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Akamai Cover Crop Mix (White clover, buckwheat, black oat): Does it benefit soil health?

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The advantage of establishing perennial legume like white clover (*Trifolium repens*) is that it can be widely adapted to different soil types and pH but prefers adequate amounts of soil moisture. Once it is established, its dense, spreading stolon and root system make it excellent for erosion control and weed suppression (Wang et al., 2003). It can also mitigate nitrogen (N) fertilizer use if mowed periodically due to its efficient N fixing capability. At 1 to 3 tons dry biomass per acre, white clover can generate 80 to 200 lb of nitrogen per acre (Smith and Valenzuela, 2002). Among the white clover varieties, 'New Zealand' white clover is most heat and drought tolerant and is well adapted to locations where slugs and snails are a problem (Ogle and St. John, 2008). Though some reported that white clover only established well in higher elevation (1500-7000 ft) in Hawaii, it has been found established fully in elevation around 500 ft without *Rhizobium* inoculum as long as it is irrigated. Authors from this article previously reported mix cover cropping of white clover with buckwheat (*Fagopyrum esculentum*) and black oat (*Avena strigosa*) help white clover to establish without the use of herbicide (Wang et al., 2023), although it took about 6 months before the white clover fully dominated the ground cover. We referred this cover crop mix as akamai cover crop mix.

Fig. 1. Eggplants planted into white clover established plots.

Soil health can be assessed by monitoring the physical, chemical, and biological properties of the soil to examine the capacity of a soil to function and sustain plant and animal health (Doran,1996). Nematodes have been used as soil health bioindicators (Bongers and Ferris, 1999) because they are present in different hierarchies of the soil food web, respond to changes of their food resources, soil physical and chemical properties, and can be classified to trophic groups and different life-strategies (1990). The objective of this project is to examine if establishing white clover using akamai cover crop mix technique can improve soil health compared to weedy fallow or bare ground plots.

Materials and Methods

Kahumana Trial

A field trial was conducted in an avocado orchard at Kahumana Organic Farm, Waianae, HI to compare changes in soil conditions between akamai cover crop (CC) plots vs untreated control plots (check, CK). The soil at this site is a Vertisol (Lualualei soil series, fine, smectitic, isohyperthermic, Typic Gypsitorrerts). Akamai cover crop (CC) mix was planted in Nov, 2021. Each plot was 8 × 25 ft^2 between 6-month-old transplanted avocado trees. All experimental plots were mulched with 3-in thick landscape yard waste compost 6 months prior to the initiation of this experiment. White clover, black oat and buckwheat were planted at 20, 70 and 60 lb seeds/acre, respectively. Treatments were repeated in 6 plots randomized between two rows of avocado trees (Fig. 1). Cover crops were sprinkle-irrigated from November 2021 to March 2022 to help the cover crop to establish. No irrigation was installed in the CK control. At the initiation of this trial, weeds were removed from the CC plots (Fig. 1A) prior to planting cover crops whereas the CK plots were fallow with weeds dominated by bristly foxtail (*Setaria verticillata*), Guinea grass (*Megathyrsus maximus*), halo koa (*Leucaena leucocephala*) (Fig 1B). Avocado trees were maintained, weeds were trimmed back periodically by the farmers. The akamai cover crop mix established in succession started with buckwheat, then black oat before white clover took over.

Fig 1. A) Intra-row spacings between avocado trees were clear off from weeds before planting akamai cover crops, B) fallow control plots where grasses and other broadleaf weeds grew over the thick thatch of yard waste compost mulch added on soil surface 6 months prior to initiation of the experiment.

Soil from each plot was monitored over 1.2 years (total of 5 soil sampling times). Six 4-in deep soil cores were composited into one bag from each plot and brought back to the laboratory. A portion of the soil was subjected to microbial respiration test (Solvita Burst Test, Wood End Laboratories) and 250 cm^3 subsample was subjected to elutriation and centrifugal floatation for nematode extraction (Byrd et al., 1976; Jenkins, 1964). All nematodes including plant-parasitic and free-living nematodes were counted to the genus level. Soil infiltration was monitored at 6 and 14 months after cover crop planting. At 8 months after cover crop planting, soil compaction was monitored using FieldScout SC 900 Soil Compaction Meter (Spectrum Technologies). Towards the end of the project, soil samples were also subjected to Solvita Labile Amino-Nitrogen test (SLAN test, Wood End Laboratories) which reports organic nitrogen reserves present as amino-sugars in the soil. Data was subjected to one-way analysis of variance by date. Means over 5 sampling dates were presented if no interaction between treatment and time ($P > 0.05$).

