Cover Crops For Soil Health: Demonstration Of On-Farm Trial

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1. Project Summary

Organic farmers in general face unique challenges in production, especially in weed and pest management, since many readily available pesticides or herbicides are prohibited. These challenges are often location-specific, and the solutions depend on many ecological—and socio-economic-factors. The sub-tropical climate prevailing in the lower Rio Grande Valley (LRGV), a major agricultural region in semi-arid subtropical Texas, poses significant agronomic challenges to farmers: need for year-round weed sand insect pest management and maintenance of soil health. For organic farmers here, the major weed management technique is intensive tillage during the late summer months, exposing soils to the intense heat and high winds, characteristic of this season in the region. This technique has been costly to the farmers as well on soil health –high winds stirrup the topsoil resulting in significant topsoil loss. Consistent with the national trends, farmers across the LRGV are also showing increased interest in cover crops. However, information on effective implementation of cover crops is lacking for this region. We conducted a 2-year study analyzing the agroecological benefits of 3 different cover crop species sudangrass (*Sorghum* × *drummondii*), sunn hemp (*Crotalaria juncea*), cowpea (*Vigna unguiculata*). Our results show that cover crops are effective in suppressing weeds. However, in terms of soil health we found mixed results. Cover crops increased the total microbial biomass, total fungi, and arbuscular mycorrhizal fungi (AMF). The most significant result being the legumes not improving the soil nitrogen content. Phospholipid fatty acid (PLFA) analysis of soils under the legumes showed 0 rhizobia biomass. The legume cover crops did not produce effective nodules or improve the soil rhizobial community leading to no improvement in total soil nitrogen. Thus, further research on legume cover crops, nodulation, and rhizobia is necessary to gain the full benefits of legume cover crops. In addition, further research on the effective termination and incorporation of cover crops in organic systems is necessary to gain the soil health benefits of cover crops.

2. Introduction to Topic

The United States is the biggest organic market in the world, with sales reaching approximately $50 billion in 2016 (OTA, 2017). However, the share of agricultural land devoted to organic production represents less than 1% of the total arable land in the country (Greene et al. 2016). In Texas, the US's second most productive agricultural state, this difference is even more glaring. While Texas ranks 4th in certified organic sales, it is 9th in certified organic land, and only 0.07% of Texas farms are certified organic (Morris and Maggiani 2016). This gap demonstrates the missed opportunity for Texas growers to grow the organic sector in the state.

The LRGV, a four-county area in deep south Texas, is a promising region for organic farming with an estimated 2.1 million acres of arable land. With the sub-tropical climate prevailing in the region, LRGV boasts a year-round growing season. Hidalgo County, at the center of the LRGV, is home to a diversity of agricultural practices and cropping systems and is considered the state-wide leader in the production of various commodity groups, including fruits and vegetables. However, this also poses agronomic challenges to farmers: year-round pest management and maintenance of soil health.

Organic farmers, in general, face unique challenges in production, especially in weed and pest management, since many readily available pesticides or herbicides are prohibited. These challenges are often highly location-specific, and the solutions depend on many ecological—and socio-economic-factors. The major weed management technique is intensive tillage during the late summer months, exposing soils to the intense heat and high winds, characteristic of this season in the region. This technique has been costly to the farmers as well as soil health –high winds stirring up large dust clouds and blowing away the topsoil is a common feature. In addition, as with many sub-tropical climates, soils here are very poor in organic matter (<1% in most cases) and very high in pH (7.8-8.4)

Cover cropping, which has become a national trend among organic farmers, are proven to provide multiple agroecosystem services such as the protection of soil from water and wind erosion (Dabney et al 2001), suppression of weeds and pests (Teasdale 1996; Creamer 2000), increased soil organic matter (Steenwerth and Belina 2008), remediation of soil compaction (Williams and

Weil 2004), prevention of nutrient loss (Gómez et al. 2009), establishes habitat or food for beneficial insects (Zhang et al. 2007; Martinez et al. 2020), and enhancement of nutrients for subsequent crops (Tonitto 2006). For example, Hoorman (2009) estimates that cover crops can reduce soil erosion by 90%, sediment transport by 75% pathogen load by 60% and nutrient and pesticide load by 50% to the natural aquatic systems.

