CULTURAL MANAGEMENT OF INSECT PESTS: USING BARRIER CROPS
TO PROTECT AGAINST INSECT INFLECTED PLANT IMPAIRMENTS

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Chapter 1

Using cultural management strategies to protect crops against aphids and whiteflies: A mini review

Abstract

A review of several cultural management strategies for managing of aphids, whiteflies, and their associated diseases and phytotoxemias was conducted. The use of reflective mulches has been extensively studied and is being successfully used to help manage aphids, whiteflies and other insect pests. Manipulation of planting date or crop sanitation alone did not consistently reduce insect pest populations. However, cultural tactics such as alteration of soil fertility, conservation tillage and crop diversification often reduced aphid and whitefly densities on the cash crop. Cultural management tactics applied singly often suppressed insect pest densities but did less often improved plant health and yield. The feasibility of integrating one or more cultural control tactics to suppress insect pest densities as well as improve plant health is being discussed.

Key words: Cultural control, crop manipulation, Aphididae, Aleyrodidae

Introduction:

Aphids and whiteflies are among the most serious agricultural pests impacting cropping systems. These insects cause major economic losses in many crops world-wide, through physical destruction of plant cells or inflicting plant impairments (e.g. diseases, disorders). Several crops are highly susceptible to aphid-transmitted viruses and whitefly
caused viruses and phytotoxemias. Current management strategies for aphids and whiteflies involve the use of insecticides, mineral oils, host plant resistance, pheromone derivatives and biological control methods. However, these management practices have been found ineffective and unreliable in controlling aphid-transmitted non-persistent virus (Hooks and Fereres, 2006). Cultural management strategies that reduce pesticide applications, and can be incorporated with other management tactics are considered more reliable and environmentally safe.

This paper reviews several cultural control strategies aimed at reducing pests densities and their damage to crops. Cultural control practices reviewed include the use of row covers, alteration of planting date, field sanitation, crop fertilization, cultivation practices and crop diversification. Among which, crop diversification has received considerable research attention. Root (1973) suggested why fewer herbivores are found in more diverse than simple habitats: (1) greater abundance of natural enemies and (2) reduced availability of necessary resources in vegetationally diverse habitats. Methods of crop diversification examined include the use of cover crops (Altieri et al., 1985; Andow et al., 1986; Costello, 1994; Costello and Altieri, 1995; Hooks et al., 1998; Frank and Liburd, 2005; Hilje and Stansly, 2008), mixed cropping or intercropping (Perrin and Phillips, 1978; Gold et al., 1989, 1990; Smith et al., 2000; Bukovinszky et al., 2003), barrier cropping (Toba et al., 1977; Jones, 1993; Difonzo et al., 1996; Page et al., 1999; Fereres, 2000), organic mulches (Jones, 1994; Summers et al., 2004; Sauke and Doring, 2004; Schmidt et al., 2004), and naturally occurring weeds (Smith, 1976a; Smith, 1976b; Altieri et al., 1985; Showler and Greenberg et al., 2003; Bezerra et al., 2004). Herbivore response to habitat diversification varied among the studies mentioned above. However,
in most instances their densities were lower in mixed vegetation cropping systems. The main objective of the review is to increase the awareness of cultural management strategies for managing aphid and whiteflies.

Cultural control is the deliberate alteration of production systems. Either the agroecosystem itself or specific crop production practices are modified to make the crop less attractive to herbivores. The use of row covers, altering planting date, field sanitation, fertilization, cultivation practices, and crop diversification influences on pest populations are reviewed and discussed.

Row covers

The use of reflective mulch to deter insects has received considerable attention. Reflective mulches emit short wavelengths and interfere with the vision and behavior of insects, preventing or decreasing contact with the susceptible crop (Antigus, 2000). Brown et al. (1993) found that the use of silver reflective mulch reduced aphid population and the incidence of virus in summer squash, *Cucurbita pepo* compared to bare-ground cultivation. Brust (2000) showed that plastic reflective mulch could significantly reduce the number of alatae aphids landing in pumpkin, *C. pepo* plantings compared to no mulch. Staplenton and Summers (2002) found cantaloupe, *Cucumis melo* grown in polyethylene reflective mulch had fewer numbers of alighting aphids and delayed the onset of virus incidence compared to bare soil.

Use of polyethane row covers reduced densities of the whitefly, *Bemisia tabaci* and aphid, *Aphis gossypii* and the incidence of squash silverleaf in zucchini compared to bare-ground (Costa et al., 1994). Smith et al. (2000) found silver reflective mulch reduced egg densities of *B. argentifollii* in snap bean, *Phaseolus vulgaris* than bare-
ground. Similarly, Summers and Staplenton (2002) found UV reflective mulch reduced population densities of *B. argentifoli* nymphs and the incidence of silverleaf in pumpkin and zucchini. UV reflective mulch delayed colonization of *B. argentifoli* and the incidence of aphid borne virus in zucchini squash, suggesting that whitefly adults as well as alatae aphids respond similarly to reflective mulches (Summers et al., 2004).

**Planting date**

Cultural practices that involve altering the crop planting date may cause a temporal disjunction between host availability and pest activity. Slosser et al. (1992) studied the influence of cotton planting date on aphids, *A. gossypii* Glover and the bandedwinged whitefly, *Trialeurodes abutilonolona* (Haldeman). The study showed that both aphid and whitefly densities reached their peak abundance during August. Therefore, early planting of cotton during mid-May was recommended in Texas. Similarly, early planting of pumpkin, *C. pepo* reduced densities of aphids and resulted in increased yield (Brust, 2000). Karungi et al. (2000) found that early planting of cowpea, *Vigna unguiculata* reduced aphid infestation and resulted in increased cowpea yield in Uganda. Whitefly vectors may also be avoided by planting early or late season. For example, Ucko et al., (1998) found that whitefly populations and sources of virus were low during June - July in the Arava region of Israel. Therefore, a one month fallow period was declared during this time. As a result, no economic damages caused by whitefly-borne viruses were recorded after the fallow period. Urias-Lopez et al. (2004) found that populations of the sweet potato whitefly, *B. tabaci* varied significantly by planting date, but aphid population remained similar throughout the season. However, late planting (16
November or later) of watermelon, *Citrullus lanatus* resulted in higher levels of virus infected plants.

**Sanitation**

Field sanitation involves removing weed hosts and rouging infected plants that may host pest and diseases of cash crops. In general, it is believed that removal of weeds from cropping areas can help reduce the availability of alternate hosts for vectors and reduce potential sources of virus inoculum. Studies conducted in the Jordan Valley of Israel showed that eradicating weed species, *Cynachum acutum* in June-July before peak migration of whiteflies may help control the spread of *Tomato yellow leaf curl virus* (TYLCV) in tomato (Cohen et al., 1988).

In some cases, the importance of weeds is negligible compared to host crops. For example, Ucko et al. (1998) found weeds did not appear to be an important source of TYLCV, because no infected weeds were detected in vegetable fields in Arava region of Israel. Thus, it appeared that cultivated crops were the major cause of viral epidemics. Hilje et al. (2001) in his review also concluded that there were not enough documentation to indicate that whitefly transmitted viruses could be successful control through weed removal alone.

**Fertilization**

Cultural methods such as crop fertilization can affect the susceptibility of plants to insect pests by altering their nutrient levels. Soils with high organic matter content harbor lower abundances of several insect herbivores. However, excessive use of inorganic fertilizer can cause nutrient imbalance and lower pest resistance (Altieri and Nicholls, 2003). Altieri et al. (1998) conducted a study in which broccoli was grown with varying
fertilization regimes (synthetic versus organic). He found that the abundances cabbage aphid (Brevicoryne brassicae) and flea beetle (Phyllotreta cruciferae) were consistently lower in organically fertilized broccoli than synthetic. The reduction in aphid and flea beetle in organically grown broccoli was attributed to lower levels of free N in the foliage. Similarly Ponti et al. (2007) found that application of compost in a broccoli grown with mustard (Brassica spp.) or buckwheat (Fagopyrum esculentum) significantly reduced aphid population than synthetic fertilizer. Morales et al. (2001) found that corn fields treated with organic fertilizer applied for at least 2 years hosted fewer aphids (Rhapalosiphum maidis) than corn treated with synthetic fertilizer. This difference was attributed to higher concentration of N in corn in synthetic fertilized plots.

Conversely, Costello and Altieri (1995) found the number of Myzus persicae to be marginally higher in broccoli with compost than synthetic fertilizer treatment. Similar study conducted by Costello (1994) found higher levels of B. brassicae in broccoli with compost fertilizer than synthetic fertilizer. Karungi et al. (2006) conducted a study in which white cabbage was grown with compost derived from market crop waste and conventional fertilizer (NPK) and found higher levels of aphid infestations in cabbage when compost was used than the conventional fertilizer. However, compost amended cabbage sustained higher aphid infestation due to larger plant size and resulted in higher marketable yield compared to conventionally fertilized plots.

Bi et al. (2001) found higher numbers of adult and immature whiteflies (B. argentifolii), as well as increased in honey dew production by whiteflies on cotton plant when increased amounts of N fertilizer was applied. Similarly, the number of eggs and nymphs on gerbera (Gerbera jamesonii H. Bolus) were greater with increased
concentration of N fertilizer (Ortega-Arenas et al., 2006). Bi et al. (2003) also showed that plant nutrient levels, particularly proteins and amino acids, increased with increasing rates of N fertilizer that resulted in higher densities of whiteflies. Therefore, soil fertility management can affect plant quality, which subsequently impacts insect abundance and associated herbivore damage.

Field cultivation

Physical disturbance of the soil caused by tillage and residue management is a crucial factor determining species diversity in agroecosystems (Altieri, 1999). Changes in cultivation practices can have adverse or beneficial effects on insects and their natural enemies. Hammond and Stinner (1987) conducted a study to investigate the population densities of soybean foliar insects in three different tillage practices (mouldboard ploughed, reduced and no-tillage). The overall impact on herbivore densities were variable on soybean, however, the abundance of predators, Nabids spp. was found higher in no-till compared to tilled habitats. Hesler and Berg (2003) in their study found that conservation tillage increased surface residue and provided favorable microhabitat that leads to greater infestation of cereal-aphid, R. padi (L.) in spring seeded barley and wheat than pre-plant tillage. Kendall et al. (1991) found Barley yellow dwarf virus (BYDV) caused by aphids was more prevalent in ploughed than direct drilled winter barley. The reduced incidence of BYDV in direct drilled plots was attributed to reduced densities of aphids due to increased abundance of predators (Linyphidae, Carabidae and Staphylinidae) in the direct drilled plots.

