 8 petri dishes. Ten grams of soil was covered with filter paper (Whatman#3, Whatman International) and hydrated with distilled water. Twenty seeds of rye grass and 10 seeds of Manoa lettuce and cress were placed in each petri dish and put in a growth chamber (figure 3.4). Seeds germinated inside the incubator (Percival Scientific, Inc., Perry, IA) with dark and light periods (12 hours each) as well as fluctuating day and night temperature (26^{o}C and 20^{o}C). Six days after germination, plant radicles (embryonic shoot and root length) were measured (picture 3.5).

b. Mitigating soil toxicity with charcoal

This study was conducted in a glass house at Magoon research and teaching facility at UHM. A factorial design used factors set as farming system (living mulch and bare ground) soils and levels of 85% activated charcoal (Co: control/ no charcoal and C1: 10% charcoal). Soil samples were taken from the field at 32 DAT of piligrass. Soils were sieved to remove rocks, roots, and other debris to get 5 mm of soil. Two hundred grams of soil was placed in 3 cells of tray for one treatment each block. Fertilizer was added at rate 168 kg N/ha as 21-0-0. Sweet corn cultivar 108 was used as an indicator plant and planted in cell trays. Levels of charcoal were randomly assigned to cells in trays. Three corn seeds were planted/cell and thinned to be one plant/cell. Seeds were grown in the glass house for 3 weeks. Corn germination and growth was used to determine if soil amendments of activated charcoal could alleviate the inhibitory nature of piligrass LM soils. Plant height and dry biomass were measured and recorded (picture 3.6).

c. Analysis of phenol in soil

Prussian blue assay (Stern, et al., 1996) method was used to determine the level of phenolic compounds in the soil. Prussian blue is used to reduce compounds such as phenols. Soil samples were taken from crop rows at depths of 0-2 and 3-10 cm for both the LM and BG plots. Two grams of soil 1-2 mm was extracted with 20 ml of methanol (CH_3OH). Samples were shaken every 2 hours using an automatic shaker, Lab-Line orbit shaker No.3590, at 100 rpm for 24 hours. Soil extractions were filtered using filter paper (Whatman#3, Whatman International). Soil extraction aliquots of 1 ml were mixed with 5 ml of H_2O in a 125 ml flask. Then, 0.36 ml of ferric ammonium sulfate (0.1M $FeNH_4(SO_4)_2$ in 0.1M HCl) was added to successive samples at one minute intervals. A 0.36 of potassium ferricyanide [0.008 M $K_3Fe(CN)_6$] was added 20 minutes after the addition of ammonium sulfate. Twenty minutes after the addition of potassium ferricyanide, the absorbance at 720 nm was measured using a spectrophotometer (Stern, et al., 1996).

3.3.4. Physical properties of soil

a. Water aggregate stability

Wet sieving of soil aggregates was performed to determine the stability of soil to rapid impact by raindrops. Water aggregate stability was measured at 102 DAT and 390 DAT of piligrass. About 50 grams of air-dried soil was transferred to a 2-mm sieve nested within a 1-mm sieve. The sieve was shaken gently to obtain aggregate 1- to 2-mm in size by only using aggregates obtained in the 1mm sieve. Ten grams of 1- to 2-mm aggregate was weighted and separated evenly over the 1-mm sieve. The other 10 grams of 1-to 2-mm aggregate was used to determine the oven-dry weight of the aggregates. The sieve with soil aggregate was placed in and out of water at a rate of 30 oscillations per minute (one oscillation is an up and down stroke of 3.7 cm on length) for 3 minutes (picture 3.7). The sieve was removed and the soil aggregates were transferred to weighing cans. The aggregates were dried at 105^{o}C for 24 hours and an oven-dry weight was determined. Water aggregate stability was calculated using the weight of the oven dried aggregate divided by the weight of the oven dried aggregate sample (Arshad *et al.*, 1996).

b. Soil moisture

The gravimetric method was used to measure soil moisture at 102 DAT and 390 DAT of piligrass. Soil moisture content of soil is determined as the mass of water per unit mass of soil. Soil samples were taken from the field for both crop and non-crop rows and at 2 different soil depths of 0-2 cm and 3-10 cm. Ten grams of soils from every sub sample were taken and put on a tin, weighed (wet weight), and then put in a dry oven at 105^{o}C for 24 hours. Dry weight was measured and used to calculate soil moisture. Percentage of soil moisture is calculated by subtracting wet weight from dry weight and dividing it by dry weight (Black, 1965).

c. Soil temperature

The data loggers were used to measure soil temperature. Eight sensors were enclosed in small plastic bags and put at 10 cm of soil depth in crop and non-crop rows from LM and BG plots (picture 3.8.). The sensors were placed in each plot from October 6, 2008 to June 12, 2009 (125-386 DAT of piligrass). Data loggers recorded the fluctuation of soil temperature every 4 hours for 24 hours. Sensor location in the field was marked with a flag. The sensors from the field were collected and sensor data was imported to the computer and analyzed.

3.3.5. Data collection and statistical analysis

Data collected for soil analysis consisted of chemical and physical properties of soil. Chemical properties included soil nutrients (total C, total N, NH_4^+, NO_3^-, P, K, Ca, Mg, and pH), bioassay test (root and shoot length), charcoal test (plant height and dry biomass), and phenol analysis (phenolics compound in soil). The physical properties of the soil analyzed included WAS and SM. In addition, piligrass plant tissue was analyzed for nutrient levels. Zucchini plant tissues were analyzed for total Nitrogen levels.

Analysis of variance was done using Statistix 9 statistical software (Analytical Software, Tallahasee, FL).

3.4. Results

3.4.1. Piligrass plant tissue

The perennial piligrass used as a LM can continually supply biomass to the soil during the growing season. The piligrass LM provided 6 Mg/ha of biomass as mulch with soil coverage of 80-90% compared to 0% for bare ground. Nutrient concentrations found in piligrass were 1.08% N, 43.03% C, 0.18% P and 1.70% K (table 3.1.) Piligrass tissue analysis also measured other nutrients such as Ca, Mg, Fe, Na, Mn, Cu, and B (table 3.1).

3.4.2. Chemical properties of soil

a. **Soil Nutrients**

On September 13, 2008 (at 102 DAT of piligrass), soil samples were taken from the two treatments to determine total C in the soil. Laboratory analysis showed that total C at a depth of 0-10 cm was not significantly different (table 3.2.). On April 26, 2009 (at 325 DAT of piligrass) total C in LM were significantly higher (1.9%) than in BG (1.3%) at 0-2 cm depth in crop row (table 3.2).

Soil samples taken after harvesting cabbage on April 26, 2009 were used to determine nutrient concentrations in the soil. Plant symptoms such as stunted growth, purple leaves, and late maturity can be an indication of nutrient deficiency. Laboratory analysis showed that piligrass LM soil had significantly higher total N (0.14%) than the BG plots (0.11%) (table 3.3.). On June 12, 2009, zucchini plant tissue was analyzed to determine the level of N in the plant. Laboratory analysis showed that the N levels of zucchini in the LM plots were significantly lower (1.7%N) than in the BG plots (3.5%N) (table 3.3.). On July 1, 2009, after harvesting zucchini in summer 2009, soil samples were taken to analyze the availability of mineralized elements of N i.e. NH_4^+ and NO_3^-. Soil analysis showed that piligrass LM soil had significantly higher NH_4^+ (3.04 mg/g) than the BG soil (1.97 mg/g) (table 3.3). However, no significant difference was found for NO_3^- for the LM (12.18 mg/g) and BG plots (13.53 mg/g) (table 3.3.). In addition, other nutrients such as P, K, Ca, Mg and soil pH in both LM and BG plots were not significant different (table 3.4.).

b. **Phytotoxicity analysis of soil**

Analysis for soil toxicity was conducted using three methods, i.e. bioassay, charcoal test, and phenolic analysis. Plant-soil debris bioassay can be used to demonstrate phytotoxicity and allelophaty (Inderjit & Weiner, 2001). Bioassay testing with rye grass, Manoa lettuce, and cress showed that their shoot length was not significantly different between LM and BG plots (table 3.5.). Root length of the indicator plants was also not significantly different between LM and BG plots (table 3.6). However, both shoot and root length of plants in the LM and BG plots was significantly different compared to the water only (control) (table 3.5 and 3.6).