Cover crops are desperately needed in this region given their potential in increasing food security and resilience in agroecosystems. But based on countless interactions with producers across the region, very few have even seen cover crops successfully employed, or are wary of the short-term impacts on soil moisture and associated forgone income. Farmers in states like California, Iowa, Washington, Wisconsin, Vermont, and North Carolina (where there is a growing and robust organic agricultural sector) are strongly supported by region-relevant research by non-profit and public institutions, where scholarship and research support have improved understanding for organic farming industries. By contrast, there is very limited research and support for organic farming in Texas, and lack of appropriate research is one of the major barriers (Morris and Maggiani 2016). For example, a study by Constance and Choi (2010) found that 80 percent of Texas producers "were not sure about" or "did not understand" organic certification, and about 80 percent reported, "lack of both informational and services support regarding organic production methods." Furthermore, the adoption of cover crops is precluded by several practical challenges such as the relatively high cost of seed (especially for organic farms), the opportunity-costs associated with using cover crops, and conflicts or insufficient information in planting and harvesting schedules (Miller et al. 2012). In our previous participatory research with local organic farmers, major concern raised by them was soil health enhancement and weed suppression-- two of the largest barriers to organic subtropical agriculture (Racelis, unpublished). Most of the available research information is on techniques best applied to non-organic, conventional farms or areas agronomically inappropriate (ie, for regions with different climate and soil conditions). Thus, on farm research and integrative extension activities are important aspects of both understanding and promoting cover crops as an appropriate tool for organic or transitioning farms in this region.

While the adoption of cover corps has gone up in the LRGV, questions regarding effective implementation of cover crops for this region still remain. This project answers some questions regarding cover crop implementation for the organic vegetable growers in the region and fill some research gaps.

3. Objectives Statement

This project was designed to address the three major research needs expressed by the farmers: weed suppression, pest management, and soil conservation. The specific objectives of this study were to determine the right cover crop or cover crop mix by evaluating the agronomic, environmental, and economic benefits, ultimately address local farmers' priorities to overcome barriers to organic agriculture in this region. We worked closely with the local organic growers to address their research needs. The goal of this project was to address the farmer-driven questions on cover crops. Specific objectives were:

1. Assessment of multiple soil health impacts of different cover crop species, through the comparative analysis of soil health parameters and demonstrate the connection between the right cover crop species and soil health benefits.
   We were unable to collect data on insect pests on cash crops as proposed due to the unusual weather conditions.

2. Assessment of agronomic and economic impacts of cover crops, through comparative analysis of costs associated with cover crop implementation (cost of labor, seeds, fuel, equipment, yield); weed and pest management.
   We were not able to collect data to successfully achieve the results for Objective 2 due to the pandemic and unexpected sever weather conditions during the study period in Texas (Hurricane Hanna during the summer of 2020 and weeklong freezing temperatures in spring of 2021). However, we are working together with an agriculture economist to determine cost and benefits of different cover crops for South Texas.

4. Materials and Methods

Our research hypothesis was cover crops, if selected properly, can provide multiple benefits, including soil health improvement and weed suppression. To test this hypothesis, we conducted field studies during the summer of 2020 and 2021, implementing different summer cover crops at the certified organic farm in Edinburg, Texas.

Research sites and experimental design:

This study was conducted in a 10 acre Certified Organic Vegetable farm located in Edinburg, TX. A 2-acre plot in the farm was selected for the study and a randomized block design with 5 replicates of each treatment was used for this study (**Figure 1**).The farm is certified by Nature's International Certification Services (NICS) for the past eight years. Terra Preta farm has produced and supplied organic crucifers (beets, cabbage, cauliflower, kohlrabi, kale), cucurbits (squash, zucchini, pumpkin, cucumber, watermelons), tomatoes, okra, and eggplant through Farm to Health, Community Supported Agriculture, Farm to School, and local farmers markets in the LRGV.