Rice and Wilde (1991) demonstrated that conservation tillage has neutral impact on densities of aphid predators in winter wheat. There was no differences in aphid
predators *Coleomegilla maculata lengi* Timberlake, *Coccinella septempunctata* L., *Scymnus* spp. or *Nabis* spp. densities across tillage treatments (conventional-, reduced-, and no- till). The study concluded that aphid predators are highly mobile and can move long distances in search of prey, and that their densities in experimental plots could be more influenced by aphid densities than tillage practices. Conservation tillage favors carabid communities than ploughing and carabids have been found to reduce cereal and sugar beet aphid populations in their early colonization phase, mainly by foraging on aphids that fell from the plant (Kromp, 1999). Conversely, Caracamo (1995) found that carabid communities were significantly higher in conventional tillage than conservation tillage in barley. Results of these studies showed varied response of insect to the tillage practices. However, Stinner and House (1990) concluded that reduced- or no- tillage cultivation practices did not alter foliage densities of arthropod pests but can support greater abundance and activity of natural enemies thereby reducing pest densities.

**Crop diversification**

**Cover crops**

Cover crops are grown within cash crops to suppress weeds, reduce erosion, enhance soil fertility and improve soil quality. Several studies have shown that crops grown with living mulches harbor significantly fewer aphids (Altieri et al., 1985; Andow et al., 1986, Costello, 1994; Costello and Altieri, 1994; Hooks et al., 1998; Frank and Liburd, 2005) and whiteflies (Smith, 1976a; Hooks et al., 1998; Frank and Liburd, 2005; Hilje and Stansly, 2007) compared to monoculture cropping systems. There are also several examples that demonstrate the successful use of under sown living mulches to
reduce plant viruses caused by aphids and whiteflies (Hooks et al., 1998; Frank and Liburd, 2005; Hilje and Stansly, 2008).

The study conducted by Hooks et al. (1998) showed a reduction in the number aphids and whiteflies, delayed incidence of aphid transmitted virus and reduced silverleaf severity symptoms. Frank and Liburd (2005) also found similar results in zucchini grown with the buckwheat and white clover living mulches. Hilje and Stansly (2008) found a living ground cover of perennial peanut reduced whitefly numbers and delayed the onset of Tomato yellow mottle virus (ToYMoyV) in tomato. Thus, it appears that the presence of cover crops within a cropping systems can help reduce insect pest densities and the occurrences of insect caused diseases and phytotoxemias. The main concern in living mulch cropping systems is potential yield reductions caused by competition between the living mulch and cash crop (Andow, 1986; Brandstaer, 1998; Hooks and Johnson, 2004). Therefore, careful consideration should be given in choosing cover crops and a management practices to avoid competition.

**Mixed cropping**

Intercropping or mixed cropping is a common cultural practice in most developing countries whereby two or more cash plants are grown within the same field. Increasing within-field diversification through intercropping or mixed cropping often reduces insect pest populations compared with monoculture plantings (Root, 1973, Perrin and Phillips, 1978). In a green house study, Perrin and Phillips (1978) demonstrated a reduction in Plutella xylostella and cabbage whitefly, Aleyrodes brassicae oviposition and damage in a cabbage-tomato intercropping systems compared to cabbage monoculture. Gold et al. (1989, 1990) found that whitefly numbers were lower and
cassava yield was higher in cassava-cowpea intercrop systems compared to cassava monoculture. Bukovinszky et al., (2003) demonstrated reduced number \textit{P. xylostella} and \textit{B. brassicae} in a Brussel sprout-barley intercropping system compared to monoculture Brussel sprout.

Despite several studies suggesting lower pest densities in intercrop or mixed cropping systems, Smith et al. (2001) demonstrated intercropping bean, \textit{Phaseolus vulgaris} L. with poor and non-host plants (i.e., cabbage, \textit{Brassica oleracea} L.; rossell, \textit{Hibiscus sabdariffa}; maize, \textit{Zea mays} L. cilantro, \textit{Coriandrum sativum} L.) did not reduce whitefly numbers in beans compared to monoculture.

\textit{Border plants/barrier cropping}

Several authors have proposed that a border/barrier crop may act as sink for aphid-transmitted non-persistent viruses (ATNPV). It is believed that aphid vectors that land on the barrier crop lose the virus from their stylets while test probing. Toba et al. (1977) demonstrated that a “protector crop” of wheat, \textit{Triticum aestivum}, significantly delayed the frequency and severity of ATNPV. Similarly Jones (1993) found a reduction in the incidence of \textit{Bean yellow mosaic virus} (BYMV) infecting narrow leafed lupin \textit{(Lupinus angustifolius)} using wheat and oat as crop borders. Difonzo et al. (1996) showed that crop borders of soybean, sorghum and wheat did not reduced landing rates of aphids. However, incidence of \textit{Potato virus Y} (PVY) was significantly reduced in seed potato compared to fallow border cultivation. Page et al. (1999) found that intercropping maize with millet and bean reduced numbers of \textit{Cicadulina} spp. and the incidence of \textit{Maize strik virus disease} (MSVD) compared with pure maize stand. Fereres (2000) found a significant reduction in the spread of \textit{Potato virus Y} (PVY) and \textit{Cucumber}
mosaic virus (CMV) in pepper plants using maize or sorghum as barrier crops compared to bare-ground. Thus, several studies have demonstrated that intercropping can be used to reduce insect caused plant viruses in the main crop.

Weeds

Weeds influence the diversity and abundance of insect herbivore and their natural enemies in a cropping system. Certain weeds such as those in the family Umbelliferae, Leguminosae and Compositae may harbor and support complexes of beneficiary arthropods that help suppress insect pest populations (Altieri, 1999). A study conducted by Smith (1976a) showed that higher numbers of alatae *B. brassicae* and *M. persicae* were found in weed-free than weedy Brussel sprouts. Numbers of *A. brassicae* (adults) and *Pieris rapae* (eggs, pupae and larvae) were also found higher in weed-free than weedy Brussel sprouts. Smith (1976b) also found higher numbers of natural enemies (mostly Syrphidae) on weed-free than weedy Brussel sprouts. It was concluded that increased natural enemies is partly responsible for the higher abundance of *B. brassicae,* that might have attracted natural enemies in weed free Brussel sprouts than in a weedy crop.

Altieri et al. (1985) found aphid densities in tomato were higher in weedy than red clover living mulch. The higher densities of aphids in the weedy plots were mainly due to the presence of the weed, *Sonchus oleraceus.* Norris and Kogan (2000) also found that aphids inhabited *Sonchus* spp., but that it may also support various beneficiary insects such as parasitic wasps, lady beetles and syrphid flies. Similarly, population densities of predacious soil arthropods (Carabidae, Staphylinidae, spiders) were higher in weed cover than bare soil tomato (Altieri et al., 1985).
A study conducted in cauliflower showed that flea beetle *P. cruciferae* and aphid *B. brassicae* were lower in weedy habitat compared to bare-soil cauliflower (Altieri et al., 1985). However, it was not clear what caused reduced densities of insect herbivores in weedy habitats. Showler and Greenberg (2003) found weed free cotton harbored more cotton aphids (*A. gossypii*) and silverleaf whiteflies (*B. argentifolii*) than weedy cotton. They suggested that dense weed growth might have impeded both whiteflies and aphids from settling in the cotton plants. Similarly, Bezerra et al. (2004) demonstrated higher infestation of *B. tabaci* on tomato when planted solely, compared to tomato grown with weeds (*Acanthospermum hispidum, Amaranthus deflexus, Datura stramonium, Euphorbia heterophylla*). The study suggested that weeds can dilute the whitefly densities in the field, resulting in lower infestation of whiteflies on tomato plants.

**Organic mulches**

Straw mulches have been studied for its ability to reduce aphid infestation and virus incidence. Jones (1994) found that applying straw evenly to the soil surface decreased landing rates of aphids and suppressed *Bean yellow mosaic virus* (BYMV). The study conducted by Sauke and Doring (2004) showed straw mulches did not reduced landing rates of alatae aphids but significantly reduced the number of aphid infested leaves as well as *Potato virus Y* (PVY) incidence in potato tubers. Similarly, Summers et al. (2004) found that wheat straw mulch delayed colonization of *B. argentifolii* and the incidence of aphid borne viruses in zucchini compared to bare-ground. The study conducted by Schmidt et al. (2004) found reduced density of cereal aphids, *R. padi* on spring wheat grown with straw mulch than in bare-ground. Reduced aphid densities in mulched plots were mainly attributed to greater abundance of predators and parasitoids.
Hence, organic mulches can be effectively used to reduce pest densities and disease incidence.

**Conclusion and Future research needs**

This review uncovered several cultural practices that can be used to help manage aphids and whiteflies. Among them, the use of reflective mulches has been extensively studied and is being widely used to help manage aphids, whiteflies and other insect pests. Manipulating planting date or practicing crop sanitation alone did not consistently reduce pest populations. Thus, these practices may need to be integrated with other management tactics. For example, Brust (2000) demonstrated that integrating reflective mulch with early planting dates helped suppressed aphid populations and reduced incidences of aphid transmitted viruses in watermelon. Other cultural manipulation tactics such as alterations of soil fertility, conservation tillage, and crop diversification often reduced insect pest densities on the cash crop.

Several studies have shown reduced herbivore densities in vegetationally diverse agroecosystems. However, reasons for lower herbivore densities in diverse vegetation are not clearly known. Many have attributed these reductions to enhanced activity of natural enemies, reduced colonization of insect pests or reduced plant quality (Root, 1973, Altieri et al. 1985; Altieri and Nicholls, 2003; Bukovinszky et al., 2004). Therefore, future research should focus on understanding the mechanisms responsible for reduced herbivore densities in vegetationally diverse agroecosystems. Further, crops grown with companion plants often resulted in lower aphid numbers and reduced incidence of aphid transmitted viruses. Fereres (2000) demonstrated the mechanism underlying reduced incidence of aphid transmitted non-persistent viruses in diverse plantings. This was one
of the few studies that examined the mechanisms responsible for lower pest densities. Finally, crops grown in vegetationally diverse habitat often resulted in reduced crop growth due to competition with the companion plants. Competition seems to be minimized either through the application of compost or the use of cover crops that supplied soil N. For example, in several instances, broccoli grown with living mulches in the presence of a compost resulted in reduced densities of aphids and increased crop growth and yield (Costello, 1994; Costello and Altieri, 1995; Ponti et al., 2007). This lack of competition probably occurred because the legumes used were low growing. Although they supplied N if they were tall probably competition would have still occurred. Brandaeter (1998) found cabbage grown with leguminous living mulches (subclover and white clover) and timely rototilling of living mulches effectively suppressed weeds and reduced competition between cabbage and living mulches. Thus, more efforts should be devoted to limiting competition in vegetationally diverse cropping systems.
References


Bi, J. L., Toscano, N. C., Madore, M. A., 2003. Effect of urea fertilizer application on soluble protein and free amino acid content of cotton petioles in relation to


CHAPTER 2

Effects of companion plants on the population dynamics of whiteflies and squash silverleaf disorder in zucchini plantings

Abstract

Field experiments were conducted to evaluate the effects of several companion plants on population densities of the whitefly, *Bemisia argentifolii* Bellow and Perring and the incidence of squash silverleaf disorder in zucchini, *Cucurbita pepo* L. on Oahu, Hawaii. Two cover crops, buckwheat *Fagopyrum esculentum* Moench and white clover *Trifolium repens* L. or sunn hemp, *Crotolaria juncea* L. and an intercropped vegetable, okra *Abelmonchus esculentus* (L.), were evaluated as companion plants during 2005 and 2006, respectively. Population densities of whiteflies varied during the two field studies. Zucchini intercropped with okra had lower numbers of adult whiteflies and resulted in significantly lower severity of silverleaf symptoms than the cover crop habitats in 2005. During 2006, zucchini grown with sunn hemp had significantly lower numbers of all whitefly stages (egg, immature and adult) and less silverleaf severity symptoms than buckwheat.