The ANOVA indicated there was not significant interaction between the factors of farming system and charcoal levels for dry weight accumulation of sweet corn (table 3.7.) but interaction was highly significant difference for plant height (table 3.8). Plant height was significantly higher in the BG plots and the addition of charcoal to the soil (figure 3.1. & 3.2). Corn biomass accumulation was not significantly affected by the soils from neither the two farming systems nor the addition of active charcoal (figure 3.3 & 3.4). These data of plant height indicated that adding charcoal 10% could increase plant height in LM plots (figure 3.5). Meanwhile, the dry weight accumulation of sweet corn do not effect to plant height. These data was not enough to support the presents of inhibitory compounds in the soil as a factor in vegetable crop yield reductions in the LM plots.

The laboratory analysis showed that the level of phenolic compounds in LM and BG plots were not significantly different for both soil depths of 0-2 and 3-10cm (table 3.10). Phenolic compounds were presents in both LM and BG treatments. The average phenolic from 0-10 cm depth in LM soil was 27 (mg/kg) and in BG soil (24 mg/g).

3.4.3. Physical properties of soil

On September 13, 2008 (102 DAT piligrass), soil samples were taken at 0-2 and 3-10 cm depth to analyze the physical properties of the soil (WAS and SM). Laboratory analysis showed that at soil depths of 0-2 cm, WAS in the BG treatment was significantly higher than in the LM treatment (table 3.11; figure 3.6). However, at the soil depth of 3-10 cm, WAS in the LM plots was significantly higher than in the BG plots (table 3.11 figure 3.6). Furthermore, on July 1, 2009 (390 DAT of piligrass), soil samples were taken from soil depths of 0-2 and 3-10cm to determine the changes in soil aggregates after 288 days of piligrass establishment. At a soil depth of 0-2 cm, piligrass LM had significantly higher WAS (28%) than in BG (16%.) (table 3.11). However, at 3-10 cm soil depth there was no significant different of WAS in LM (26%) compare to BG (23%) (table 3.11; figure 3.6).

From the same soil samples used for WAS, SM was measured. At 102 DAT of piligrass, the soil moisture from soil depths of 0-2 and 3-10 cm were not significantly different between LM and BG plots (11-12% SM) (table 3.12). In addition, at 390 DAT of

piligrass at soil depths of 0-2cm and 3-10cm, soil moisture in the LM and BG plots were also not significantly different (11-12% SM)) (table 3.12; Figure 3.7.).

Soil temperature was recorded by data loggers from October 6, 2008 (125 DAT piligrass) to 12 June 2009 (386 DAT piligrass). Eight data loggers were put in every block of the LM and BG plots. Two of the four sensors did not record data, thus only 2 sensors from the LM plots and 4 sensors from BG plots were used. The temperature data showed that in general BG plots were warmer than LM plots. Figure 3.8 shows that on December 22, 2008 the average soil temperatures for both LM and BG were the same 23^{o}C. On March 21, 2009 the soil temperature was 24^{o}C in the BG plots and 22^{o}C in the LM plots, then on June 20, 2009 the soil temperature was 28^{o}C in the BG plots and 26^{o}C in the LM plots. Thus, in general soil temperatures in piligrass LM plots were cooler than in the BG plots with an average difference of 2^{o}C.

3.5. Discussion

3.5.1. Chemical properties of soil

Piligrass LM grown together with tropical vegetable crops produced 6 Mg/ha of biomass. Sainju and Singh, 1997 reported that a non-legume CC can produce 1.5-7.1 Mg/ha while legume CC can produced 0.7-9.3 Mg/ha of biomass. The adding of 2.6 Mg/ha carbon from piligrass biomass every mowing application dramatically increased total soil C. From the 2nd - 7th mowing, the total soil C in the crop rows at a soil depth 0-2 cm in the LM plots increased from 1.5-1.9% (improving 27 %), while, the total C in the BG plots decreased from 1.4-1.3% (5% reduction). The no-till LM system is generally considered an effective practice to minimize SOC loss and enhance SOC sequestration for agriculture (Blanco-Canqui & Lal, 2007; Follet, et al., 2009).

However, since piligrass has a high C/N ratio of 40, the decomposition process may be slow. The C/N ratio is a measure of the relative carbon content of organic materials in the soil related to the breakdown of organic materials in the soil. The C/N ratio also provides clues as to the effects of crop residues on soil N levels and the rate of nutrient release from crop residues. According to Hazelton & Murphy (2007), if the C/N >25, the

decomposition of C is slow unless N is added. Nitrogen can be tied up in decomposing organic material when C/N>25, and not be available to any crops.

High C/N ratios in organic material can decrease the availability of N for crops (Hazelton & Murphy, 2007). In this experiment, we found that total N and NH_4^+ in LM piligrass plots was higher than in the BG plots and the level of NO_3^- was similar among treatments. Total N and NH_4^+ in the conventional BG system was perhaps due to leaching from the root zone, runoff in exposed surface soil, and crop uptake. Furthermore, the piligrass LM plots had double the NH_4^+ and medium levels of total N (0.14%) in the soil (where 0.15-0.25% total N considered as medium level) compared to the BG plots that had low total N (0.11%) (where 0.05-0.15% total N was in low rate) (Hazelton & Murphy, 2007). Hartwig & Ammon (2002) explained that LM increased N availability in soil and soil organic matter. In this experiment, the higher N in the LM plots was due to continuous supplying of 64.8 kg N/ha from 6 Mg/ha of piligrass biomass. A non-legume LM can increase N levels 14-90 kgN/ha (Sainju & Singh, 1997).

The analysis of zucchini leaves showed that nutrient concentration in the plant was N-deficient in the LM plots. The level of nutrients in a plant is directly related to the availability of nutrients in the soil. In this experiment, the visual symptoms of N deficiency were visible on both cabbage and zucchini crops such as stunting, chlorosis, purplish coloring on cabbage leaves and delayed maturity. Cook & Ellis, (1987) explained that a deficiency of N causes stunted growth and loss of chlorophyll. Nitrogen particularly effects the vegetative growth of plants; the leave became light green and gradually turned yellow. For cabbage plants, N deficiency showed yellow, red, or purplish tints of leaves. Furthermore, zucchini plant tissue was 1.7 % N in the LM plots compared to 3.5% N in the BG plots. The rate of N in LM was at a deficient level according to the critical values of N for summer squash compared to the BG plots, which were at an adequate level (Kelley, 2008). The deficiency of N in the plant due to NO_3^- was used by microbes N-immobilization. Hazelton & Murphy, (2007) showed that the immobilization of N occurs when NH_4^+ and NO_3^- is used by the growing microbes to build proteins. In this experiment, the plant-available N (NO_3^-) was tied up by microbes in the decomposition process causing N-deficiency in the plant (diagram 3.1).