Figure 1. Segment of the cover crop study plots. Ariel view taken just before termination. Image credit, The University of Texas Rio Grande Valley Center for Sustainable Agriculture and Rural Advancement (UTRGV-SARA).

The experimental plots were plowed and disked after the vegetable growing season in May in both 2020 and 2021. Soil samples from each treatment plot were collected with a soil probe at 0-12 cm depth for biological and chemical analysis. The seeds were weighed, and legume seeds were inoculated with the producer recommended inoculant planted with handheld broadcast seeder. In 2020, due to hurricane Hanna damaging the experimental plots, with 1 full week of standing water in the study plots, the experiment was repeated in the first week of August. The cover crops were maintained for 12 weeks and terminated to prepare the farm for spring vegetable planting.

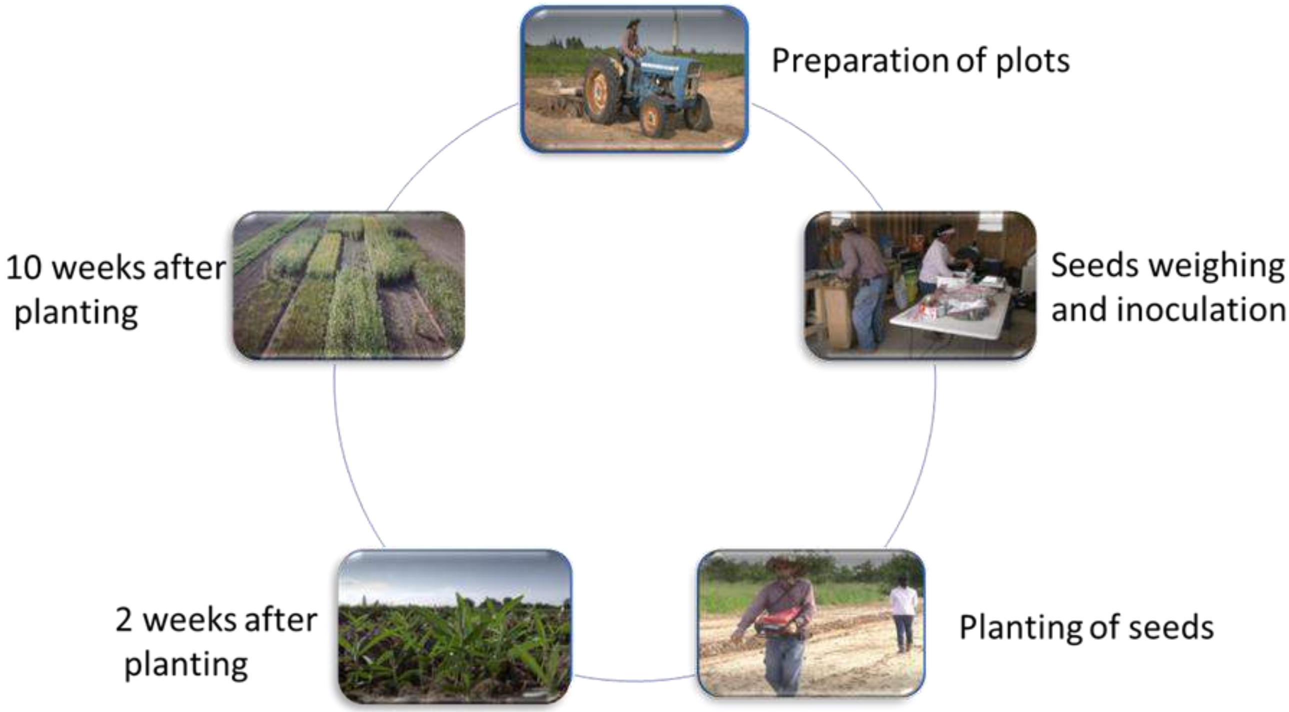

Figure 2: Methods implemented during the cover crops study period.

Measurements.

We analyzed the following variables: total cover crop and weed biomass, nodulation in legume cover crops, soil quality (soil organic matter, total soil carbon and nitrogen, soil microbial biomass and overall microbial community).