Keywords: Companion plant, zucchini, whitefly, squash silverleaf disorder, phytotoxemia

Introduction

In Hawaii, the Silverleaf whitefly, *Bemisia argentifolii* Bellows and Perring is an important zucchini (*Cucurbita pepo* L.) pest (Costa et al., 1993a). *B. argentifolii* induces
a phytotoxemia known as squash silverleaf disorder (SSL). Only immature stages of *B. argentifolli* are capable of causing SSL (Yokomi et al., 1990, Costa et al., 1993b). SSL causes a reduction in photosynthesis (Burger et al., 1988) and plants with silvered leaves may suffer significant yield reduction compared to uninfected plants (Costa et al., 1994). In addition to SSL, excessive whitefly feeding can cause a reduction in plant vigor (McAuslane et al., 2004) and irregular fruit ripening (Cohen et al., 1992). Whiteflies are also capable of transmitting viruses to healthy plants (Gibson et al., 2004; Hilje and Stansly, 2008). Attempts to manage *B. argentifolli* with the use of insecticides are not always successful, and over dependence on insecticides have resulted in their building up resistance to some insecticides (Omer et al., 1992). Because of the limitations of pesticides in managing whiteflies in cucurbits, alternative pest management strategies are needed.

Several studies have shown reduced densities of insect herbivores in vegetationally diverse agroecosystems compared to monoculture systems (Root, 1973; Smith, 1976; Perrin and Phillips, 1978; Andow et al., 1986; Theunissen and Schelling, 1996; Altieri, 1999; Hooks and Johnson, 2002; 2004). Further, several studies have shown that whitefly densities are reduced in mixed cropping systems (Smith, 1976; Gold et al., 1989) and crops inter-planted with cover crops (Hooks et al., 1998; Frank and Liburd et al., 2005; Hilje and Stansly, 2008).

The use of reflective mulches as a cultural management practice to control silverleaf whitefly in cucurbits has been well studied (Costa et al., 1994, Summers and Staplenton, 2002; Summers et al., 2004). However, the use of crop diversification as a cultural management practice to control SSL has received limited research attention. Thus, the
purpose of this study was to determine whether cover crop and intercrop systems could be used effectively to reduce populations of whiteflies and the occurrence of SSL in zucchini plantings.

Materials and Methods

Field experiments were conducted on the island of Oahu at the University of Hawaii’s Poamoho Research Station in Wailua and Aloun Farms in Ewa during years 2005 and 2006, respectively. Zucchini (variety “Spineless Beauty”, Syngenta seeds Inc.) was used as the main crop. Two cover crops, buckwheat *Fagopyrum esculentum* Moench (Peaceful Valley Farm Supply, Grass Valley, CA); white clover *Trifolium repens* L. (variety “New Zealand” Peaceful Valley Farm Supply, Grass Valley, CA) and an intercropped vegetable, okra *Abelmonchus esculentus* (L.) (variety “Dwarf Green Long”, Crossman Seeds), were evaluated as barrier plants during 2005. Because white clover failed to establish on numerous occasions in 2006, it was replaced by sunn hemp, *Crotolaria juncea* L. (variety “Tropic Sunn”, USDA-NRCS). The cover crop buckwheat, was chosen because it was found to be an effective companion plant in reducing the occurrence of SSL in an earlier study (Hooks et al., 1998), but it senesces early during zucchini growth cycle. Cover crops white clover and sunn hemp, and a vegetable intercrop; okra were chosen because they have a longer growing season and thus might suppress whiteflies in zucchini for a longer period. Additionally, okra and sunn hemp are tall with respect to zucchini and thus may act as physical barriers and reduce the number of whiteflies entering the zucchini plantings.

The experiment was set up in a randomized complete block design with each treatment replicated 4 times. Each plot measured 13.2 m x 13.2 m. Zucchini plantlets
were transplanted in between rows of the companion plants in diculture plots. Ten rows of zucchini transplants were inter-planted so that each row was surrounded on either side by a row of companion plants. The intra- and inter-row spacing was 1.2 m and each plot contained 110 zucchini plants. Bare-ground plots contained a total of 11 rows of zucchini plants and each plot was separated by a minimum of 5 meters.

Twelve to 14 day old greenhouse grown zucchini plantlets were transplanted into the barrier plant treatment plots on September 12, 2005 and September 3-5, 2006 at Poamoho and Aloun Farms, respectively. Sunn hemp was pruned regularly to avoid competition with the zucchini plants through shading. Okra was pruned on occasion to mimic a common cultural practice in growing this crop. Border and plot areas were kept weed free, whenever needed by applying glyphosate (Roundup®, Monsanto Corporation) and hand weeding, respectively. Rows of sudan grass (Sorghum bicolor var. sudanese Moench) planted around the experimental site were sprayed with OF 120 NF Naturalyte fruitfly bait (OF 120®, Dow AgroScience) to help manage melon fly populations. *Bacillus thurigiensis* var. *kurtaski* (Crymax®, Certis USA) was sprayed on zucchini plants at a rate of 1.2 g. per liter of water using a hand pumped knap sack sprayer to manage pickleworms, *Diaphania nitidalis* (Stoll). Additionally, Spinosad (Success®, Dow AgroScience) was also sprayed on zucchini plants at the rate of 2.2 ml. per liter water to help manage pickleworms at Aloun Farms, one week prior to zucchini harvest. During both years, zucchini plants were fertilized with urea at the rate of 25 grams per plot.

**Foliar counts**

On each sampling date, 20 zucchini plants were randomly selected in each treatment plot for counting adult whiteflies. Whiteflies on the underside of leaves were counted
after gently turning over the most recently mature leaf of each randomly selected zucchini plant (Hooks et al., 1998). When whitefly densities were high (>50 per leaf) counts were taken from half of the leaf and multiplied by 2 to estimate whole leaf total. Sampling of whitefly adults was conducted weekly from October 5 (9 DAP) to November 9 (44 DAP) and 12 September (7 DAP) to 17 October (42 DAP) in 2005 and 2006, respectively.

**Cork borer counts**

To estimate the number of whitefly eggs and immature stages (nymphs and pupae), a cork borer was used to remove a 3.14 cm² circular disc sample from zucchini leaves of 15 randomly selected plants per plot (Smith et al., 2000). The leaf samples were partitioned according to plant stratum (upper, n = 5; medium, n = 5 and lower, n = 5 leaves). Disc samples were collected from the area half way between the leaf tip and petiole, and half way between the leaf margin and mid vein. Leaf discs were placed in a plastic bag and transported to the laboratory in a chilled cooler. All whitefly eggs and immature stages found on the abaxial leaf surface were recorded using a dissecting microscope. Leaf disc sampling was conducted weekly from October 13 (17 DAP) to November 10 (43 DAP) and September 28 (23 DAP) to October 21 (46 DAP) in 2005 and 2006, respectively.

**Silverleaf evaluation**

Squash silverleaf severity symptoms were recorded from all plants in three interior rows of each treatment plot. Rows were randomly selected each inspection date. Silverleaf severity symptoms were rated on the new leaf growth on a scale of 0 - 5 (0 = no silvering to 5 = 95 to 100% leaf silvering) (Paris et al., 1987; Hooks et al., 1998). Plants were rated for squash silverleaf symptoms at 10 day intervals from October 6 (10
DAP) to October 26 (30 DAP) and 21 September (16 DAP) to 12 October (37 DAP) in 2005 and 2006, respectively.

**Statistical analyses**

Data from arthropod counts were analyzed by using mixed model analysis of variance (PROC MIXED, SAS Institute). The model was constructed to examine the main effect of treatment by date, and block was designated as a random factor. Within the model, the following pre-planned orthogonal contrasts were conducted: diculture (zucchini + intercrop and zucchini + cover crops) vs. monoculture (zucchini bare-ground); (zucchini + intercrop) vs. (zucchini + cover crops) and (zucchini + buckwheat) vs. (zucchini + clover or sunn hemp). All data for arthropod counts were $\log_{10}(x + 1)$ transformed to stabilize variances. Reported means are from non-transformed data.

**Results**

**Foliar counts**

The population density of adult whiteflies was generally low (~1.0 per leaf) during the 2005 study. Zucchini grown with cover crops had significantly higher number of adult whiteflies compared to the intercrop treatment on the last three sampling dates from 30 to 44 DAP (30 DAP: $F_{1,9} = 11.83; P = 0.0074$; 37 DAP: $F_{1,9} = 12.54; P = 0.0063$ and 44 DAP: $F_{1,9} = 9.96; P = 0.0116$, Figure 1). Unlike year 1, adult whitefly density was high (~11.0 per leaf) during the 2006 study. The diculture treatments had significantly higher numbers as compared to monoculture treatment on 14 and 28 DAP (14 DAP: $F_{1,9} = 5.95; P = 0.0374$, 28 DAP: $F_{1,9} = 18.36; P = 0.002$). Whitefly numbers were higher in the okra-intercropped than cover crop treatments at 7 DAP ($F_{1,9} = 9.28; P = 0.0139$). There was a significantly higher number of whiteflies in buckwheat compared to sunn hemp treatment...
from 7 to 28 DAP (7 DAP: $F_{1,9} = 12.24; P = 0.0067$; 14 DAP: $F_{1,9} = 40.05; P = 0.0001$; 21 DAP: $F_{1,9} = 24.87; P = 0.0008$ and 28 DAP: $F_{1,9} = 11.11; P = 0.0087$, Figure 3).

Cork borer counts

Numbers of whitefly eggs (~0.6 per leaf disc) and immature stages (~0.07 per leaf disc) were low during the 2005 study. The abundance of whitefly eggs was similar during all sampling dates and was not significantly different among the treatment habitats (Figure 2A). Unlike egg counts, numbers of immature stages were significantly higher in bare-ground contrasted with diculture treatments during the last two sampling dates (37 DAP: $F_{1,9} = 12.64; P = 0.0062$; 43 DAP: $F_{1,9} = 8.00; P = 0.0198$, Figure 2B). During 2006 study, numbers were significantly higher in buckwheat contrasted with the sunn hemp treatment from 23 to 37 DAP (23 DAP: $F_{1,9} = 14.18; P = 0.0044$; 30 DAP: $F_{1,9} = 12.97; P = 0.0057$ and 37 DAP: $F_{1,9} = 5.28; P = 0.0472$, Figure 4A). Number of immature stages was also significantly higher in buckwheat contrasted to sunn hemp from 23 to 37 DAP (23 DAP: $F_{1,9} = 22.16; P = 0.0011$; 30 DAP: $F_{1,9} = 9.77; P = 0.0122$ and 37 DAP: $F_{1,9} = 5.62; P = 0.0412$, Figure 4B).