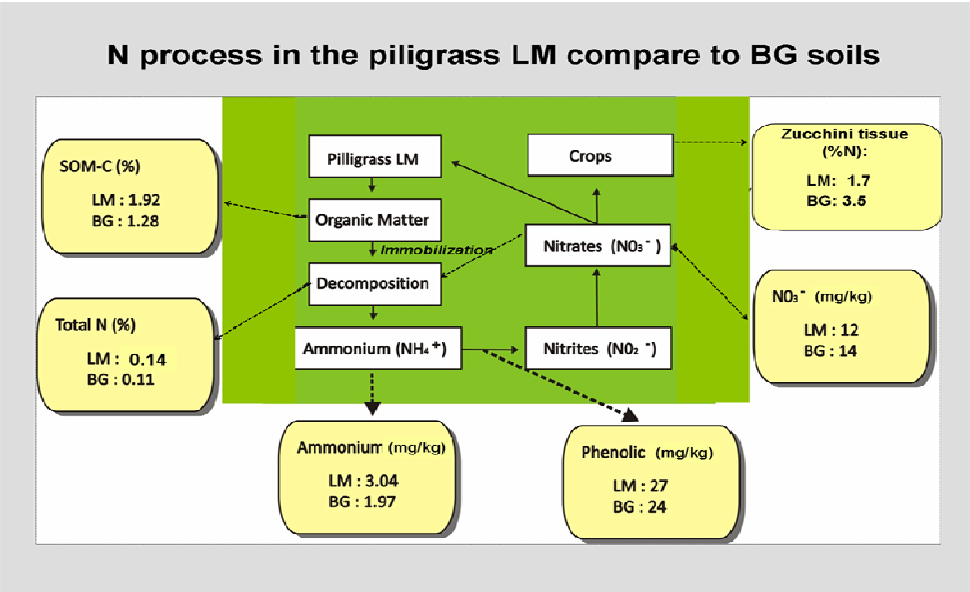


Diagram 3.1. Diagram the N flow in the piligrass living mulch soil compare to BG soil

The laboratory analysis showed that P, K, Ca, and Mg levels in the soil were not significantly different between LM and BG plots. The LM soil also had a similar pH 6.4 with the BG soil. Thus, there was no problem in the soil related to the availability of nutrients and pH level, except for N.

The visual symptoms of poor plant health might be associated with growth suppression due to allelochemicals (Inderjit & Weiner, 2001). In addition, Chandramohon *et al*., (1973) explained that the decomposition of organic matter from plant residue produces a number of phenolic acids like p-Amino benzoic, p-coumaric, ferullic, vanilic, and cinnamic acids and that they can accumulate in soil. Along with nutrient deficiency, plant growth and yield suppression, might be also due to inhibitory substances. This is important because allelochemical may affect both plants and soils by 1) direct plant-plant interference mediated by allelochyemicals or, 2) the effect on secondary compounds released by a plant on the abiotic and biotic properties of soil (Inderjit & Weiner, 2001). The secondary compounds such as phenolics and terponoids may play an important role in the inhibition oxidation of ammonium (NH_4^+) by nitrifying microorganisms and influencing a plant nutrient status (McCarty & Bremner, 1986; Inderjit & Weiner, 2001). In this

experiment, bioassay tests, charcoal test, and phenolic analysis could not support any allelopathic effects in the soil.

From the analyses on chemical properties of the soil, it can be concluded that piligrass LM maintenance higher N level than BG (total N and NH_4^+), did not affect the soil pH, and increased soil carbon. However, piligrass had a high C/N ratio that resulted in immobilization in the soil causing reduced growth in LM plots (diagram 3.1).

3.5.2. Physical properties of soil

The effects of piligrass LM on the physical properties of soil was determined on soil aggregate stability, soil moisture, and soil temperature at a soil depth of 0-10cm. Previous analysis showed that piligrass had increased total carbon in the soil with a high C/N ratio. In our study, the increase of organic matter in the soil improved the stability of aggregate soil. The stability of aggregates is influenced by the type of organic matter present, and the type and size of the microbial population (USDA –NRCS, 1996). In contrast, the deterioration of soil structure is caused by exposure of bare soil to rain and a decline in the concentration of organic matter (Betay, 2000).

At 102 DAT of piligrass, LM soil aggregate stability has not improved. At 390 DAT of piligrass, LM soil had improved WAS in the surface soil (0-2 cm depth) from 10 to 28% (100% increased). The aggregate stability at 30-10 cm depth was improved from 20 to 26% (increased 30%). Liu *et al*, (2005) found similar results with non-leguminous cover crops. The cover crops had increased percentages of water stability 2 to 6 mm aggregates under intensive cultivated soil. They estimated that dilute acid-extractable polysaccharide as binding agent under short-term cover crops. Hazelton & Murphy, (2007) described the rating of 1-2 mm stable aggregates using a wet sieving method where WAS <10% (very low), 10-20% (low), 20-30% (moderate), and >30% (high). The WAS rate of soil at 0-2 cm depth in the crop rows at 102 DAT were the same at low rate for both LM (10%) and BG plots (16%). Furthermore at 390 DAT of piligrass in LM plots, there was an increase to a moderate rate (28%), however in the BG plots the WAS did not change (still in low rate). A rating of moderate level means that the soil has an average structural condition and average

structural stability. Organic matter is decomposed by microbes that produce extracellular mucilaginous polysaccharide materials which are glue to build and stabilizes soil aggregate into peds (Hartwig & Ammon, 2002); Franzluebbers, 2004; Liu, Ma, & Bomke, 2005). Another study found that straw mulching increased soil carbon and improved near-surface aggregate (Blanco-Canqui & Lal, 2007).

Piligrass as a LM maintained soil moisture (SM) around 11-12% at a soil depth of 0-10 cm in both crop and non-crop rows with no difference seen in the BG plots. There was no significant difference of SM values between the LM and BG plots. A previous study found that the LM reduced soil water content between 0.3-0.9m soil depths, even after intense rainfall, probably due to high evapotraspiration and root density (Liedgens *et al*., 2004). In this experiment, the piligrass LM balanced SM from water infiltration, water absorption, and evapotranspiration in the soil. In the exposed BG conventional plots, there was high evaporation and probably a runoff effect, however, the SM content was not significantly different from the LM plots. There was no difference on SM between the LM and BG plots likely due to a daily water supply from the drip irrigation system to the crop rows.

Piligrass as a LM affectively reduced soil temperature (ST). The soil temperature was recorded for 9 months from October 2008 to June 2009. Overall the soil temperature in the LM plots was lower than in the BG plots. At certain points in the year, the soil temperature in the BG plots was hotter than in the LM plots. On the 21 December 2008, the LM and BG plots had a similar ST of 23^{o}C, on 20 March 2009; BG plots had a warmer temperature (24^{o}C) than LM plots (22^{o}C). Moreover, on 20 June 2009, soil temperature in the BG plots was 28^{o}C compared to 26^{o}C in the LM plots. A change of $\pm$ 1^{o}C in soil temperature is sufficient to have a major impact on plant growth and development (Livingston, 1993). Walters et al., (2005) also reported that winter ryegrass mulch produced lower ST resulting in reduce growth and productivity of zucchini squash. In addition, low soil temperature may delay squash development resulting in later fruit production (Walters & Young, 2008). In this experiment, the cabbage and zucchini yield in piligrass LM plots were lower and had delayed fruit maturity compared with the BG plots. Thus, the change of 2^{o}C in soil temperature in the piligrass LM treatment could reduce cabbage and zucchini growth and

yields. Brady & Weil (1996) explained that crop residues in no-till systems had consistently lower soil temperatures during July and August and the depression of soil temperatures had a serious negative impact on corn yield. Furthermore, Biazzo & Masiunas (2000) explained that an exposed soil surface allows more solar radiation to reach the soil surface and thus warms the soil. The soil temperature is also related to soil moisture, generally drier soils are warmer than wet soils. The warmer soil provides some beneficial impacts to plant growth such as expanding microbe activities, root growth and development. Meanwhile, cooler soils provide a reduced rate of water evaporation in the soil. In our experiment, the cooler soil in LM plots may have contributed to reduce plant growth and yield. Figure 3.9 shows that root growth in the BG plots was greater than in the LM plots. Thus, the temperature of soil must be included as a contributing factor in LM yield reduction.