Cover crop and weed biomass: Cover crop and weed biomass were be calculated by destructively harvesting the cover crops and weeds from 4 different quadrants (2' X 2') in each treatment plots (**Figure 2**). The harvested plant materials were sorted by weeds and covered crops and dried in an oven, and the dry weight was determined. This number was used to determine the weed suppression potential of different cover crop species.

Nodule formation

10 plants of sunn hemp and cowpea were randomly selected three times (2 weeks after planting, 4 weeks after planting, and 10 weeks after planting/when the cover crops were in full bloom) from each of the treatment plots and examined for nodule formation and activity. The roots were examined for: total number of nodules, nodule activity (red color), and nodule location.

Figure 3. Graduate students in sunn hemp treatment plot collecting plant biomass and inspecting roots for nodules.

Soil quality: soil samples from each treatment and their replicates were be sampled and analyzed a total of 4 times during the study period. The first set of samples were collected at the beginning of the study to determine the preexisting soil nutrient status. The second sampling was done four weeks after incorporating the cover crops into the soil. Third sampling was be done after the cash crops were harvested. Fourth sampling was done four weeks after incorporating the during the second year. A portion of the soil sample was stored in the -80°C refrigerator until biological analysis. Soil samples were sent to Ward Laboratories for the phospholipid fatty acid (PLFA) analysis. Total C and N in each of the soil samples were analyzed using the Leco CN Determinator, soil organic matter was determined following the loss on ignition method (450°C for 4 hours in a muffle furnace). ***Soil moisture was not monitored as proposed as the unusually wet summers which resulted mostly wet soils during the study period.***

Data analysis

All data were subjected to normality test. When data (weed biomass in cover crops) was not normalized with transformation, non-parametric test was conducted. Initially, cover crop biomass, weed biomass, soil organic matter, total N, and total C in the two years were subjected to a 2-way ANOVA (year × cover crop treatments). As there was no significant difference in the biomass, organic matter, total N, and total C in the two years, data for both years was averaged and analyzed following the Wilcoxon Method. Impact of cover crops on soil microbes was compared using the Kruskal Wallis Rank Sums Test. Difference in the soil organic matter, total N, and total C pre and post cover crops among different treatments was analyzed using one way ANOVA. Results were considered significant if $P \leq 0.05$.

5. Project Results

Cover Crop and Weed Biomass

We compared the biomass of different cover crops species during the two-year study period. Among the three cover species, sudangrass had the highest biomass, followed by sunn hemp and cowpea ($P<0.001$), while control had the lowest. However, there was no difference in the biomass of cowpea and sunn hemp ($P=0.307$).