Silverleaf evaluation

Silverleaf symptoms were not observed on the first sampling date (10 DAP) in the 2005 study. There was significantly lower severity symptoms in zucchini intercropped with okra contrasted to cover crop treatments on two sampling dates (20 DAP: $F_{1,9} = 23.19; P = 0.001$; 30 DAP: $F_{1,9} = 18.32; P = 0.002$, Table 1). Silverleaf severity symptoms were significantly lower in bare-ground contrasted to diculture treatments on the final sampling date (30 DAP: $F_{1,9} = 7.33; P = 0.021$). During the 2006 study, mean silverleaf severity symptoms were highest on zucchini plants in buckwheat plots and were
significantly higher in buckwheat contrasted with sunn hemp plots on each sampling date
(16 DAP: \( F_{1,9} = 8.35; P = 0.0179 \); 26 DAP: \( F_{1,9} = 5.91; P = 0.0379 \) and 37 DAP: \( F_{1,9} = 20.89; P = 0.0013 \), Table 2).

**Discussion and conclusions**

Whitefly population densities varied during the two field studies. During the 2005 study, zucchini intercropped with okra had lower numbers of adult whiteflies and this resulted in significantly less silverleaf severity symptoms than cover crop habitats. During the 2006 study, zucchini grown with sunn hemp had significantly lower numbers of all whitefly stages (egg, immature and adult) and significantly less silverleaf severity symptom than buckwheat habitat.

At the Poamoho site, low whitefly numbers were encountered in all treatment plots. Thus, silverleaf severity symptoms were also low and no differences could be detected in treatment habitats on most dates. Similarly, Costa et al. (1994) and Hooks et al. (1998) found low population of whiteflies at Poamoho during their studies. In contrast, the Aloun Farms study site had higher whitefly populations and differences could readily be detected among treatments. During both studies, mean silverleaf severity rating declined over time in all treatment plots. This may be partially contributed to the early occurrences of aphid-transmitted non-persistent virus. Leaves that were mottled twisted and deformed because of viruses often display low silverleaf symptoms. Further, diculture treatments had higher silverleaf severity symptoms than monoculture at Poamoho where bare-ground treatments contained a higher percentage of virus-infected zucchini plants.

Plants intercropped with okra had the lowest silverleaf severity symptoms and were significantly lower compared with cover crop treatments. However, Hooks et al. (1998)
found the mean silverleaf severity symptoms were lowest on zucchini in buckwheat treatments on all sampling dates at Poamoho, but that study did not evaluate white clover or okra. In Florida, Frank and Liburd (2005) found a reduction in whitefly densities in zucchini grown with buckwheat compared with monoculture habitats.

However, adult whitefly density was higher in the buckwheat treatment at Aloun Farms. Numbers of whitefly eggs and immature stages were also similarly higher in buckwheat habitat. As expected, the mean silverleaf rating was also significantly higher in buckwheat treatments on all sampling dates. It was noted through casual observations that buckwheat served as a whitefly host and this may have contributed to zucchini plants in these habitats having higher whitefly numbers. Additionally, buckwheat is a short term annual that started to senesce shortly after zucchini planting. Thus, whiteflies may have moved from the buckwheat over to the neighboring rows of zucchini. In contrast, zucchini plants grown in sunn hemp plots had lowest counts of all whitefly stages and silverleaf severity symptoms, respectively.

During both trials, lowest number of whitefly adults and immature stages were found in zucchini intercropped with okra. As such, zucchini intercropped with okra may be a promising system to help suppress whitefly numbers and associated silverleaf disorder. An additional advantage is the potential economic return from okra harvest. Buckwheat appears to work well as a companion crop in lessening the occurrences of non-persistent aphid-borne viruses and silverleaf disorder when whitefly densities are low (Hooks et al., 1998). However, buckwheat may not be an ideal companion plant in areas with high whitefly populations. Under high whitefly pressure, sunn hemp might be the better
companion plant. Therefore, when choosing a companion plant to grow with zucchini, consideration should be made with regards to the insect pest complex and their densities.
References


CHAPTER 3

Effect of barrier plants on the occurrences of aphid-transmitted non-persistent viruses in zucchini

Abstract

The potential of barrier plants to reduce the density of aphid and incidence of aphid-transmitted non-persistent virus (ATNPV) in zucchini, *Cucurbita pepo* L. was evaluated during 2005 and 2006 on Oahu, Hawaii. Two cover crops, buckwheat *Fagopyrum esculentum* Moench and white clover *Trifolium repens* L., or sunn hemp, *Crotolaria juncea* L. and an intercropped vegetable, okra *Abelmonchus esculentus* (L.), were evaluated as barrier plants during the studies. Results of the field experiments showed that densities of alatae aphids in water pan traps did not differ significantly among treatment habitats during both study years. However, foliar counts of aphids were significantly less in diculture than monoculture habitats during 2006. Higher abundances of the aphid predators, coccinelids and chrysopids, were found in monoculture than diculture habitats during 2006. The percentage of zucchini plants showing virus symptoms was significantly lower in diculture than monoculture habitat during both years. Results from field and laboratory experiments supported the hypothesis that barrier plants protected zucchini plants from NPVs by acting as a virus sink.

*Key words: Aphis gossypii, Myzus persicae, barrier plants, Cucurbita pepo*
Introduction

Major pests and diseases of cucurbits in Hawaii include the melon aphid, *Aphis gossypii* Glover and several aphid-transmitted non-persistent viruses (ATNPVs), respectively (Ullman et al., 1991). Non-persistent viruses (NPVs) are transmitted during brief bouts of aphid probing (within seconds to minutes) and are readily lost after the vector probes a healthy plant (Pirone and Perry, 2002). *Zucchini yellow mosaic virus* (ZYMV) and *Papaya ringspot virus* - watermelon strain (PRSV-w), potyviruses, are economically important NPVs. Plants infected with these viruses display severe symptoms including mosaic and chlorotic leaves, stunted plants, deformed fruits, and yield reduction (Blua and Perring, 1989; Ullman et al., 1991). Current control strategies are heavily reliant upon insecticidal sprays (Perring et al., 1999), however, insecticidal sprays are generally ineffective in managing ATNPVs (Budnik et al., 1996; Thackray et al., 2000). Using biological control agents to manage NPVs also has inherent problems. For example, when attacked by natural enemies, aphids emit an alarm pheromone (Nault, 1976; Kunnert et al., 2005), which may trigger increased vector movement and cause greater virus spread. Because of limitations of current management practices, alternative strategies that can either suppress aphids and/or reduce their potential to spread NPVs should be evaluated.

Several studies have demonstrated reduced aphid densities in vegetationally diversified agroecosystems (Smith, 1976; Altieri et al., 1985; Andow et al., 1986; Costello, 1994; Costello and Altieri, 1995; Hooks et al., 1998; Frank and Liburd, 2005). Hooks et al. (1998) showed a reduction in aphid densities and delayed occurrence of ATNPVs in zucchini inter-planted into two living mulch habitats. Other studies have
shown reduced incidence of NPVs in crops grown with barrier plants (Toba et al., 1977; Difonzo et al., 1996; Fereres, 2000). Barrier plants are secondary plants grown in or around the field for the purpose of disease suppression. One mechanism proposed for the lower virus incidence of susceptible plants grown with barrier plants is “the virus sink hypothesis” (Toba et al., 1977). This suggests that infective aphids that land on a barrier plant lose the virus while test probing the plant. Thus, barrier plants can reduce the likelihood of aphids transmitting or spreading virus to the main crop and provide a sustainable means of reducing ATNPVs. Another mechanism proposed is that barrier plants act as physical barrier and thus reduce the number of vectors entering the field (Simons, 1957). As such, the purpose of this study was to determine whether cover crop and intercrop systems could be used to reduce aphid densities and the occurrence of NPVs in zucchini plantings.

Materials and methods

Field experiments were conducted on the island of Oahu at the University of Hawaii’s Poamoho Research Station in Wailua and Aloun Farms in Ewa during years 2005 and 2006, respectively. Zucchini, *Cucurbita pepo* L. (variety “Spineless Beauty”, Syngenta seeds Inc.) was used as the main crop. Two cover crops, buckwheat *Fagopyrum esculentum* Moench (Peaceful Valley Farm Supply, Grass Valley, CA); white clover *Trifolium repens* L. (variety “New Zealand seeds” Peaceful Valley Farm Supply, Grass Valley, CA) and an intercropped vegetable, okra *Abelmonchus esculentus* (L.) (variety “Dwarf Green Long”, Crossman Seeds), were evaluated as barrier plants during 2005. Because white clover failed to establish on numerous occasions in 2006, it was replaced with sunn hemp, *Crotalaria juncea* L. (variety “Tropic Sunn”, USDA-NRCS). The cover
crop buckwheat, was chosen because it was found to be an effective companion plant in reducing the incidence of ATNPV in an earlier study (Hooks et al., 1998). White clover and sunn hemp cover crops and an okra vegetable intercrop were chosen because they have a longer growing season and thus might suppress aphids in zucchini for a longer period than buckwheat. Additionally, okra and sunn hemp are tall with respect to zucchini and thus may act as physical barriers and reduce the number of aphids entering zucchini plantings.

The experiment was set up in a randomized complete block design with each treatment replicated 4 times. Each plot measured 13.2 m x 13.2 m. and zucchini plantlets were transplanted in between rows of the established barrier plants. Ten rows of zucchini transplants were inter-planted so that each row was surrounded on either side by a barrier plant row. The intra- and inter-row spacing was 1.2 m and each plot contained 110 zucchini plants. Bare-ground plots contained a total of 11 rows of zucchini plants and each plot was separated by a minimum of 5 meters.

Twelve to 14 day old green house grown zucchini plantlets were transplanted into the barrier plant treatment plots on September 12, 2005 and September 3-5, 2006 at Poamoho and Aloun Farms, respectively. Sunn hemp was pruned regularly to avoid shading effect on zucchini plants. Okra was trimmed back on occasion to mimic a common cultural practice in this crop. Border and plot areas of the study site were kept weed free, whenever needed by applying glyphosate (Roundup®, Monsanto Corporation) and hand weeding, respectively. Rows of sudan grass (Sorghum bicolor var. sudanese Moench) surrounding the experimental plots were sprayed with GF 120 NF Naturalyte fruitfly bait (GF 120®, Dow AgroScience) to help manage melon fly populations.
Bacillus thurigiensis var kurtaki (Crymax®, Certis USA) was sprayed at a rate of 1.2 g. per liter of water on the zucchini plant using a hand-pumped knap-sack sprayer to help manage pickleworms, Diaphania nitidalis (Stoll). Additionally, Spinosad (Success®, Dow AgroScience) was also sprayed at the rate of 2.2 ml. per liter of water on zucchini plants to help manage pickleworms at Aloun Farms one week prior to zucchini harvest. During both years, zucchini plants were fertilized with urea at a rate of 25 grams per plant.