From our analyses on physical properties of soil, it can be concluded that piligrass improved soil quality in terms of increasing the stability of soil aggregate and maintaining soil moisture. On the other hand, the piligrass LM provided cooler soil than in the BG plots.

3.5.3. Others external factors affecting the crop production

In this experiment, strong evidence points to N-deficiency as major factor in the reduction in crop yield of LM plots. Other soil factors were not serious problems in the piligrass LM plots such as the availability of other nutrients, soil pH, organic matter and the soil physical qualities.

There were probably additional factors reducing vegetable crop yield. External factors such as the rotation system, crop selection, pest and disease management, and weather may have also affect crop yield. This experiment used the rotation system between cabbage and zucchini. For using cabbage in the rotation system, a farmer should consider the planting time. A Germany an crop consulting agency (PAN-OISAT) (2009) suggested that to avoid serious problems of pests and diseases of cabbage, cabbage or other members of *Brassica* family should not be grown in the same place for three consecutive years. Intercropping with certain combinations of plants will have a beneficial effect on reducing pest damage. Instead of intercropping, this experiment applied the rotation system to reduce the life cycle of pests and diseases. In the second growing season, both cabbage and

zucchini were sprayed more frequent than the first growing to reduce pests and diseases. Although, the intensity of spraying insecticide was increased, the plant damage in terms of pest and diseases appeared to increase too. In Hawai'i, the growing season is all year, thus, managing insect pests is one of the most difficult aspects of working with vegetable crops (Arakaki, 2003).

Crop selection is a critical factor when using piligrass as a LM. In addition, special consideration should be given to the type of LM used due to nutrient competition and nitrate competition with the crop plant (Hartwig & Ammon, 2002). The appropriate combination of LM and crop species along with the development of optimum methodologies to reduce competition must be improved. There is no single species or methodology that will work in all locations under all conditions (Biazzo & Masiunas, 2000). Even though, the piligrass LM soil had a higher nitrogen concentration, its vegetable crops had N-deficiency. Therefore, the selection of main crops with the use of piligrass as a LM may be better suited to a crops with lower N-requirement in piligrass LM system than zucchini and cabbage.

Weather is one factor that affected crop damage. This experiment showed that planting vegetable crop especially zucchini in the winter season in Hawai'i was accompanied by many problems. Many plants died and became sick due to heavy rains and cool damp conditions.

The last important factor in piligrass LM management is to reduce the effects of shading by applications of stunting and mowing of the LM. More frequent mowing will reduce LM shading and provide better crop growth. With more frequent mowing, grass clipping added to soil surface would less likely to be highly lignified, thus reducing N-immobilization. Overall, the use of piligrass as a LM had effects on chemical and physical properties of the soil. Piligrass had a high C/N ratio that caused N-deficiency due to N-immobilization. However, piligrass improved soil physical quality while maintaining the availability of non N-nutrients, soil pH, and soil moisture. In addition, the rotation system, crop selection, weather and LM management also affected crop production. The diagram of the characteristics of piligrass used as a LM in relation to crop production can be seen at diagram 3.2 below.

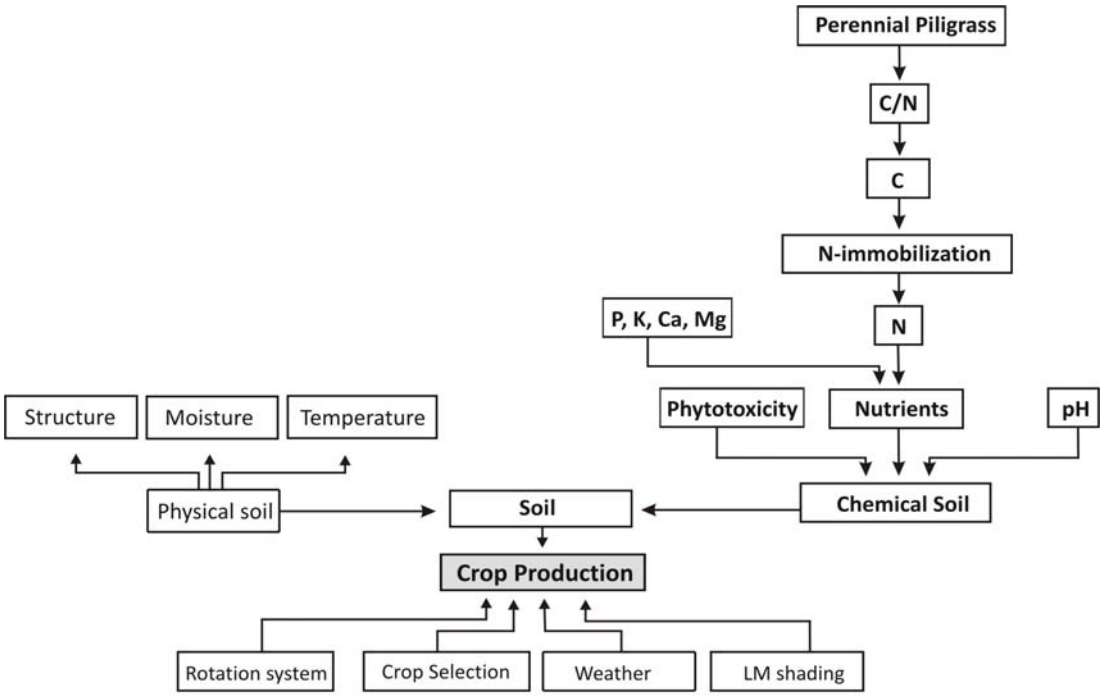


Diagram 3.2. The changes of soil properties and factors affecting crop production in piligrass LM system

3.6. Conclusions and recommendations

Based on our analyses of the soils, it can be concluded that piligrass affected the chemical and physical properties of the soil. Piligrass as a LM had higher total N, total C, and NH_4^+ compared to the BG plots. Furthermore, P, K, Ca, Mg, and pH in both LM and BG plots were not significantly different. Analysis of the phytotoxicity of the soil from three tests (bioassay, charcoal, and phenolic) did not detect any inhibitory substances in the soil. In general, the piligass LM improved the soil physical quality. Piligrass as a LM increased WAS while maintaining SM and reducing surface ST. However, we did find nutrient deficiency in the crop. Zucchini foliage had N deficiency in the LM plots. Hence, the potential problem in the piligrass LM plots was the uptake of N by microbes for the decomposition and cooler soil temperatures.