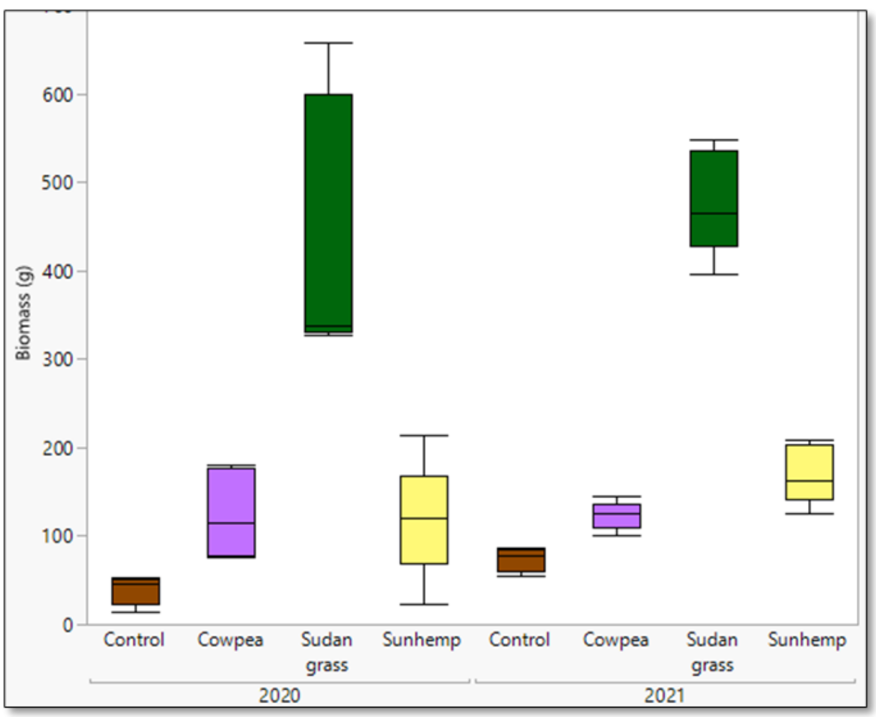

Figure 4. Weed and cover crop biomass during the 2 study years.

signs of nodulation in the roots of both the cover crop spices (**Figure 5 a**). During the second year, both the cover crops had nodules in their roots at the third sampling time (10 weeks after planting) (**Figure 5 b, c**). However, a limited number of nodules, mostly on the main root were fixing nitrogen while none of the nodules in cowpea were fixing nitrogen.

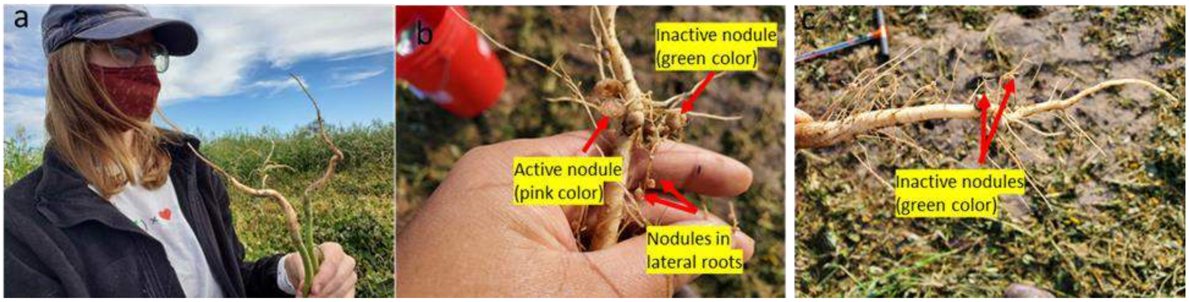

Figure 5. Graduate student inspecting nodules in the roots of sunn hemp and cowpea (**a**). 2020 roots showing no signs of nodulation; (**b**) sunn hemp root from 2021 with active and inactive nodules; and (**c**) cowpea roots from 2021 with inactive nodules.

Soil microbial community

There was significant increase in the total soil microbial biomass after cover crops in both the years (**Figure 6**). Sudan grass and sunn hemp had higher microbial biomass compared to cowpea and control.

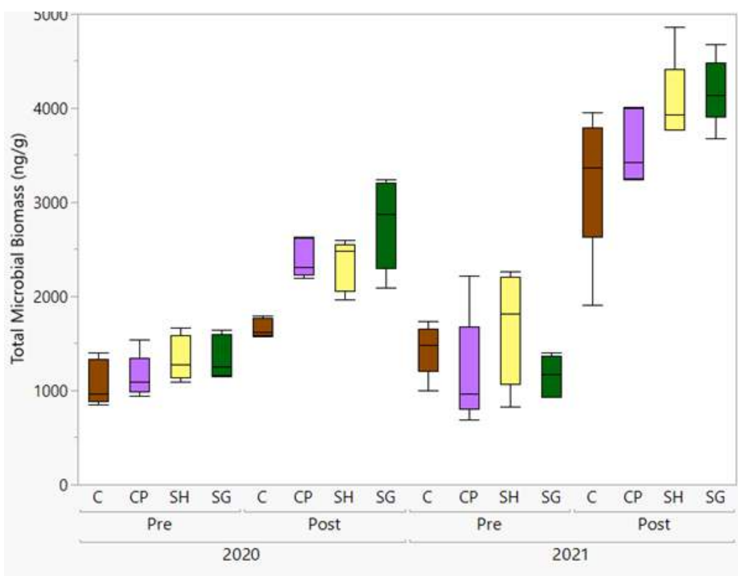

Figure 6. Difference in the total microbial biomass among the different treatments pre and post cover crops.