Alatae aphids monitoring

Alatae aphids were monitored using water pan traps, adjusted to the zucchini plant height. Four traps constructed of clear plexi-glass (diameter 12.5 cm, depth 5.5 cm) were placed in each plot. Two each were randomly placed in the zucchini intra-row and barrier plant rows, respectively. In bare-ground plots, two traps were placed in the zucchini intra-row and inter-row spaces, respectively. Traps were initially set at 6 and 4 DAP in 2005 and 2006, respectively. Aphids were collected from each trap weekly from October 10 to November 14 and September 16 to October 22 in 2005 and 2006, respectively. Aphid samples collected from each traps were taken back to the laboratory and counted under a microscope.

Foliar counts of arthropods

On each sampling date, 20 zucchini plants in each treatment plot were randomly selected for counting arthropods. Arthropods counted included alatae aphids and potential predators (coccinellids, chrysopids) and spiders. All arthropods were counted by gently turning the most recently matured leaf of the selected zucchini plants (Hooks et al., 1998). During the 2005 experiment, sampling was initiated 9 DAP and conducted weekly
from October 5 to November 9. During the 2006 experiment, sampling was initiated 7 DAP and conducted weekly from September 12 to October 17.

To further estimate the number of alatae and apterae aphids, a 3.14 cm$^2$ circular disc sample was removed from the leaves of 15 randomly selected zucchini plants per plot. Leaf samples were partitioned according to plant stratum (upper, n = 5; medium, n = 5 and lower, n = 5 leaves. Disc samples were collected from the area half way between the leaf tip and petiole, and half way between the margin and mid vein of the leaf (Smith et al., 2000). Leaf samples were then placed into plastic bags and transported to the laboratory in a chilled cooler. Aphids found on the abaxial surface were recorded using a dissecting microscope. During the 2005 experiment, sampling was initiated 17 DAP and conducted at weekly intervals from October 13 to November 10. During the 2006 experiment, sampling was initiated 23 DAP and conducted at weekly interval from September 28 to October 21 in 2006.

**Virus symptomatic plant evaluation**

The percentages of infected zucchini plants were estimated by visually inspecting all zucchini plants in each plot for virus symptoms. The number of plants showing viral symptoms such as mosaic leaves and deformed fruits were recorded. Evaluation for virus incidence was initiated 10 DAP and conducted at weekly intervals during both years. Plants were inspected for virus symptoms from October 6 to November 17 and September 14 to October 12 in 2005 and 2006, respectively.

**Laboratory test**

The virus sink hypothesis was tested in the laboratory to determine whether viruliferous aphids could lose their ability to transmit a NPV after probing into barrier
plants. Methods similarly described by Fereres (2000) were used. Barrier plants evaluated included zucchini, buckwheat, white clover, okra and sunn hemp and the NPV used was *Papaya ringspot virus* – watermelon strain (PRSV-w). Two species of aphids, *Aphis gossypii* and *Myzus persicae* were used during the tests. The virus isolate used during the experiment was obtained from field collected samples of a symptomatic zucchini plant that tested positive for PRSV-w using ELISA. The virus source was maintained on zucchini plants by using the mechanical inoculation method as described by Purcifull et al., (1998) and Ng and Perry (1999). Aphids were subjected to a 60 minute pre-acquisition starvation and then exposed for a 5 minute acquisition period on PRSV-w zucchini source plants. Thereafter the aphids were transferred in groups of five to a series of recently potted zucchini plants (n = 30) for a further 5 minutes in the laboratory. The following sequences were used:

1. Virus host to zucchini (control);
2. Virus host to zucchini to zucchini;
3. Virus host to buckwheat to zucchini;
4. Virus host to white clover to zucchini;
5. Virus host to okra to zucchini;
6. Virus host to sunn hemp to zucchini.

Following their final transfer, test aphids were removed and all zucchini plants were sprayed with imidacloprid (Provado® 1.6, Bayer) at the rate of 1 ml per liter of water. The plants were then transferred to an insect proof chamber (26°C, 24 hour exposure to grow-light) for 4 weeks. The incidence of PRSV-w was initially checked by symptom expression of zucchini plants after two weeks and continued weekly.
**Statistical analyses**

Data from arthropod counts and percentage of plants showing virus symptoms were analyzed by using a mixed model analysis of variance (PROC MIXED, SAS Institute). The model was constructed to examine the main effect of treatment by date and block was designated as a random factor. Within the model, the following pre-planned orthogonal contrasts were conducted: diculture (zucchini + intercrop and zucchini + cover crops) vs. monoculture (zucchini bare-ground); (zucchini + intercrop) vs. (zucchini + cover crops) and (zucchini + buckwheat) vs. (zucchini + clover or sunn hemp). Comparison of the transmission efficiency of PRSV-w between different treatments with control was analyzed using χ²-square tests, on proportion of plants with viral symptoms.

In 2005, because of low counts of coccinelids and spiders, their totals were pooled prior to analysis. During the 2006 experiment, data were divided into early, mid and late zucchini growing season and analyzed accordingly. All data for arthropods counts were log₁₀(x +1) transformed to stabilize variances. The percentage data for plants showing virus symptoms were arcsine [sqrt (percentage/100)] transformed. Reported means are from non-transformed data.

**Results**

*Alatae aphids monitoring*

No significant difference (P > 0.05) was detected in mean aphid trap catches among treatment habitats in 2005 (Figure 5). Aphid trap catches were also similar among treatment habitats on most dates during 2006. However, trap catches were significantly less in zucchini grown with cover crops than okra intercrop at 11 and 18 DAP (11 DAP: F₁,₉ = 30.04, P = 0.004; 18 DAP: F₁,₉ = 10.36, P = 0.0105; Figure 6).
**Foliar counts of arthropods**

During the 2005 experiment, numbers of alatae aphids per zucchini leaf were similar among treatment habitats on most sampling dates ($P > 0.05$). However, aphid numbers were significantly lower in dicluture than monoculture habitat at 37 DAP ($F_{1,9} = 7.59$, $P = 0.0223$), cover crop habitats than intercropped okra at 44 DAP ($F_{1,9} = 6.36$, $P = 0.0326$) and clover than buckwheat during the initial sampling date (9 DAP: $F_{1,9} = 17.47$, $P = 0.0024$), respectively (Figure 7). During the 2006 experiment, aphid numbers were significantly lower in dicluture compared to monoculture on several sampling dates from 7 through 35 DAP (7 DAP: $F_{1,9} = 12.66$, $P = 0.0061$; 14 DAP: $F_{1,9} = 9.93$, $P = 0.0135$; 21 DAP: $F_{1,9} = 20.23$, $P = 0.0015$; 28 DAP: $F_{1,9} = 5.55$, $P = 0.0429$; 35 DAP: $F_{1,9} = 29.49$, $P = 0.0004$; Figure 8). Numbers were also significantly lower in cover crop habitats compared to intercropped okra at 7, 14 and 28 DAP (7 DAP: $F_{1,9} = 9.36$, $P = 0.0136$; 14 DAP: $F_{1,9} = 6.70$, $P = 0.0293$; 28 DAP: $F_{1,9} = 8.22$, $P = 0.0185$).

Few aphid predators were encountered on zucchini leaves during 2005. The total numbers of coccinelids encountered for all sampling dates were $0.25 \pm 0.25$, $0.25 \pm 0.25$, 0 and $3.25 \pm 0.75$ in bare-ground, buckwheat, clover, and okra habitats, respectively. The abundance of coccinelids was significantly higher in intercropped-okra compared to cover crop habitats ($F_{1,12} = 39.66$, $P < 0.0001$). Pooled spider numbers on zucchini leaves were $3.25 \pm 1.03$, $1.75 \pm 1.03$, $1.75 \pm 0.85$ and $1.00 \pm 0.71$ in bare-ground, buckwheat, clover, and okra habitats, respectively. No significant differences were observed in the abundance of spiders among treatment habitats ($P > 0.05$).

During the 2006 experiment, coccinelids were found only during late season (Table 3). No significant differences were found in the abundance of coccinelids between
different treatment habitats ($P > 0.05$). Chrysopids were found throughout the growing season and were significantly more abundant in monoculture compared to diculture habitats during mid and late zucchini growing cycle (mid: $F_{1,9} = 17.80, P = 0.0022$; late: $F_{1,9} = 11.13, P = 0.0087$). Significantly more chrysopids were also found in cover crop habitats compared to intercropped okra during the late growing season ($F_{1,9} = 5.51, P = 0.0436$) (Table 4). Spiders were found throughout the sampling period and in significantly higher numbers in intercropped-okra compared to the cover crop habitats during early and mid growing seasons (mid: $F_{1,9} = 8.10, P = 0.0192$; late: $F_{1,9} = 5.97, P = 0.0372$). Zucchini grown with sunn hemp had higher spider abundance as compared to buckwheat throughout the crop cycle (early: $F_{1,9} = 7.48, P = 0.023$ mid: $F_{1,9} = 8.49, P = 0.0172$; late: $F_{1,9} = 34.06, P = 0.0002$; Table 5).

During the 2005 experiment, numbers of alatae and apterae aphids per leaf disc were significantly lower in cover crop than intercrop habitats at 17, 23 and 43 DAP (17 DAP: $F_{1,9} = 5.20, P = 0.0486$; 23 DAP: $F_{1,9} = 11.71, P = 0.0076$; 43 DAP: $F_{1,9} = 6.05, P = 0.0362$; Figure 9). Numbers were significantly lower in diculture than monoculture habitats on only one sampling occasion (30 DAP: $F_{1,9} = 5.65, P = 0.0415$). Similarly, in 2006, numbers were significantly lower in diculture than monoculture habitats at the first two sampling dates (23 DAP: $F_{1,9} = 5.83, P = 0.039$; 30 DAP: $F_{1,9} = 6.92, P = 0.0273$; Figure 10).

**Virus symptomatic plant evaluation**

The percentage of zucchini plants showing virus symptoms was significantly different among treatment habitats during both experiments. In 2005, the percentage of zucchini plants showing virus was significantly lower in diculture than monoculture from
24 DAP through 52 DAP (24 DAP: $F_{1,9} = 17.24, P = 0.0025$; 30 DAP: $F_{1,9} = 18.45, P = 0.002$; 39 DAP: $F_{1,9} = 13.31, P = 0.0053$; 46 DAP: $F_{1,9} = 12.33, P = 0.0066$; 52 DAP: $F_{1,9} = 5.51, P = 0.0408$). Similarly, cover crop habitats had significantly lower numbers of plants showing virus symptoms compared to intercropped okra during same sampling dates (24 DAP: $F_{1,9} = 6.14, P = 0.0351$; 30 DAP: $F_{1,9} = 15.85, P = 0.0032$; 39 DAP: $F_{1,9} = 17.93, P = 0.0022$; 46 DAP: $F_{1,9} = 14.46, P = 0.0042$; 52 DAP: $F_{1,9} = 5.70, P = 0.0408$; Figure 11).