Fig. 2. Intra-row spacing between young avocado trees for the cover crop plots were A) covered with yard waste compost prior to cover crop (CC) planting, B) covered with buckwheat and black oat at 2 months after CC planting, c) barely covered with white clover for the first 6 months, D) monitored for soil compaction using a Soil Compaction Meter.

Results

Soil microbial activities: Repeated measure (5 sampling dates) of soil microbial respiration over 1.2 years after cover crop planting showed that CC increased soil microbial activities compared to the control (CK) ($P \leq 0.05$, Fig. 4).

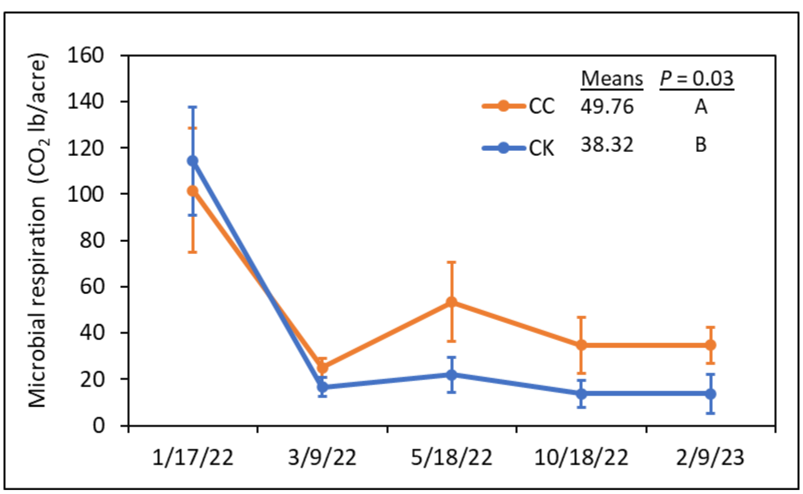

Fig. 4. Soil microbial respiration rate monitored using Solvita Burst test. Means (n=30) on the top right corner followed by different letters indicate significant differences based on ANOVA.

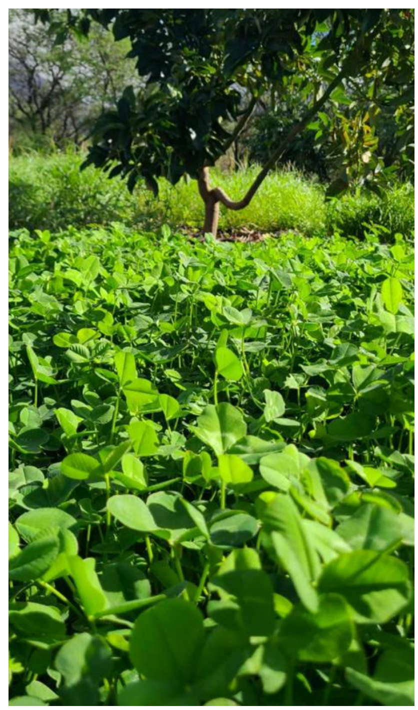

Fig. 3. White clover established between avocado trees 1.2 years after planting.

Nematode community analysis: Despite higher microbial respiration rates in CC, more bacterivorous nematodes were detected in the control (CK) in 4 out of the 5 sampling dates (Fig. 5A), indicating more bacterial decomposition in CK than CC. White clover also supported more spiral nematodes (*Helicotylenchus* spp.) ($P \leq 0.10$) which led to higher abundance of herbivorous nematodes (Fig. 5B). However, white clover seems to be very tolerant of spiral nematode infection as seen in the vigorous growth of the cover crop (Fig. 3). Though the abundance of fungivorous nematodes were not different between CC and CK in all sampling dates (data not shown), the ratio of Fungivorous/(Fungivorous + bacterivorous nematodes, F/F+B) were higher in CC (Fig. 5D), indicating that planting of white clover in these heavily mulched plots led to fungal dominated decomposition. Meanwhile, CC started to increase abundance of predatory nematodes 6 months after planting (May 19, 22) when the white clover fully established (Fig. 5C). Though nematode diversity fluctuated in CC (Fig; 5 E), nematode enrichment index (EI) was higher in CC than CK in all sampling dates (Fig. 5F), indicating more nutrient enrichment.