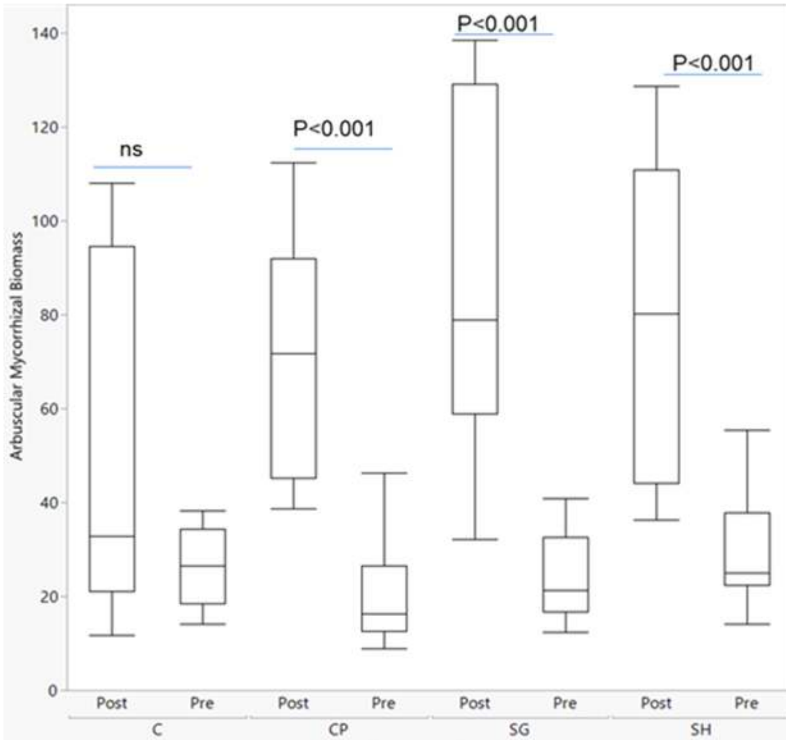

Figure 7. Difference in the total AMF biomass among the different treatments pre and post cover crops during the 2-year study period. s during the 2-year study period.

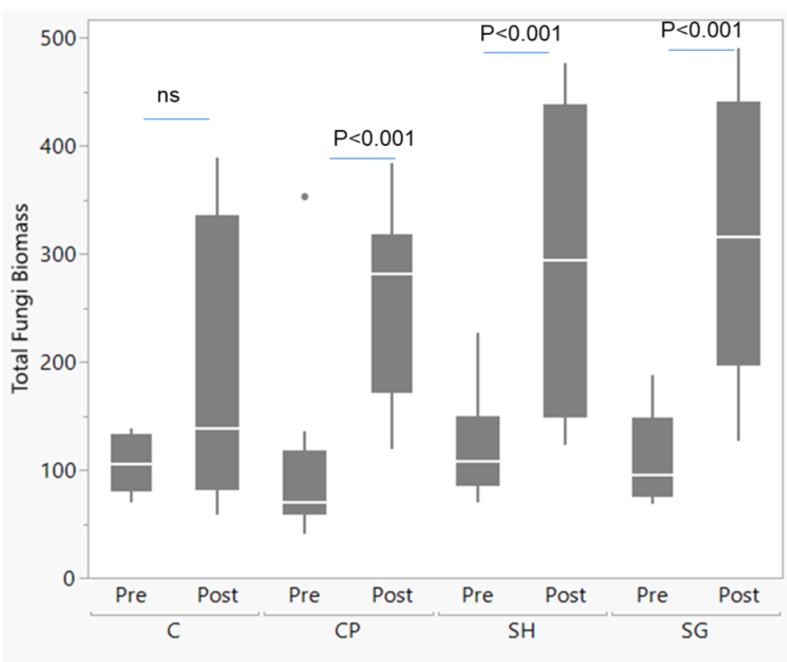

Figure 8. Difference in the total fungal biomass among the different treatments pre and post cover crops during the 2-year study period. s during the 2-year study period.