Percentage of virus symptomatic plants was significantly lower in diculture habitats compared to monoculture on all sampling dates (10 DAP: $F_{1,9} = 28.77, P = 0.0005$; 17 DAP: $F_{1,9} = 74.79, P < 0.0001$; 24 DAP: $F_{1,9} = 191.74, P < 0.0001$; 31 DAP: $F_{1,9} = 160.08, P < 0.0001$; 38 DAP: $F_{1,9} = 15.49, P = 0.0034$). Similarly, cover crops had significantly lower levels of virus than okra intercrop habitats from 17 through 38 DAP (17 DAP: $F_{1,9} = 8.34, P < 0.0179$; 24 DAP: $F_{1,9} = 21.65, P = 0.0012$; 31 DAP: $F_{1,9} = 26.94, P = 0.0006$; 38 DAP: $F_{1,9} = 27.32, P = 0.0005$) and buckwheat was significantly less than sunn hemp during the last two sampling dates (31 DAP: $F_{1,9} = 37.04, P = 0.0002$; 38 DAP: $F_{1,9} = 40.00, P = 0.0001$; Figure 12).

**Laboratory test**

The transmission efficiency of PRSV-w by *A. gossypii* to zucchini plants were significantly reduced compared to control when zucchini, buckwheat, white clover, or sunn hemp were used as barrier plants ($P < 0.05$, DF = 1). Similarly, the transmission efficiency of PRSV-w by *M. persicae* was significantly reduced compared to control when zucchini, okra and sunn hemp was used as barrier plants ($P < 0.05$, DF = 1) (Table 6).


**Discussion and conclusions**

Results of the field experiments showed no differences among treatments in the number of alatae aphids caught in water pan traps. However, in 2006 aphid numbers on zucchini foliage in diculture were significantly lower than monoculture habitats. Percentages of zucchini plants showing virus symptoms were also significantly lower in diculture habitats than monoculture on most sampling dates during both years.

Several studies have shown reduced aphid populations on crops grown with companion plants (Andow et al., 1986; Altieri et al., 1985; Costello, 1994; Costello and Altieri, 1995; Hooks et al., 1998). The study conducted in 2005 showed varied results but aphid numbers were lower in diculture than monoculture habitat on a few sampling dates. During the 2006 experiment, fewer alatae aphids were found in diculture than monoculture habitats. In most instances, zucchini intercropped with okra resulted in higher aphid numbers than cover crop habitats. Because okra and zucchini host similar aphid species, it is not surprising to find higher aphid counts on zucchini plants grown with okra than non-host plants. No significant differences were found between monoculture and diculture treatments in the number of aphids caught in water pan traps. These results are similar to the findings of Fereres (2000), who found similar numbers of aphids landed in water pan traps in pepper plants grown in bare-ground and with barrier plants, suggesting that the barrier plants did not act as a physical barrier and reduce the number of aphids entering the plots.

Studies have shown greater natural enemy abundance in vegetationally diverse habitats and an associated reduction in aphid density (Root, 1973; Altieri et al., 1985). However, during the 2006 study, higher abundance of aphid predators (coccinellids and
chrysopids) was found in monoculture than diculture habitats. Similarly, Hooks et al. (1998) found lower number of aphid predators in zucchini grown with buckwheat or yellow mustard than monoculture zucchini. The increased abundance of natural enemies in monoculture habitats might be due to higher aphid densities than diculture habitats. However, Frank and Liburd (2005) found significantly higher number of natural enemies in zucchini grown with buckwheat and white clover compared to monoculture.

As expected, the percentage of plants showing virus symptoms was consistently reduced in diculture habitats compared to monoculture during both years. The results also suggested that cover crop habitats significantly delays the incidence of virus compared to okra intercrop and that buckwheat is a better barrier crop than sunn hemp. Similarly, Fereres (2000) demonstrated that maize and sorghum barrier plants can reduce the transmission of both *Potato virus Y*, PVY and *Cucumber mosaic virus*, CMV to pepper by *A. gossypii* and *M. persicae*, respectively. The laboratory studies showed transmission of PRSV-w by *A. gossypii* on zucchini plants was significantly reduced when they were first allowed to probe barrier plants (buckwheat, clover, okra, or sunn hemp) compared to control. The mean percentage of transmission of PRSV-w in control was 90 and 46.7 by *A. gossypii* and *M. Persicae*, respectively, which suggest that *A. gossypii* is a more efficient vector than *M. persicae* in transmitting PRSV-w to zucchini. The results also suggested that buckwheat, which reduced transmission efficiency of *A. gossypii* by 51.7%, may be the most efficient “virus sink plant” among those tested. These findings also support field results that showed zucchini plants grown with buckwheat had a lower incidence of virus than other treatment habitats. However, tests conducted with *M.*
*persicae* showed zucchini, followed by sunn hemp and okra, were the most effective barrier plants.

Results of this study showed that barrier plants can be useful in reducing aphid populations and their ability to spread NPVs in zucchini. However, okra which hosts aphids capable of transmitting NPVs might not be a suitable choice for reducing the spread of NPVs. Additionally, barrier crops used during this study did not increase the activity density of natural enemies or reduce the numbers of aphids entering the plot. Thus, the results of this study support the hypothesis that barrier plants reduced virus incidence by acting as a virus sink. More studies are needed to evaluate other potential barrier crops and to integrate barrier crops with other strategies aimed at reducing the occurrences of NPVs.
References


CHAPTER 4

Effects of companion plants on zucchini growth and marketable yield

Abstract

Field experiments were conducted to examine the effect of companion plants on zucchini (Cucurbita pepo L.) growth rate and marketable yield on Oahu, Hawaii. Two cover crops, buckwheat (Fagopyrum esculentum Moench) and white clover (Trifolium repens L.) or sunn hemp, (Crotolaria juncea L.) and an intercropped vegetable, okra (Abelmonchus esculentus (L.)), were evaluated as companion plants during 2005 and 2006, respectively. Results from year 1 showed that zucchini grown with cover crops had significantly larger plant compared to intercropped okra. During year 2, zucchini plant size was significantly larger in sunn hemp habitat compared to buckwheat. Marketable fruit yields were also significantly higher in zucchini grown with cover crop habitats compared to intercropped okra during year 1. However, there was no effect of treatment on marketable fruit yield during Year 2.

Key words: Zucchini, companion plant, plant growth, marketable yield.

Introduction

Zucchini, Cucurbita pepo L. is an important vegetable crop in Hawaii and its production is often constrained by insect herbivores (e.g., aphids and whiteflies) and their associated plant impairments [aphid-transmitted non-persistent viruses (ATNPV) and squash silverleaf disorder (SSL)]. Several studies have shown a reduction in herbivore
densities in vegetationally diverse agroecosystems (Root, 1973; Smith, 1976; Perrin and Phillips, 1978; Garcia and Altieri, 1991; Frank and Liburd; 2005). However, most of these studies failed to consider the impact of companion plants on host plant growth and quality. In many cases, the quantity and quality of fruit are significantly reduced in crops grown in vegetationally diverse habitats (Andow et al., 1986; Theunissen and Schelling, 1996; Hooks and Johnson, 2002, 2004; Bukovinszky et al., 2004). Gold et al. (1989, 1990) suggested that the reduced growth rate of cassava (Manihot esculenta) was caused by competition from intercropped cowpea (Phaseolus vulgaris). Thus, companion plants may compete with the main crop impacting its growth and yield. Therefore, the objective of this study was to examine the influence of companion plants on zucchini growth parameters and marketable yield.

**Materials and methods**

Field experiments were conducted on the island of Oahu at the University of Hawaii’s Poamoho Agriculture Research Station in Wailua and Aloun Farms in Ewa during the years 2005 and 2006, respectively. Two cover crops, buckwheat Fagopyrum esculentum Moench; white clover Trifolium repens L. and an intercropped vegetable, okra Abelmonchus esculentus (L.), were evaluated during 2005. Because white clover failed to establish on numerous occasions in 2006, it was replaced by sunn hemp, Crotolaria juncea L.

Each plot measured 13.2 x 13.2 m and the experimental layout was a randomized complete block design with each treatment replicated four times. Ten rows of zucchini were planted so that each row was surrounded on either side by a companion plant row. The intra- and inter- row spacing was 1.2 m and each plot contained 110 zucchini plants.
Bare-ground plots contained 11 rows of zucchini plants. Each plot was separated by a minimum of 5 meters of bare soil. Border and plot areas were kept nearly weed free, whenever needed by applying glyphosate (Roundup®, Monsanto Corporation) or hand weeding. Rows of sudan grass (Sorghum bicolor var. sudanese Moench) surrounding the experiment plots were sprayed with GF 120 NF Naturalyte fruit fly bait (GF 120®, Dow AgroScience) to suppress melon fly populations.

**Planting time and cultural practices**

White clover (variety “New Zealand” Peaceful Valley Farm Supply, Grass Valley, CA) was sown at approximately 47 g per row on March 17, 2005. The seed were sown by hand into a ~8 cm wide furrow. On September 5, prior to planting the zucchini, a motor operated weed eater was used to clear ~1 m rows for the zucchini plants in each clover plot. Buckwheat seeds (Peaceful Valley Farm Supply, Grass Valley, CA) were broadcasted uniformly in the plots and covered using a garden rake. The seeds were broadcasted on September 8 - 9 and August 14 in 2005 and 2006, respectively. The per plot seeding rates were 1.8 kg and 3.6 kg in 2005 and 2006, respectively. Green house grown okra seedlings (variety “Dwarf Green Long”, Crossman Seeds) were transplanted on June 20 (intra-row spacing of 60 cm) and May 31 (intra-row spacing of 1 m) in 2005 and 2006, respectively. The plants were pruned regularly to follow normal cultural practices and to avoid over shading the zucchini plants. Sunn hemp seeds (variety “Tropic Sunn”, USDA-NRCS) were sown at 48 g per row on June 1, 2006. The seeds were sown by hand into a ~8 cm wide furrow. Sunn hemp rows were clipped on July 24, August 14 and 31, and September 20 to reduce possible competition through shading of the zucchini plants.
Twelve to 14 days old green house grown zucchini plantlets (variety “Spineless Beauty”, Syngenta Seeds Inc.) were planted in pre-established plots of companion plants on September 12 and September, 3-5 in 2005 and 2006, respectively. Plants were fertilized with urea (approximately 25 grams per plant) on October 10 and September 21 in 2005 and 2006, respectively. During the 2005 experiment, *Bacillus thuringiensis* var *Kurtaski* (Crymax®, Certis USA) was sprayed on zucchini plants at the rate of 1.2 grams per liter of water on October 10 and 19 to help manage pickleworms, *Diaphania nitidalis* (Stoll). During the 2006 experiment, Spinosad (Success®, Dow AgroScience) was sprayed at a rate of 2.2 ml per liter of water on October 1 and 8 followed by Crymax® on October 14 to help manage pickleworms.

**Plant measurement**

Ten plants were randomly selected from the interior rows of each treatment plot. These plants were used for measuring plant growth parameters, and were not used for sampling arthropods. Leaf production, leaf width and canopy diameter were measured for each plant at weekly intervals from each treatment plot. The plant measurement was initiated on October 12 (12 DAP) and terminated on 10 Nov, 2005 at Poamoho and from September, 19 (14 DAP) to October 10, 2006 at Aloun Farms.