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Tables

A. Piligrass compounds

Table 3.1. The composition of nutrients in *H. contortus* (Piligrass) at 68 DAT

Nutrients	Compound (%)
N	1.08
C	43.03
P	0.18
K	1.70
Ca	0.23
Mg	0.23
Na	0.01
Fe	129
Mn	47
Zn	17
Cu	6
B	3
Biomass (Mg/ha)	6

B. Chemical properties of soil (nutrients)

Table.3.2. Soil **Carbon** changes in the piligrass living mulch (LM) and bare ground (BG) soils. Symbol (**) indicates highly significant difference (P<0.01) between means of treatments

Treatment	Total C (%) at 0-2 cm depth	
	102 DAT of piligrass	325 DAT of piligrass
LM	1.50	1.92 **
BG	1.35	1.28

Table.3.3. **Nitrogen** compounds in the piligrass living mulch (LM) and bare ground (BG) soils and zucchini plant tissue. Symbol (*) indicates a significant difference (P<0.05); (**) highly significant difference (P<0.01) between means of treatments

Treatment	Soil in crop row 0-2 cm depth			Zucchini tissue
	Total Nitrogen (%)	NH_4^+ (mg/kg)	NO_3^- (mg/kg)	N (%)
LM	0.14 *	3.04 *	12.18	1.7
BG	0.11	1.97	13.53	3.5 *

Table.3.4. **Other soil nutrients** and **pH** of soil in crop rows 0-2 cm at 325 DAT of piligrass no significant difference in the piligrass living mulch (LM) and bare ground (BG) treatments

Treatment	P (mg/kg)	K (mg/kg)	Ca (mg/kg)	Mg (mg/kg)	pH
LM	366.5	816.5	3498	2416	6.45
BG	305.0	619.5	3371	2354	6.43

C. Soil Phytotoxicity

1. Seed germination bioassay

Table 3.5. **Shoot length** of rye grass, cress and Manoa lettuce of seed germination bioassay. Control (water only) significant different compare to piligrass living mulch (LM) and bare ground (BG) treatments

	Shoot length (cm)		
Treatment	Rye	Cress	Lettuce
LM	7.26 a	3.89 a	1.99 a
BG	7.72 a	4.29 a	1.92 a
Control	4.86 b	2.25 b	1.26 b

Mean followed by the same letter within column are not significantly different, lower case means ($p<0.05$)

Table 3.6. **Root length** (cm) of rye grass, cress and Manoa lettuce of seed germination bioassay. No significant different among piligrass living mulch (LM), bare ground (BG), and control (water only).

	Root length (cm)		
Treatment	Rye	Cress	Lettuce
LM	8.11 ab	6.78 ab	2.19 a
BG	9.99 a	7.37 a	1.99 ab
Control	5.98 b	4.68 b	1.52 b

Mean followed by the same letter within column are not significantly different, lower case means ($p<0.05$)

2. Charcoal test

Table 3.7.Analysis of variance (ANOVA) of sweet corn dry biomass in charcoal test. Farming system, charcoal levels, and interaction no significant different (ns)

Source	DF	SS	MS	F	P
Block	3	0.09187	0.03062		
Trt	1	0.39062	0.39062	3.57	0.0915 **ns**
Charcoal	1	0.10563	0.10563	0.96	0.3517 **ns**
Trt*Charcoal	1	0.14062	0.14062	1.28	0.2864 **ns**
Error	9	0.98563	0.10951		
Total	15				
Grand Mean	1.6313	CV 20.29			

Table 3.8.Analysis of variance (ANOVA) of sweet corn plant height in charcoal test. Interaction farming system (LM & BG) and levels of charcoal was significant different (*). Farming system and charcoal levels were highly significant difference (**).

Source	DF	SS	MS	F	P
Block	3	16.4169	5.4723		
Trt	1	36.9056	36.9056	40.04	0.0001 **
Charcoal	1	20.0256	20.0256	21.73	0.0012 **
Trt*Charcoal	1	4.7306	4.7306	5.13	0.0497 *
Error	9	8.2956	0.9217		
Total	15				
Grand Mean 32.031	CV 3.00				

Table 3.9. Percentage increasing of plant height of sweet corn due to adding activated charcoal to the soil compare to non-charcoal soil in the piligrass living mulch (LM) and bare ground (BG) treatments.

Treatments	% increasing of plant height
LM	11
BG	3

3. Phenolic analysis

Table 3.10. Phenolic compounds in soil at 390 DAT piligrass in crop rows. No significant difference between piligrass living mulch (LM) and bare ground (BG) soils.

Treatment	0-2cm (mg/kg)	3-10cm (mg/kg)
LM	27.84	26.83
BG	26.75	22.08

D. Physical properties of soil

Table 3.11. Water aggregate stability (WAS) changes from different times and soil depths in crop rows. Symbol (*) indicated significant difference ($P<0.05$) between means of treatments.

Treatment	WAS at 102 DAT of piligrass		WAS at 390 DAT of piligrass	
	0-2 cm	3-10cm	0-2 cm	3-10cm
LM	10	20 *	28 *	26
BG	16 *	13	16	23

Table.3.12. Soil moisture (SM) data reported no significant different SM in terms of different times and soil depths in the living mulch (LM) and bare ground (BG) treatments

Treatment	SM at 102 DAT of piligrass		SM at 390 DAT of piligrass	
	0-2 cm	3-10cm	0-2 cm	3-10cm
LM	11.3	12.0	11.8	11.7
BG	11.1	11.6	12.5	11.9

Figures

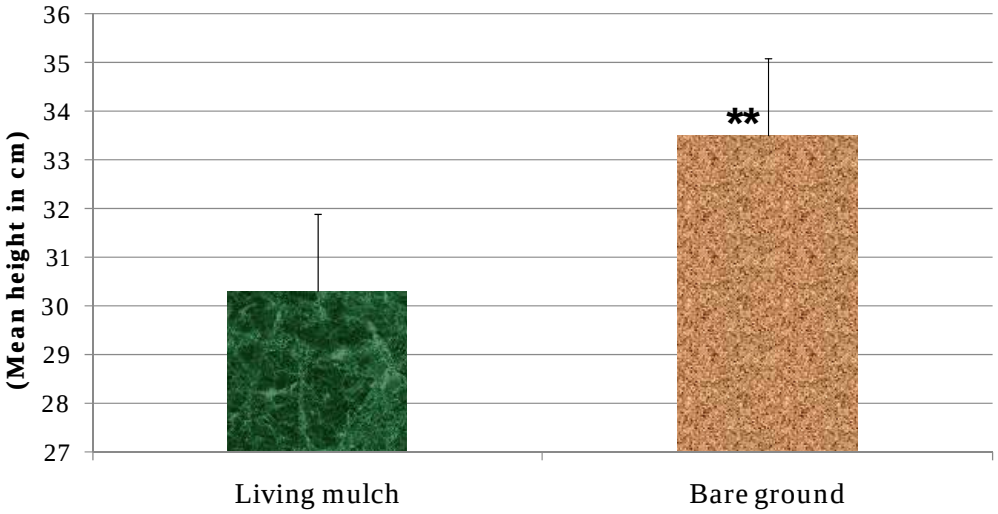


Figure 3.1. **Plant height** of sweet corn in cm after three weeks growing in glass house. Plant height in bare ground highly significant different (**) than in piligrass living mulch treatment

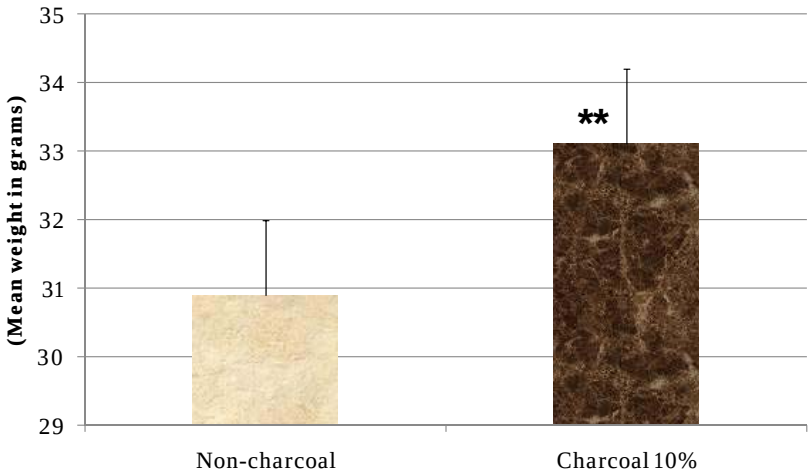


Figure 3.2. **Height** of sweet corn in cm after three weeks growing in glass house. Plant height in 10% activated charcoal highly significant different (**) than in no-charcoal (soil only) treatment.