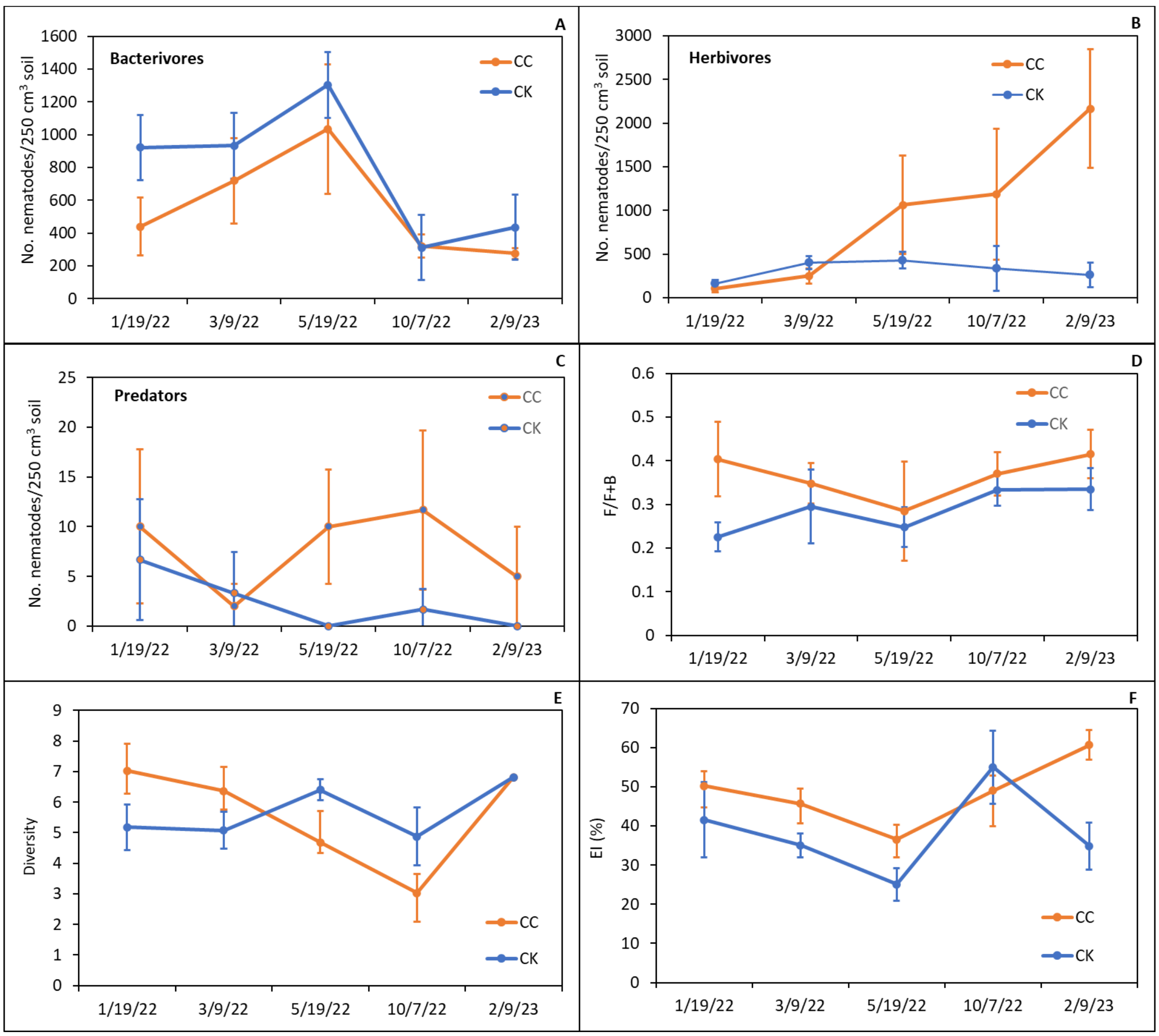

Fig. 5. Abundance of A) bacterivorous nematodes, B) herbivorous nematodes, and C) predatory nematodes. D) Fungivorous/(Fungivorous + bacterivorous nematodes), E) diversity of nematodes, and F) nematode enrichment index (EI). * and @ indicates significant differences between cover crop (CC) and untreated control check (CK) on the specific date at $P \leq 0.05$ and 0.10, respectively based on analysis of variance.