Cover crop treatments had a significant impact on the soil arbuscular mycorrhizal fungi (AMF) biomass (**Figure 7**). All cover crops resulted in the increase in the AMF biomass while there was no difference in the control. However, there was no significant difference among the different cover crop species (P=0.179). Similarly, total fungal biomass was also significantly in the cover crop treatment plots after cover crop termination (P<0.01), while there was no significant difference in the control plots (**Figure 8**). A rather unexpected result was, the legumes, even after inoculation, did not produce any nodules (**Figure 5 a**) in 2020 and some in 2021; however, our PLFA results showed 0.00 rhizobia biomass in both the years.

Soil Chemistry

Cover crops had a mixed effect on the soil properties (**Table 1**). While the soil organic matter increased after the cover crop treatment (P=0.038), there was no significant difference in the soil organic matter among the different cover crops and control. Cover crops had a significant impact on the soil total C. The cover crop treatments had significantly higher total C compared to the control (P<0.001). Total carbon was highest in the sunn hemp treatment followed by cowpea and sudangrass. Total N in the soil also increased after cover crop treatments. The three different cover crop treatments had significantly higher total N compared to the control. However, an unexpected result was that sudangrass had significantly higher total N compared to cowpea (P=0.048), a legume and there was no significant difference between sudangrass and sunn hemp (P=0.046).

Table 1. Means with standard error in parenthesis of soil organic matter, total C and total N pre and post different cover crop treatments.

Treatment	Organic matter %		Total C%		Total N%	
	Pre	Post	Pre	Post	Pre	Post
Sunn hemp	0.826 (0.044)	0.922 (0.026)	1.671 (0.035)	2.005 (0.074)	0.057 (0.002)	0.072 (0.004)
Cowpea	0.857 (0.049)	0.915 (0.032)	1.589 (0.015)	1.854 (0.078)	0.052 (0.001)	0.069 (0.006)
Sudangrass	0.863 (0.044)	0.950 (0.066)	1.648 (0.065)	1.853 (0.052)	0.099 (0.044)	0.105 (0.047)
Control	0.903 (0.050)	0.905 (0.026)	1.564 (0.017)	1.513 (0.016)	0.053 (0.001)	0.095 (0.046)

6. Discussions and Conclusions

We conducted a two-year study to determine the agroecological benefits of cover crops in organic vegetable systems. Though several weather-related challenges limited data collection on the overall benefits of cover crops, our study highlights some important issues faced by organic growers interested in implementing cover crops in their farms.

Farmers grow cover crops in between crop cycles to achieve several agroecology benefits including weed control, erosion prevention, nutrient recycling, reduce the pest pressure, etc. Though cover crops are reported to provide such benefits, improper selection of cover crop species can potentially add the cost for growers and create several challenges. Our study shows that agroecological benefits of cover crops are species specific and farmers need to select the cover crop species based on their needs and the target. For example, increase in soil nitrogen is an expected benefit of using legume cover crops, particularly for growers in arid and semi-arid regions where soil nitrogen is naturally low. If the legumes do not form effective root nodules, as seen in our study, they may not add additional nitrogen to soil. In our study, the legumes had similar biomass as sudangrass, but the sudangrass plots had similar or higher soil nitrogen as the legume plots. This could be the result of effective nitrogen scavenging and recycling by sudangrass. While legumes such as alfalfa, red and white clover have been reported to provide 75 to 200 pounds fixed nitrogen per acre, the summer annual legume widely popular in the region and used in our study are reported to have lowest nitrogen concentration (Redfearn 2016). In addition, unfavorable soil conditions and unsuitable seed inoculation techniques can also limit nodule formations in legumes (Kasper et al. 2019; Rai et al. 2021) Thus, there is a need to explore new varieties of legume cover crops suitable for the environmental conditions in the LRGV region and selection of appropriate inoculant and inoculation technique.