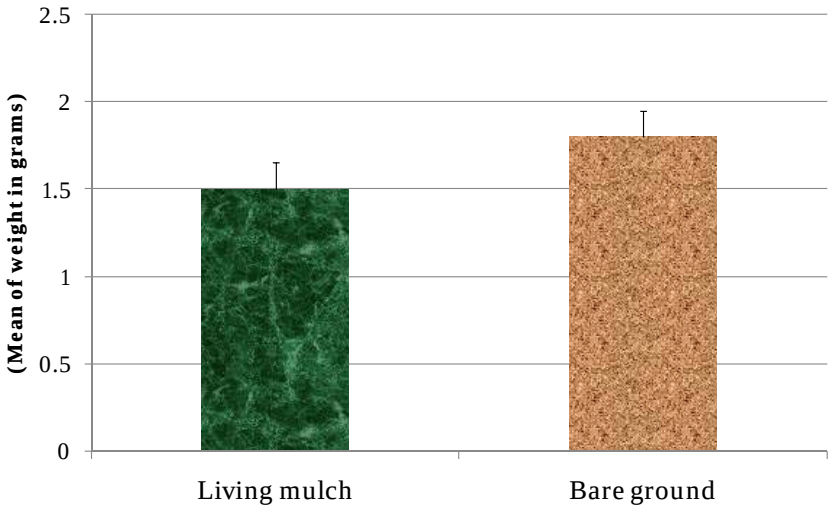


Figure 3.3. **Dry biomass** of sweet corn in cm after three weeks growing in glass house. Dry biomass no significant different in piligrass living mulch and bare ground treatments.

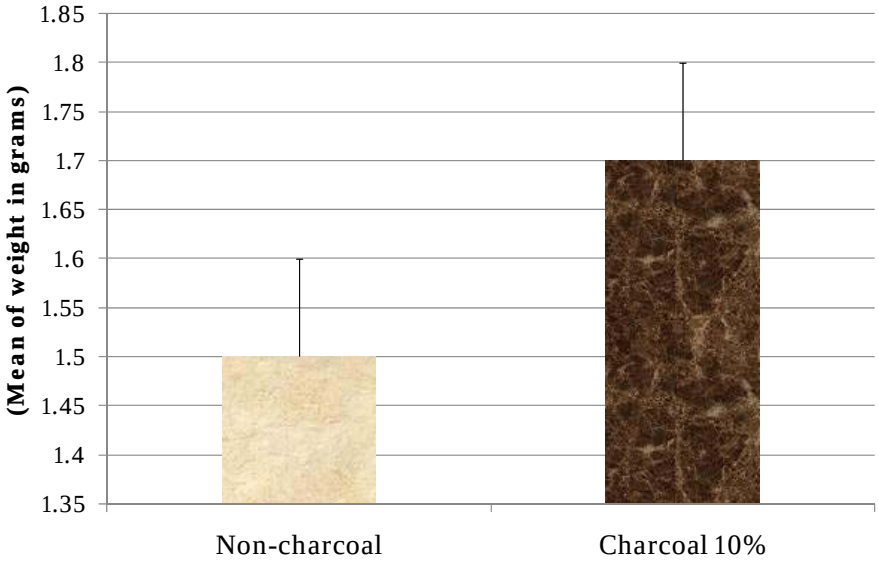


Figure 3.4. **Dry biomass** of sweet corn in cm after three weeks growing in glass house. Dry biomass no significant different in no-charcoal (soil only) and 10% activated charcoal treatments.

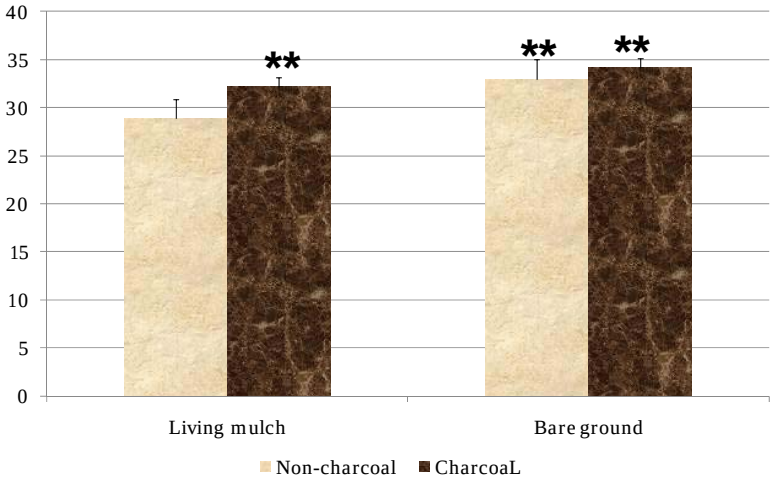


Figure 3.5. The **plant height** (cm) interaction between framing system (LM & BG) and levels of charcoal were highly significant different. Charcoal 10% had increased plant height in LM plots.

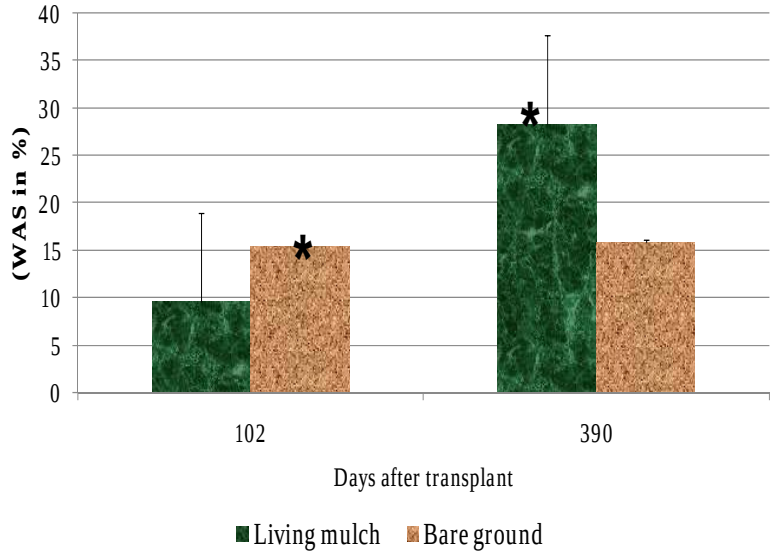


Figure 3.6. 1-2 mm stable soil aggregate in crop row 0-2 cm depth. At 390 DAT of piligrass percentage of **water aggregate stability** (WAS) in the piligrass living mulch significantly higher (*) than bare ground soil.