Other soil properties: Other changes in soil quality affected by white clover were rather slow but were showing a trend of improvement. Water infiltration rate measured by double ring method was slightly higher in CC than CK 6 months (5/26/22) after CC planting (Fig. 6A). It was unclear why infiltration reading at 14 months after planting (2/9/23) was very low, possibly due to break down of the yard waste compost over time. Soil tilth measured on 5/26/23 by soil compaction meter was also slightly better (deeper penetrance) in CC (8.6 in) than CK (7.6 in, Fig 6B) though not statistically different. CC increased total soil C content by 1.72% and 2.79% at 3 and 14 months after planting, respectively ($P > 0.05$; Fig. 6C). This is a rather big increase in soil C over a 1.2-year period, though not significant. Solvita SLAN test did not detect a significant increase in SLAN by CC (Fig 6D).

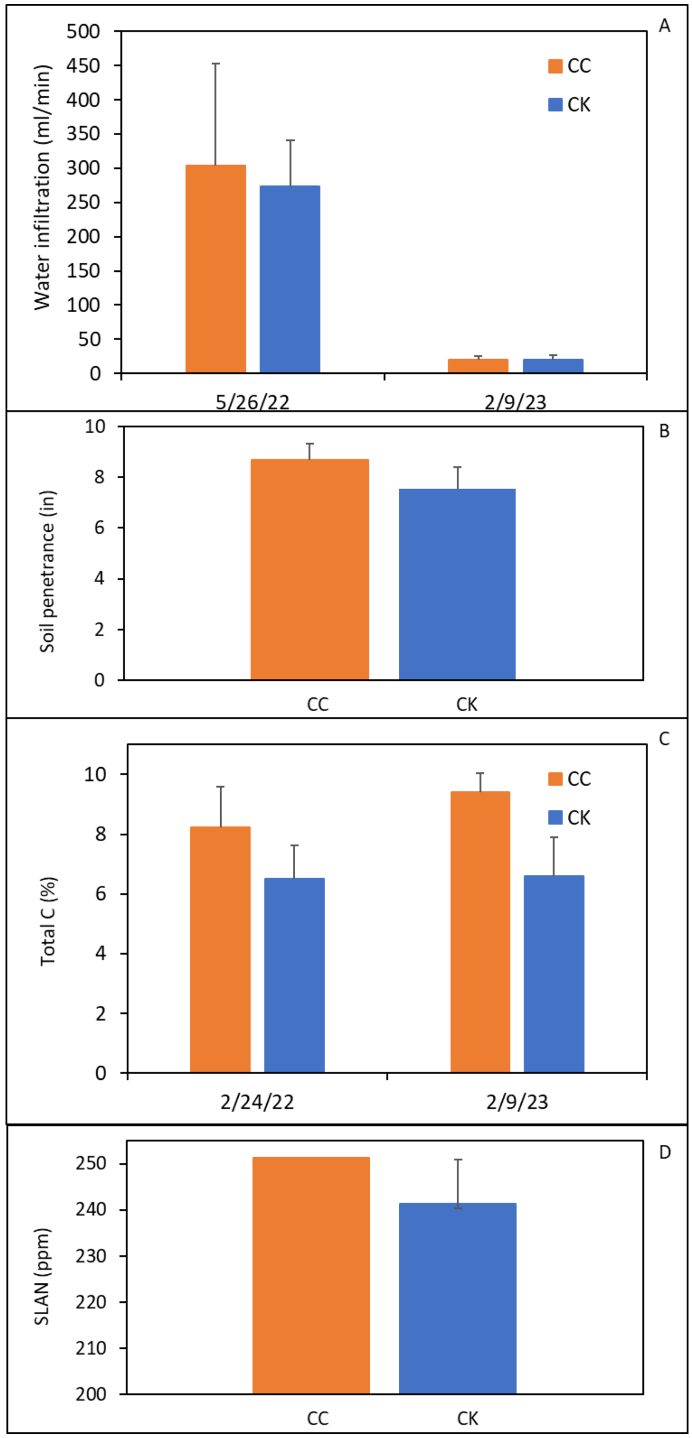

Fig. 6. Effects of white clover on A) water infiltration, B) soil penetrance, C) total soil carbon, and D) soil labile ammonia nitrogen (SLAN). CC=cover crop, CK = no CC control.