At Poamoho, the newest fully emerged leaf was marked during the first measurement (12 DAP). Afterwards, the number of leaves produced between sampling dates were recorded. At Aloun Farms, the first measurement was taken at 14 DAP. The widest portion of the leaf perpendicular to the mid rib was measured to obtain leaf width. Squash leaf area (A) was estimated using the procedure described by NeSmith (1992) based on the regression model,
\[ A = -2.5 + 0.77(w^2), \quad R^2 = 0.976; \]

where \( w \) is leaf width. Plant canopy diameter was estimated by measuring the distance between two extreme leaf tips on opposite ends of a zucchini plant.

**Yield**

Harvested squash were graded as marketable and unmarketable. Unmarketable fruits were further classified as cull, fruits displaying viral symptoms, and fruit fly or pickleworm damaged fruit. The fruit weight was separated by category and used to obtain total fruit weight per plot. Fruits were harvested from October 27 to November 21, at Poamoho and from October 7 to October 18, at Aloun Farms during 2006.

To estimate okra yield, four continuous plants were selected from five alternating rows (\( n = 20 \)) excluding border rows. Marketable sized fruits were harvested from July 26 till September 28 in 2005 and July 12 to September 10 in 2006. Yield data from the 20 plants/plot were used to estimate yields per hectare.

**Statistical analyses**

Data from plant measurements were analyzed by using repeated-measures analysis of variance (PROC GLM, SAS Institute). The model was constructed to examine the main effect of treatment with date and block as random factors and plant as the repeated subject. Yield data were analyzed using mixed model analysis of variance (PROC MIXED, SAS Institute). Within the model, the following pre-planned orthogonal contrasts were conducted: diculture (zucchini + intercrop and cover crops) vs. monoculture (zucchini bare-ground); (zucchini + intercrop) vs. (zucchini + cover crops) and (zucchini + buckwheat) vs. (zucchini + clover or sunn hemp). The data for yield were
log_{10}(x) transformed to stabilize variances. Reported means are from non-transformed data.

Results

2005

Plant measurement

The effect of companion plants on zucchini plant growth was similar for the different parameters measured. Leaf production, leaf area and canopy diameter of zucchini plants intercropped with okra was significantly less. The number of leaves produced in the okra treatments was significantly less contrasted to cover crop treatments on each sampling date except 33DAP (19 DAP: $F_{1,9} = 7.01; P = 0.0266$; 26 DAP: $F_{1,9} = 21.74; P = 0.0012$; 39 DAP: $F_{1,9} = 13.06, P = 0.0056$; 45DAP: $F_{1,9} = 16.71, P = 0.0027$, Figure 13). Although no significant difference was found between monoculture and diculture treatments early during the cropping cycle, zucchini grown with bare-ground produced significantly fewer leaves contrasted with diculture treatments by the final measurement date (45 DAP: $F_{1,9} = 5.15, P = 0.043$).

Similarly, zucchini leaf area in the okra treatment was significantly less contrasted to cover crop treatments at 12, 33, 39 and 45 DAP (12 DAP: $F_{1,9} = 6.45; P = 0.0318$; 33 DAP: $F_{1,9} = 5.75; P = 0.0401$; 39 DAP: $F_{1,9} = 20.13, P = 0.0015$; 45DAP: $F_{1,9} = 5.79, P = 0.0394$, Figure 14). No significant differences were found between monoculture and diculture treatments. The zucchini leaf area was significantly greater in the buckwheat treatments contrasted to clover at 12 DAP ($F_{1,9} = 16.74, P = 0.0027$).

Canopy diameter was also significantly less in zucchini grown with okra contrasted to cover crop treatments at each date except 19 DAP (12 DAP: $F_{1,9} = 21.86, P$
26 DAP: $F_{1,9} = 5.3, P = 0.0486$; 33DAP: $F_{1,9} = 15.22, P = 0.0036$; 39 DAP: $F_{1,9} = 68.48, P < 0.001$; 45DAP: $F_{1,9} = 118.2, P < 0.0001$, (Figure 15). The canopy diameter was significantly less in zucchini monoculture contrasted to diculture treatments at 39 and 45 DAP (39 DAP: $F_{1,9} = 8.95, P = 0.0152$; 45 DAP: $F_{1,9} = 18.74, P = 0.0019$).

At 12 DAP, zucchini grown with clover was significantly less than buckwheat treatment ($F_{1,9} = 16.74, P = 0.0027$).

**Yield**

 Marketable fruit yield varied significantly among the treatments ($F_{3,9} = 18.15, P = 0.0004$) and was significantly less in okra plots contrasted to cover crop treatments ($F_{1,9} = 54.43, P < 0.0001$, Figure 19). Similarly, zucchini fruits exhibiting viral symptoms were significantly different by weight among treatments ($F_{3,9} = 3.99, P = 0.0462$). The proportion of fruits by weight exhibiting viral symptoms was 27.9, 10.6, 11.3 and 15.1% in bare-ground, buckwheat, clover and okra plots, respectively. The mean okra yield was 27,930 kg.ha$^{-1}$ at Poamoho.

**2006**

**Plant measurement**

Growth parameters of zucchini grown with buckwheat was severely less compared with sunn hemp. The number of leaves produced by zucchini plants in the buckwheat treatment was significantly less contrasted to sunn hemp treatment on all sampling dates except 21 DAP (14 DAP: $F_{1,9} = 33.38, P = 0.0012$; 28 DAP: $F_{1,9} = 11.33, P = 0.0151$; 36 DAP: $F = 20.50, P = 0.004$, Figure 16). The number of leaves produced was also found to be significantly less in diculture treatments contrasted with monoculture treatment at 14 and 36 DAP (14 DAP: $F_{1,9} = 13.97, P = 0.0096$; 36 DAP:
Leaf production was significantly less in cover crop treatments contrasted to okra intercrop at 14 and 36 DAP (14 DAP: $F_{1,9} = 8.42$, $P = 0.0273$; 36 DAP: $F_{1,9} = 12.13$, $P = 0.0131$).

Leaf area was significantly less in zucchini grown with buckwheat contrasted to sunn hemp at each measurement date (14 DAP: $F_{1,9} = 27.97$, $P = 0.0005$; 21 DAP: $F_{1,9} = 15.32$, $P = 0.0035$; 28 DAP: $F_{1,9} = 12.40$, $P = 0.0065$; 36 DAP: $F_{1,9} = 6.17$, $P = 0.0347$, Figure 17). However, there was no significant differences between monoculture and diculture treatments in leaf area except at 21 DAP when diculture treatments were significantly less contrasted to monoculture at 21 DAP ($F_{1,9} = 7.20$, $P = 0.0251$). The canopy diameter of zucchini was significantly less in buckwheat plots contrasted to sunn hemp plots on all dates (14 DAP: $F_{1,9} = 45.49$, $P < 0.0001$; 21 DAP: $F_{1,9} = 41.95$, $P = 0.0001$; 28 DAP: $F_{1,9} = 31.42$, $P = 0.0003$; 36 DAP: $F_{1,9} = 23.03$, $P = 0.001$, Figure 18).

**Yield**

Total fruit yields were lower at Aloun Farms compared to Poamoho. Overall, 38.2% of fruits were infested with melon flies across all treatments at Aloun Farms, causing a significant reduction in marketable fruit yields. Results showed that marketable yields as well as fruits exhibiting virus symptoms did not differ significantly among treatments (Figure 20). The percentage of fruits by weight exhibiting viral symptoms were 12.52, 4.19, 3.99 and 2.79% in bare-ground, buckwheat, okra and sunn hemp plots, respectively. Mean okra yield was 27,930 kg.ha$^{-1}$ and 41,552 kg.ha$^{-1}$ at Poamoho and Aloun Farms, respectively.
Discussion and conclusions

Field experiments were conducted to examine the effect of four companion plants on zucchini growth and marketable yield. The results showed that zucchini plants grown with cover crops buckwheat or white clover were significantly larger compared to zucchini intercropped with okra in 2005. Zucchini plants were significantly larger when grown with sunn hemp compared to buckwheat during the 2006 experiment. Costello (1994) found that the leaf area and yields of broccoli grown in clover living mulches were higher than in clean cultivated plots. Additionally, higher marketable yields were obtained from zucchini plants grown with clover and sunn hemp during 2005 and 2006, respectively.

During the 2005 study, interspecific competition between the white clover and zucchini was observed during the initial three weeks of plant growth, however, zucchini growth was greatest in clover habitat by 26 DAP compared with other treatment habitats. The zucchini growth rate was reduced in buckwheat habitat at Aloun Farms which was mainly due to higher whitefly densities in buckwheat habitat (refer chapter 2). Zucchini plants in buckwheat plots showed severe SSL symptoms which slowed plant growth resulting in lower fruit yield. Studies have shown high numbers of silverleaf whitefly on zucchini causes reduction in plant height, internodal length and petiole length (McAuslane et al., 2004) and yield reductions (Costa et al., 1994). At Poamoho, zucchini growth and yield was severely reduced in okra habitat. This reduction in growth and yield was mostly attributed to damages caused by avian pests, which perched on okra plants and damaged the growing axils of zucchini plants. Fourteen % of the zucchini plants in...
okra plots were destroyed by avian pest and the remaining plants consistently produced fewer leaves and had smaller leaf and canopy diameter.

Melon flies were problematic at Aloun Farms. A standard control procedure includes spraying a liquid protein bait, GF 120® to sudan grass borders serving as a trap crop for melon flies. Higher marketable fruit may have been obtained through early and regular spraying of the sudan grass borders surrounding the study site. However, the benefit of trapping technique was nullified as large numbers of flies were migrating from an untreated pumpkin patch and other crops surrounding the study area. Additionally, rain that occurred during the harvesting period may have washed the GF 120® sprays off the sudan grass rows and thus caused it to be less effective for suppressing melon fly. Harvesting discontinued when fruit fly population reached uncontrollable levels.

In conclusion, zucchini interplanted with the leguminous cover crops (white clover and sunn hemp) had greater crop growth resulting in increased marketable yields compared to other habitats. These cover crops may have increased soil N contributing to increased growth and yield of zucchini plants. Lower densities aphids and whiteflies, virus incidence and SSL (chapters 2 and 3) and increased nutrients may have all contributed to plants being larger in white clover and sunn hemp plots. It remains unclear how much each factor contributed to yield increase. However, to determine the direct impact of companion plants on crop growth parameters and yield would require it be done in the absence of insect pest and other factors that may impact plant growth. This may be difficult to do at sites where non-persistent viruses are prevalent. Still, the effect of companion plants on crop growth should received greater attention in future studies.
investigating the impact of companion plant on insect herbivores and associated crop yields.
References


Figure 1: Mean numbers (± Standard Error, SE) of adult whiteflies per zucchini leaf in different treatment habitats in 2005 at Poamoho Research Station.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover and okra, zucchini intercropped with okra.

b represents intercrop significantly less than cover crops.
Table 1: Mean rating (± SE) of silverleaf severity symptoms on zucchini plants in 2005 at Poamoho Research Station.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Days after planting^1</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>10</td>
<td>21 (b)</td>
</tr>
<tr>
<td>Bare-ground</td>
<td></td>
<td>0</td>
<td>0.60 ± 0.07</td>
</tr>
<tr>
<td>Buckwheat</td>
<td></td>
<td>0</td>
<td>1.42 ± 0.13</td>
</tr>
<tr>
<td>Clover</td>
<td></td>
<td>0</td>
<td>1.51 ± 0.15</td>
</tr>
<tr>
<td>Okra</td>
<td></td>
<td>0</td>
<td>0.13 ± 0.04</td>
</tr>
</tbody>
</table>

^1 bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover; okra, zucchini intercropped with okra;

^a represents monoculture significantly less than diculture; b represents intercrop is significantly less than cover crops.
Table 2: Mean rating (± SE) of silverleaf severity symptoms on zucchini plants in 2006 at Aloun Farms.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Days after planting</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>16 (e)</td>
</tr>
<tr>
<td>Bare-ground</td>
<td>3.99 ± 0.10</td>
</tr>
<tr>
<td>Buckwheat</td>
<td>4.00 ± 0.16</td>
</tr>
<tr>
<td>Okra</td>
<td>3.21 ± 0.15</td>
</tr>
<tr>
<td>Sunn hemp</td>
<td>2.36 ± 0.13</td>
</tr>
</tbody>
</table>

'bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; okra, zucchini intercropped with okra; sunn hemp, zucchini grown in sunn hemp.