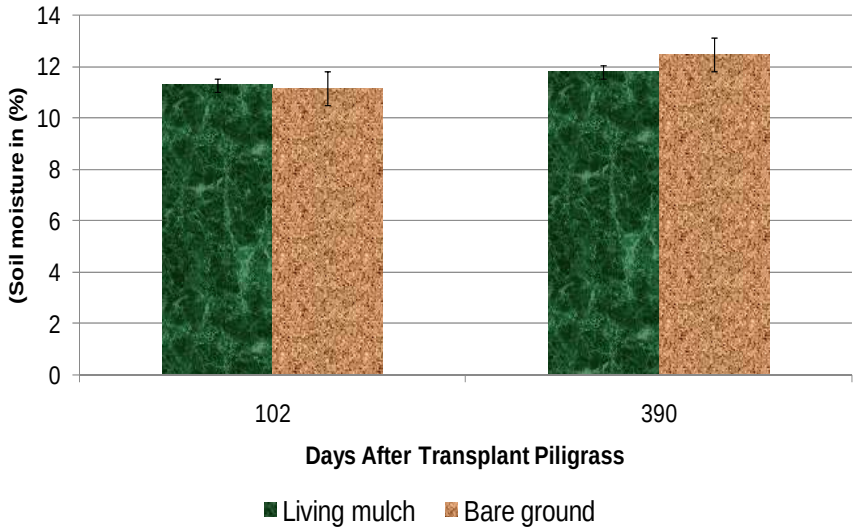


Figure 3.7. .**Soil moisture** in crop row 0-2 cm depth. Soil moisture no significant difference in the piligrass living mulch and bare ground soils at 102 DAT and 390 DAT of piligrass.

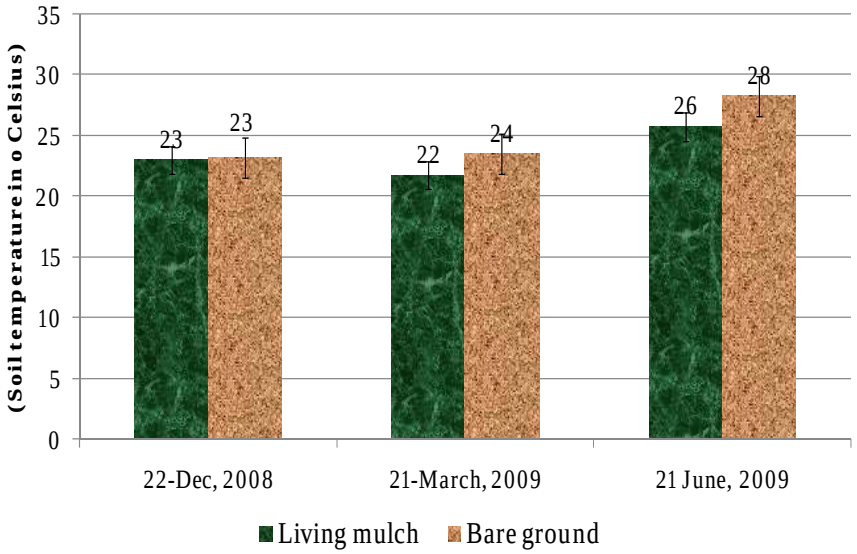


Figure 3.8. **Soil temperature** changes since October 2008 until June 2009 in the piligrass living mulch and bare ground treatments. The piligrass LM soil has lower soil temperature (cooler soil).

Pictures

Soil sampling

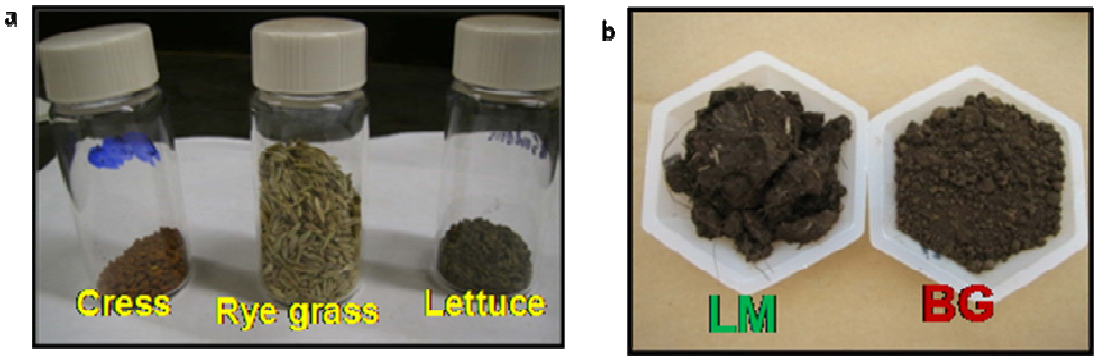
Picture 3.1. Taking four sub-samples soil per plot from 0-5 cm depth, 15 cm away from drip irrigation turbin using a core sampler in the piligrass living mulch and bare ground treatments for charcoal test

Plant tissue sampling

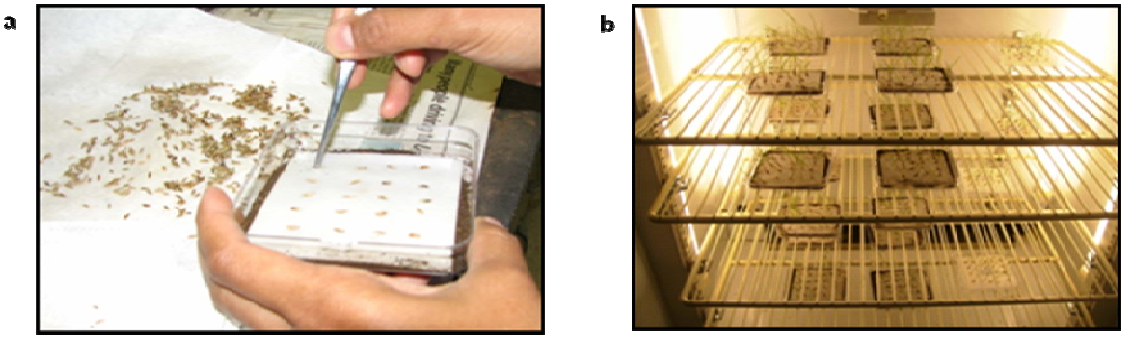
Picture 3.2. Zucchini plant sampling at 46 DAT of zucchini (23 days after fertigate) for analyzing nitrogen, sample ten leaves/plot taken from the mid-section of plant

Soil phytotoxicity test

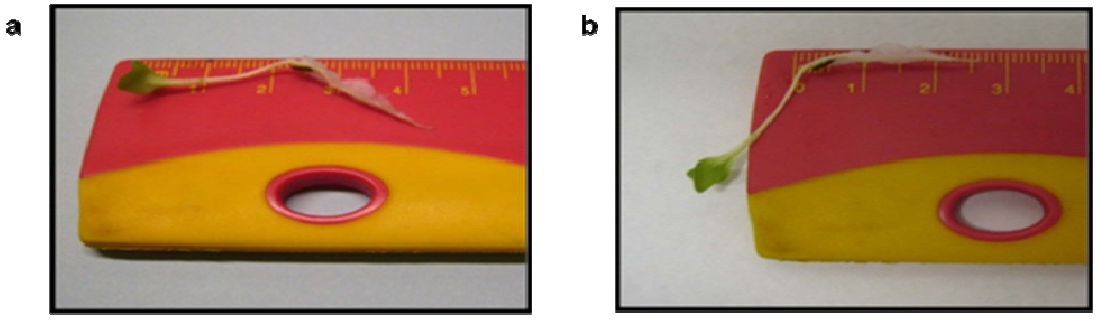
1. Seed germination bioassay



Picture 3.3. a) The seeds of cress, Rye grass and Manoa Lettuce; b) soils from piligrass living mulch (LM) and bare ground (BG) treatments