Summary

It is encouraging that establishing white clover in a heavily mulched soil increased soil carbon content from the no CC plots by 2.79% at 1.2 years after planting. This is promising because soil captured more C than the air, French Agricultural Research Centre for International Development (CIRAD) initiated a "4/1000 initiative" suggesting that increasing soil C by 0.4% per year in the top 1 ft of soil could mitigate the CO_2 increase in the air (CIRAD, 2015). On the other hand, simply adding yard waste compost to the soil did not increase soil C from 6 to 14 months after the initiation of this experiment. Increase in soil C in CC was most likely due to increase in soil microbial activities shown in the Burst test, this is largely due to increase in the fungal decomposition (high F/F+B). Although this significant increase in soil C by white clover did not reflect in a significant increase in water infiltration or soil tilth over 1.2 years, it was coincided with higher EI and predatory nematodes in CC than CK, suggesting more nutrient enrichment.

Mao Farm Trial

Fig 7. Cover crop mix of buckwheat, black oat and white clover were planted as ground cover in between lilikoi plants using metal door screens as trellises. A) 3 weeks after cover crop planting, B) 9 months after planting, C) young lilikoi seedlings next to cover crops, D) weeds overgrown on some plots 4 months after plating, and E) yard waste compost mulch in the control plots as Mao Farm standard practice.

Another demonstration trial was established at Mao Farm, Waianae, HI where the farmer transplanted passion fruit seedlings on a trellis (Fig. 1C). Inter-plant spacings each of 3×16 ft^2 were either planted with akamai cover crop mix (Fig 1A) or mulched with 3-in thick yard waste compost mulch (Fig 1 E) in Feb 2022. Each treatment was replicated in 4 plots. Soil samples were taken from each plot on Jun 16 and October 7, 2022 (4 and 9 months after cover crop planting, Fig 1B, D). Soil was subjected to nematode community analysis as well as performing soil respiration test using Solvita Burst Test as described above. All data were analyzed by 2×2 (cover crop × time) analysis of variance.

Results

Based on ANOVA, grassy weeds voluntarily grown in the mulched control plots (CK) increased spiral and ring nematodes during the June sampling (4 months after planting, MAP), resulted in higher abundance of herbivorous nematodes compared to the cover crop plots (CC) (Fig. 8 A), though the effect was not significant in the October sampling (9 MAP). Planting of cover crops increased the abundance of omnivorous nematodes at 4 MAP (Fig 8B), indicating a more structured soil food web, though the effect became not significantly later at 9 MAP. More weed volunteers (dominated by Guinea grass and *Amaranthus* sp.) in the CK plots might have resulted in higher nematode diversity in CK than CC (Fig. 1C). Predatory nematodes were rarely detected in this field but did occur 9 MAP only in the CC plots (Fig. 1D) but the number was very low. Nematode richness was not different between CC and CK during this study period. Although initially the cover crop enhanced soil microbial respiration rate at 4 MAP (Fig. 9), this difference disappeared as the lilikoi canopy fully shaded the experimental plots at 9 MAP (Fig. 7B).