Cover crops are known to improve soil health and significantly influence the soil microbial communities. Our results show that the cover crops increased the soil PLFA. Cover crops also increased the total fungi, AMF, and total bacteria. The increase in the total microbial biomass, fungal biomass, and AMF biomass could be the result of added organic material in the soil. Cover crops are reported to increase fungi/bacteria ratio (Schmidt et al. 2019). While we did see an increasing the total fungi and AMF, we did not see an increase in the fungi/bacteria ratio. Our result is consistent with our previous study showing that cover crops can increase the AMF populations in soil (Soti et al. 2016) which can potentially benefit subsequent cash crops.

While we did not collect data on weeds in cash crops, the dense growth of cover crops prevented any growth of weeds thus there were no weeds in the cover crop plots. This result is similar to our previous study showing the weed suppression potential of cover crops (Soti & Racelis 2020). Given that the control plots had unusually lower weed biomass, this could be the result of the weeklong hot standing water killing the seedlings of weeds that had germinated. Cover crops biomass reported in our study is lower than other studies, this could be because of the delay in planting the cover crops (due to unfavorable weather conditions). There is a possibility that our results could be different if the cover crops were planted in early June as they normally are. However, it should be noted that legume cover crops not producing effective nodules is not exclusive to our study (see Kasper et al. 2019).

In conclusion, cover crops used in our study had the potential to suppress weeds and increase the overall microbial biomass along with fungal and AMF biomass. The legume cover crops did not increase the soil nitrogen, given that legume cover crop seeds cost more than the non-legume, sudangrass, used in our study, farmers need to prioritize their needs while selecting cover crop species. Changing climatic variables such as prolonged drought, excessive heat, freezing temperature, and heavy rainfall resulting in flooding have a significant impact on both cash crops and cover crops. Thus, planning the timing of cover crop planting and termination and selection of resistant varieties are important. Current cover crop technique commonly used by growers is shredding followed by cultivation to incorporate the cover crop residue. Using cover crops such as sunn hemp and sudangrass, which produce high biomass, requires higher soil disturbance, resulting in the loss of the soil health benefits of cover crops. Thus, more research is necessary to determine an effective termination and incorporation of cover crops in the organic farms in the tropics and subtropics where winterkill of summer cover crops or herbicide use is not an option.

7. Outreach

Due to COVID-19 restrictions, all filed visits and farm tours for students and farming community were canceled. Results and limitations of this project were presented to UTRGV faculty member and administrative staff in Fall 2021, and the Graduate Advanced Sustainable Agriculture course taught by P. Soti.

Results of this project will be presented at the Texas Organic Farmers and Gardeners Association Annual Meeting in 2023. A video of the project is currently under development and will be shared to the local growing community through the UTRGV Center for Sustainable Agriculture and Rural Advancement website. A manuscript on the impact of different cover crop species on the soil microbial communities is currently under preparation to submit to a peer reviewed journal. In addition, we will also preparer a manuscript on the comparison of costs and benefits of legume vs non-legume cover crops.

8. Financial accounting

- This project supported graduate student and undergraduate student mentored by P.Soti.
- The farm was paid for cover crop seeds, planting, maintaining plots, and termination of cover crops.
- Funds were used to purchase consumables and to pay Ward Laboratories for the PLFA analysis.

Please see attached Financial Report Budget for details.

9. Leveraged resources

Based on the preliminary data collected in this project, P. Soti is currently developing a ***Integrated Research, Education, and Extension Competitive Grants Program – Organic Transitions*** grant proposal in collaboration with researchers from Clemson University and USDA-ARS to be submitted in April 2022.

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11. Photos and other addenda:

A video demonstrating the project activities is currently under development and will be shared when ready.

Hurricane Hanna (2020) damage to study site. Pre Hanna (left), during Hanna (center), 2 weeks post Hanna (right).



Treatment plots, ariel view of treatment plots 10 weeks after planting, Fall 2020 top) and 8 weeks after planting Fall 2021 (bottom).

Cover crops as habitats for beneficial insects and pests.