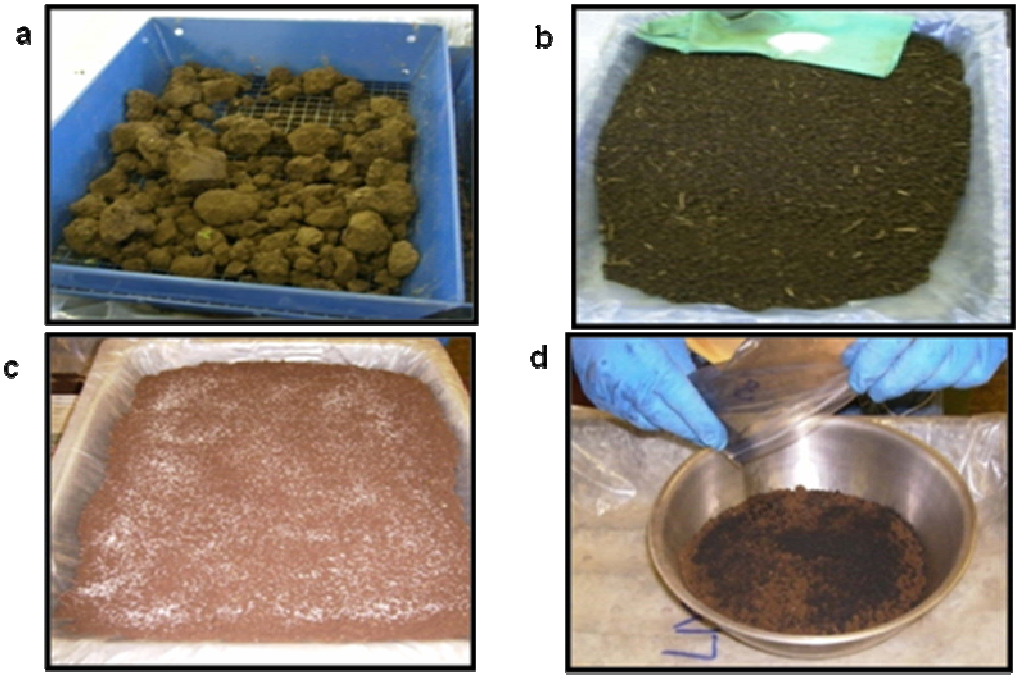


Picture 3.4. a) Atwenty seeds of Rye grass placed on the soil in Petri dish; b) germination the seeds in incubator with mimic temperature 20^{o}C(night) and 26^{o}C (day) for 6 days.



Picture 3.5. a). Measuring the shoot length in cm; b) measuring root length in cm after seed germination in incubator

2. Charcoal test

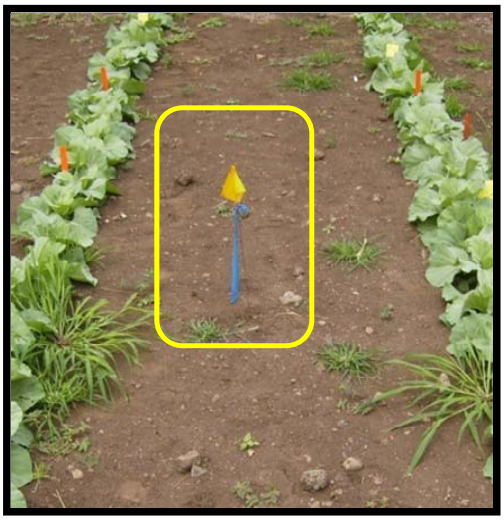


Picture 3.6. Preparing media for charcoal experiment: a) sieving the soil samples from rocks, roots, and other debris; b & c) fertilizing 168 kg N/ha as 21-0-0; d) mixing 85% activated charcoal in soil.

Physical properties soil analysis

Picture 3.7. Mechanical oscillating sieving for measuring 1-2 mm stable soil aggregate; 30 oscillations per minute for 3 minutes sieving

Soil temperature



Picture 3.8. The location of data loggers in the field for measuring the fluctuation of soil temperature in the piligrass living mulch and bare ground treatments

The condition of root growth

a

b

Picture 3.9. The condition of cabbage root growth, a) representative cabbage plant from the piligrass living much treatment; b) representative cabbage plant from bare ground treatment

CHAPTER IV
SUMMARY AND FUTHER RESEARCH

4.1. Summary

Based on our study, it can be concluded that *Heteropogon contortus* (piligrass) has beneficial aspects that make it valuable for use as living mulch (LM) for tropical vegetable crops in Hawai'i. The effects of piligrass as a LM were 1) increased weed suppression, 2) increased population & biodiversity of insects, 3) increased nitrogen levels, 4) improved soil structure (aggregate stability), 5) maintained soil moisture and cooler soil temperatures, 6) reduced pests and diseases effects and 7) no clear detectable toxic compounds. Nevertheless, the negative effects of piligrass as a LM were a N-deficiency in the crop due to N-immobilization. In addition, several additional factors that influenced crop growth and yield were cooler soil temperatures, the rotation system, crop selection, weather conditions, and the management of the LM (chemical stunting and mowing). The cooler soil temperatures can have positive or negative impacts depending on the circumstances such as weather, type of crop, and time of year.

Based on the four important characteristics of a LM, piligrass has proven it can be used successfully as a LM. The important characteristics of choosing a LM are rapid establishment to prevent soil erosion and to control weeds; adequate adaptability and persistence to allow for entrance into the field; tolerance of drought and low-fertility soils; and a minimal maintenance budget associated with fertilizer applications, mowing and chemical stunting (Paine & Harrison, 1993; Arakaki, 2003). However, the use of piligrass as a LM in this study did not increase crop production.

Reduced yield in the LM system is a major problem when using LM because a reduction in crop yield directly affects the cost production of a farmer obtains from a crop. However, the cost loss associated with crop reduction can be substituted by a reduction in other services such as soil tilling, the labor cost of hand-weeding, pesticides, and pre-emergence herbicides (DeFrank, 1990, Leary and DeFrank, 2000; Hartwig & Ammon,

2002). Sustaining ecological health and the conservation of a native Hawaiian plant should also be taken into consideration when deciding to use piligrass as a LM system.

4.2. Further research

The research results indicated that piligrass LM reduced crop yields due to N-immobilization. Therefore, an advanced study needs to be conducted to achieve a better ecological understanding of the perennial piligrass on the soil. Furthermore, field experiments and laboratory incubation studies can be performed to determine immobilization and mineralization rates of nitrogen during decomposition of plant residues in the soil (Stojanovic & Broadbent, 1956). The incubation study can also be used to determine the release of any inhibitory substances that can impact crop growth (McCarty & Bremner, 1986). In addition, comparing piligrass LM with a N- fixation crop or a crop that requires less nitrogen might be useful. Improving the piligrass LM management includes wider spacing and higher chemical rates for a higher level of stunting.

4.3. Literature citations:

1. Arakaki, A. S., 2003. Growing vegetables in living shield cover crop. Unpublished case study. Cooperative state research, education, and extension service, U.S. Department of Agriculture and the Agriculture Experimental Station, Utah state Univ.
2. DeFrank, J., 1990. Ground cover management in reduce tillage cropping system in Hawai'i, p.51-53. In. Proc. Intl. Conf. Agr: 21st Century, 12-14 Oct., Maui, Hawai'i.
3. Hartwig, N.L., and Ammon, H.U., 2002. 50th anniversary-invited article, cover crop and living mulches. Weed Science, 50: 688-699.
4. Leary, J. and J. DeFrank, 2000. Living mulches for organic farming systems. HortTechnology 10(4): 692-698.
5. McCarty, G.W. and J.M. Bremner, 1986. Effects of phenolic compounds on Nitrification in soil. Journal of Soil science society of America. 50:920-92.
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7. Stojanovic, B.J. and F.E. Broadbent, 1956. Immobilization and mineralization rates of Nitrogen during decomposition of plant residues in soil. Journal of soil science society of America 20:213-218.