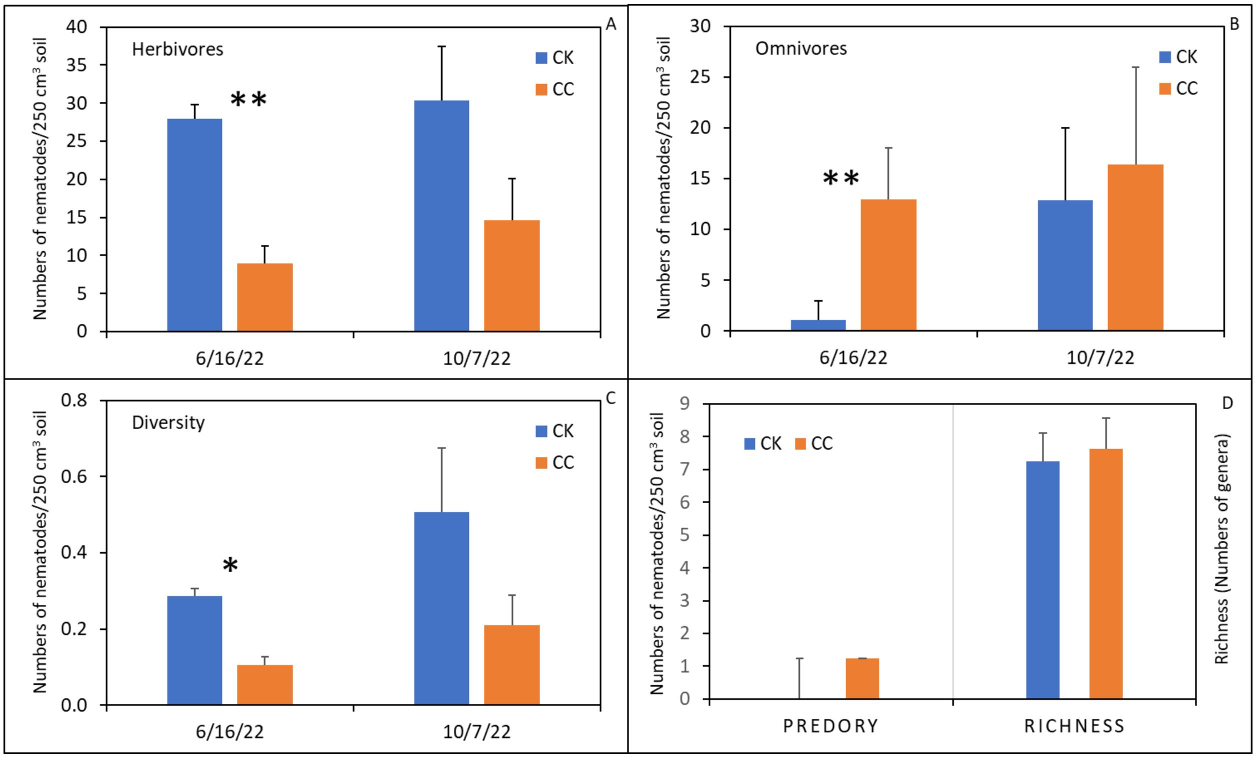

Fig. 8. Effects of akamai cover crop mix on A) abundance of herbivorous nematodes, B) abundance of omnivorous nematodes, C) nematode diversity and D) abundance of predatory nematodes and nematode richness in two sampling times at Mao Farm. CC=cover crop, CK = no CC control.

Overall Summary and Remarks

Both on-farm demonstration trials showed that white clover could establish in between trees using akamai cover crop mix technique if irrigation was provided during the initial growth (3 months). While this cover crop mix increased spiral nematodes on white clover growing areas in the Kahumana Trial, it maintained a very low abundance of plant-parasitic nematodes in the Mao Trial. This is possibly pending on the presence of plant-parasitic nematode species at the field sites. None-the-less, established white clover consistently improved soil food web structure (increased abundance of predatory nematodes in Kahumana Trial and omnivorous nematodes in Mao Trial) and soil microbial respiration rates compared to the no cover crop control even though the control plots were heavily mulched with yard waste compost. This study showed the benefits of cover crop as living mulch over mulching with dead organic mulch. Since white clover is a perennial cover crop with rhizome and stolon, over time, it generates a thick thatch of root mass to smother weeds. However, white clover demands some shade and good soil moisture to establish. Once it was fully established, minimal irrigation was needed. Improvement in soil

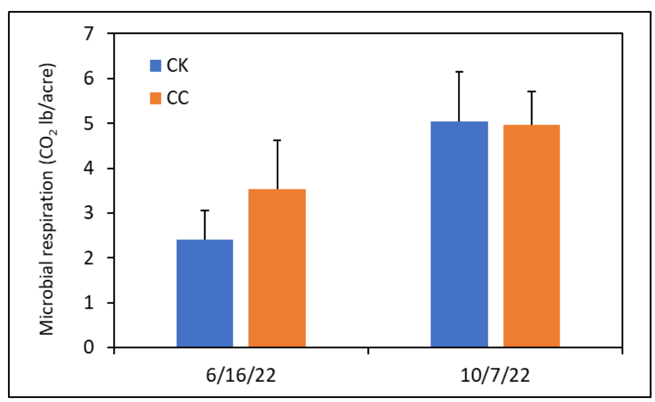

Fig. 9. Effects of akamai cover crop mix on soil microbial respiration rate at Mao Farm. CC=cover crop, CK = no CC control.

food web structure coincided with the increase in soil microbial respiration rates in the Kahumana avocado orchard throughout the 1.2 year of study period, but only up to 6 MAP in the Mao lilikoi trellis. This difference could be due to the fact that lilikoi canopy fully shadowed the study sites at 9 MAP and created a healthy soil environment in both CC and CK plots. While minimal soil chemical and physical properties were monitored in the Mao Trial, we documented 2.79% increase in soil C by the white clover compared to the mulched control in the Kahumana Trial. Thus, white clover is a viable perennial legume as ground cover in tropical orchard systems that can benefit soil health compared to mulching with yard waste compost mulch.

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