'c represents sunn hemp significantly less than buckwheat.
Figure 2: Mean numbers (± SE) of whitefly (A) eggs and (B) immatures per zucchini leaf disc found in different treatment habitats in 2005 at Poamoho Agriculture Research Station.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover and okra, zucchini intercropped with okra.

a represents dicultures significantly less than monoculture
Figure 3: Mean numbers (± SE) of adult whiteflies per zucchini leaf found in different treatment habitats in 2006 at Aloun Farms.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

a represents monoculture significantly less than dicultures; b represents cover crops significantly less than intercrop; c represents sunn hemp significantly less than buckwheat.
Figure 4: Mean numbers (± SE) of whitefly (A) eggs and (B) immatures per zucchini leaf disc in different treatment habitats in 2006 at Aloun Farms.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

c represents sunn hemp significantly less than buckwheat.
Table 3: Seasonal abundance of coccinelids (± SE) on zucchini plants grown in different habitats in 2006 at Aloun Farms.

<table>
<thead>
<tr>
<th>Treatments (^{1})</th>
<th>Early (^{b})</th>
<th>Mid (^{a})</th>
<th>Late</th>
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<tbody>
<tr>
<td>Bare-ground</td>
<td>0</td>
<td>3.50 ± 1.85</td>
<td>3.50 ± 2.02</td>
</tr>
<tr>
<td>Buckwheat</td>
<td>0</td>
<td>0</td>
<td>0.75 ± 0.75</td>
</tr>
<tr>
<td>Okra</td>
<td>2.75 ± 1.80</td>
<td>1.00 ± 0.58</td>
<td>1.00 ± 0.41</td>
</tr>
<tr>
<td>Sunn hemp</td>
<td>0</td>
<td>0</td>
<td>2.75 ± 2.10</td>
</tr>
</tbody>
</table>

\(^{1}\) bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

\(^{a}\) represents monoculture significantly high than diculture; \(^{b}\) represents intercrop significantly high than cover crops.
Table 4: Seasonal abundance of chrysopids (± SE) on zucchini plants grown in different habitats in 2006 at Aloun Farms.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Early</th>
<th>Mid&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Late&lt;sup&gt;a,c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare-ground</td>
<td>1.50 ± 1.59</td>
<td>10.25 ± 1.43</td>
<td>10.5 ± 2.96</td>
</tr>
<tr>
<td>Buckwheat</td>
<td>3.50 ± 2.17</td>
<td>1.75 ± 1.18</td>
<td>6.50 ± 1.76</td>
</tr>
<tr>
<td>Okra</td>
<td>0</td>
<td>1.50 ± 0.96</td>
<td>3.75 ± 1.31</td>
</tr>
<tr>
<td>Sunn hemp</td>
<td>0.25 ± 0.25</td>
<td>4.5 ± 1.55</td>
<td>2.5 ± 0.5</td>
</tr>
</tbody>
</table>

<sup>i</sup> bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

<sup>a</sup> represents monoculture significantly high than diculture; and <sup>c</sup> represents sunn hemp significantly high than buckwheat.
Table 5: Seasonal abundance of spiders (± SE) on zucchini plants grown in different habitats in 2006 at Aloun Farms.

<table>
<thead>
<tr>
<th>Treatments</th>
<th>Early&lt;sup&gt;c&lt;/sup&gt;</th>
<th>Mid&lt;sup&gt;b,c&lt;/sup&gt;</th>
<th>Late&lt;sup&gt;b,c&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bare-ground</td>
<td>1.25 ± 0.48</td>
<td>1.50 ± 0.87</td>
<td>2.50 ± 0.65</td>
</tr>
<tr>
<td>Buckwheat</td>
<td>0.25 ± 0.25</td>
<td>0.50 ± 0.29</td>
<td>0.50 ± 0.29</td>
</tr>
<tr>
<td>Okra</td>
<td>2.25 ± 0.75</td>
<td>4.25 ± 0.75</td>
<td>5.75 ± 1.25</td>
</tr>
<tr>
<td>Sunn hemp</td>
<td>2.50 ± 0.96</td>
<td>3.00 ± 0.91</td>
<td>7.5 ± 1.32</td>
</tr>
</tbody>
</table>

<sup>l</sup>bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

<sup>b</sup>represents intercrop significantly high than cover crops and <sup>c</sup>represents sunn hemp significantly high than buckwheat.
Table 6: Transmission efficiency of PRSV-w by *A. gossypii* and *M. persicae* from infected zucchini plants to zucchini test plants as influenced by transfer to receptor plants.

<table>
<thead>
<tr>
<th>Sequence of receptor plants</th>
<th>Transmission efficiency(%)</th>
<th>(\text{number of infected plants/number of plants tested})</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><em>A. gossypii</em></td>
<td><em>M. persicae</em></td>
</tr>
<tr>
<td>a. Zucchini (control)</td>
<td>95.0 (19/20)</td>
<td>46.7 (14/30)</td>
</tr>
<tr>
<td>b. Zucchini - zucchini</td>
<td>50.0 (10/20)*</td>
<td>6.7 (2/30)*</td>
</tr>
<tr>
<td>c. Buckwheat - zucchini</td>
<td>43.3 (13/30)*</td>
<td>30.0 (9/30)</td>
</tr>
<tr>
<td>d. Clover - zucchini</td>
<td>63.3 (19/30)*</td>
<td>30.0 (9/30)</td>
</tr>
<tr>
<td>e. Okra - zucchini</td>
<td>80.0 (24/30)</td>
<td>20.0 (6/30)*</td>
</tr>
<tr>
<td>f. Sunn hemp - zucchini</td>
<td>66.7 (20/30)*</td>
<td>20.0 (6/30)*</td>
</tr>
</tbody>
</table>

* Significant differences when compared to with the control \(\chi^2\) goodness of fit test, \(P < 0.050\), D.F. = 1
Figure 5: Mean numbers (± SE) of alatae aphids in water pan trap in different treatment habitats in 2005 at Poamoho Research Station.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover and okra, zucchini intercropped with okra.
Figure 6: Mean numbers (± SE) of alatae aphids in water pan trap in different treatment habitats in 2006 at Aloun Farms.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp; okra, zucchini intercropped with okra.

b represents cover crops significantly low than intercrop.
Figure 7: Mean numbers (± SE) of alatae aphids per zucchini leaf in different treatment habitats in 2005 at Poamoho Research Station.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover and okra, zucchini intercropped with okra.

a represents diculture significantly less than monoculture; b represents cover crops significantly less than intercrop; c represents clover significantly less than buckwheat.
Figure 8: Mean numbers (± SE) of alatae aphids per zucchini leaf in different treatment habitats in 2006 at Aloun Farms.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

a represents diculture significantly less than monoculture; b represents cover crops significantly less than intercrop.
Figure 9: Mean numbers (± SE) of alatae and apterae aphids per zucchini leaf disc in different treatment habitats in 2005 at Poamoho Research Station.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover and okra, zucchini intercropped with okra.

a represents diculture significantly less than monoculture; b represents cover crops significantly less than intercrop.
Figure 10: Mean numbers (± SE) of alatae and apterae aphids per zucchini leaf disc in different treatment habitats in 2006 at Aloun Farms.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

a represents diculture significantly less than monoculture.
Figure 11: Mean percentages (± SE) of zucchini plants showing virus symptoms in different treatment habitats in 2005 at Poamoho Research Station.

Bareground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover; okra, zucchini intercropped with okra.

a represents diculture significantly low than monoculture; b represents cover crops significantly less than intercrop.
Figure 12: Mean percentages (± SE) of zucchini plants showing virus symptoms in different treatment habitats in 2006 at Aloun Farms.

Bareground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp; okra, zucchini intercropped with okra.

a represents diculture significantly low than monoculture; b represents cover crops significantly less than intercrop; c represents buckwheat significantly less than sunn hemp.
Figure 13: Mean numbers (± SE) of zucchini leaf production per week in different treatment habitats in 2005 at Poamoho Research Station.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover and okra, zucchini intercropped with okra.

a represents monoculture significantly less than dicultures, b represents intercrop significantly less than cover crops.
Figure 14: Mean leaf area (± SE) of zucchini plants at each sampling date in different treatment habitats in 2005 at Poamoho Research Station.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover and okra, zucchini intercropped with okra.

b represents intercrop significantly less than cover crops and c represents clover significantly less than buckwheat.
Figure 15: Mean canopy diameter (± SE) of zucchini plants at each sampling date in different treatment habitats in 2005 at Poamoho Research Station.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover; okra, zucchini intercropped with okra.

a represents monoculture significantly less than dicultures, b represents intercrop significantly less than cover crops and c represents clover significantly less than buckwheat.
Figure 16: Mean numbers (± SE) of zucchini leaf production per week in different treatment habitats in 2006 at Aloun Farms.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

a* represents diculture significantly less than monoculture, b represents intercrop significantly less than cover crops, b* represents cover crops significantly less than intercrop and c represents buckwheat significantly less than sunn hemp.
Figure 17: Mean leaf area (± SE) of zucchini plants at each sampling date in different treatment habitats in 2006 at Aloun Farms.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

a* represents diculture significantly less than monoculture and c represents buckwheat significantly less than sunn hemp.
Figure 18: Mean canopy diameter (± SE) of zucchini plants at each sampling date in different treatment habitats in 2006 at Aloun Farms.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp and okra, zucchini intercropped with okra.

a represents monoculture significantly less than dicultures; c represents buckwheat significantly less than sunn hemp.
Figure 19: Mean zucchini fruit yield from different treatments habitats in 2005 at Poamoho Research Station.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; clover, zucchini grown with white clover; okra, zucchini intercropped with okra.

b represents marketable fruit in intercrop significantly less than cover crops.
Figure 20: Mean zucchini fruit yield from different treatments habitats in 2006 at Aloun Farms.

Bare-ground, zucchini monoculture; buckwheat, zucchini grown with buckwheat; sunn hemp, zucchini grown with sunn hemp; okra, zucchini intercropped with okra.