MULTIFUNCTIONALITY OF COVER CROPS ON ORGANIC VEGETABLE FARMS IN SOUTH TEXAS

A Thesis

by

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ABSTRACT

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Situated in deep South Texas, the Lower Rio Grande Valley (LRGV) is considered one the most productive agricultural regions in the southern US. With the highest concentration of organic farms in the state (Hidalgo county), finding management practices that comply with organic certification is increasingly pertinent. Cover cropping can serve multiple functions in an agroecosystem such as: suppressing weeds, increasing soil organic matter (SOM), increasing soil nitrates, and enhancing soil biodiversity. The four cover crops (lablab, sunn hemp, sudangrass, and pearl millet) were assessed to see their potential to increase soil nitrogen, to increase soil organic matter, and to suppress weeds. The results show that these subtropical varieties of cover crops have potential to enhance ecosystem services on agricultural land in the LRGV by increasing soil organic matter (in all varieties), increasing nitrogen in topsoil (Sunn Hemp), and reducing weeds (Sudangrass).

DEDICATION

I would like to dedicate the completion of my masters of science to the small organic vegetable growers throughout the world who believe in the stewardship of the land and the health of the people. Most importantly to my mentor Dr. Alexis Racelis for showing me that I could make an impact on the farming community, while completing my masters thesis. I would like to dedicate this thesis to the farmers I worked with Juan Raygoza and Saul & Diana Padilla without their support and cooporation this research would not have happened. I would also like to thank Dr. Pushpa Soti and Dr. Carlo Moreno for so much guidance and patience, Lindsey Richards and Bobby Escamilla for help collecting data in the field, the entire Agroecology Lab, and my family and friends in California for inspiring and respecting my passion of sustainable agriculture.

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I would also like to acknowledge funding from the USDA under the Subtropical Organic Agriculture Research (SOAR) partnership grant that allowed me to collaborate with Terra Preta Farm and Yahweh Farm the National Center for Appropriate Technology (NCAT) to conduct on farm research that provided a service to those growers. I also would like to thank Southern Sustainable Agriculture Research and Education (SSARE) for my graduate student research grant that allowed me to conduct and analyze the large-scale research plots of my thesis.

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CHAPTER I

INTRODUCTION

Land under crop production and pastures make up about 40% of terrestrial land use worldwide (Millennium Ecosystem Assessment, 2003 & Ramankutty 1999). Much of this land is under conventional agriculture management centered on maximizing production and maximizing profits. On a global scale, this model was very successful at meeting a growing demand for food from a growing population, especially in the 50 years after the Green Revolution, an era of scientific innovation and technological advancement that included modified, improved seeds, intensification though mechanization and monoculture production, and fertilizers and pesticides. However, in these past 15 years of this new millennium, there is building evidence that these techniques and approaches were in conflict with and often degraded the resources on which agricultural is wholly dependent on: soil health, water quality, and biodiversity at all scales. There is mounting evidence of the consequences of these conflicts: agriculture is linked to drastic degradation of water systems (Vörösmarty & Sahagian, 2000), degradation of soils (Vorosmarty & Sahagian, 2000; Pimentel 2005), pollution of the environment, including to humans (Schafer et al., 2004), and loss of forested ecosystems (Kissinger & Herold, 2012). The tremendous yields attributed to conventional agriculture is a result of its increasing dependence external inputs such fuel-fossils, etc, as well as on improved seed and synthetic fertilizers and pesticides that are owned by large multinational corporations. In this way, conventional agriculture has been a driver of loss of local control over agricultural production and resultant global inequalities. The FAO found in 2004, 70% of farmers worldwide are considered extremely poor and suffer from food insecurity —in other words, those that grow our food, cannot access it. As detailed further below in this thesis, this rings especially true here in the Rio Grande Valley.

It is in this context, the challenge in modern agriculture to find ways to make agriculture productive, sustainable, and fair. Farmers are expected to grow more food on dwindling amounts of arable land for a growing world population—all in the face of climate change, volatility, and increasing scarcity of agricultural inputs (UN 2010). This calls for a new approach to agriculture that builds on the resource-conserving practices of traditional agriculture while incorporating modern ecological knowledge and methods, in ways that, at a minimum, do not contribute further to the consequences of conventional agriculture and are sustainable[1]. The application of ecological concepts and principles to design and management of sustainable food systems is known as agroecology (Altieri, 1995).

What is Agroecology?

The study of agroecology not only explores agronomic practices that are environmentally sound and sustainable, but also focuses on ways to maintain or improve productivity so that farming remains economically solvent for the farmer. With the growing awareness of the implications of our current agricultural model, there has been a modest surge in agroecology research that furthers our understanding of how classic and modern ecological principles play out

[1] Sustainability in this context is any action that needs of the present without compromising the ability of future generations to meet their own needs. According to the Brundlant Report (1987) this includes the concept of **need**s, "in particular the essential needs of the world's poor, to which overriding priority should be given"; and the idea of **limitations** "imposed by the state of technology and social organization on the environment's ability to meet present and future needs." (p.41).

in agroecosystems. For example, the application of the theory of island biogeography (MacArthur & Wilson, 1967) is relevant to agroecological practices include intercropping, cover cropping, planting of permanent hedgerows. Other concepts such as Grinnel's niche theory applies to crop rotations or companion planting, and Connell's Intermediate disturbance hypothesis informs suggestions for reduced tillage, or habitat modification to include biodiversity on landscapes. Many of these practices serve to increase biodiversity at the foundation of what are considered *supporting* ecosystems services (Wratten et al 2013) such as nutrient recycling, primary production and soil formation. Ultimately, these practices contribute to the overall sustainability of agricultural land, reducing dependency on external inputs and the negative environmental impacts associated with their use.

This project, in partial fulfillment of my master's program, uses an agroecological framework to examine specific ecological principles towards more sustainable management practices on agricultural land in the Lower Rio Grande Valley south Texas. The RGV is an ideal place to conduct this work, as the potential for participatory action research implies that theory can be put into practice immediately. The RGV, an agricultural mecca of subtropical climate, also has a budding segment of growers that are dedicated to sustainable, organic practice. Using a participatory action research approach, I worked with farmers from the Subtropical Organic Agricultural Research Partnership to examine specific aspects of ecological services[2] from cover crops, or the practice of off-season plantings to improve growing conditions. With a specific focus on cover crops, I analyze multiple functions or ES provided by cover crops on small farms in the Lower Rio Grande Valley (LRGV) region of Texas. In particular, chapters II and III analyzes the potential of cover crops to contribute to weed suppression and to increase biodiversity of soil mycorrhizae in subtropical organic farms in south Texas. Both of these

[2] Ecological services (ES) are defined as the benefits people obtain from ecosystems.

chapters are presented here in a format required for publication in peer-reviewed journals. At the time of submission for this thesis, Chapter is under review in the Journal of HortScience. Chapter 3 was published as presented here in the Journal of Agriculture Science (June 2016).

Chapter IV summarizes the context of this work in terms of which cover crop performed best at different ecosystem services, and also reflects on the importance and impact of participatory action research. In the Racelis Agroecology Lab at UTRGV, master's students are required to contextualize their thesis research as part of a larger service to the LRGV community. In collaboration with Yahweh Farm, Terra Preta Farm, and the National Center of Appropriate Technology I used participatory action research (PAR) to develop ground breaking cover crop research in USDA growing zone 9b to serve as a cover crop guide for farmers in the LRGV. In the nature of PAR, this project was inspired by farmer's concerns, which I then designed and developed a thesis experiment to address the concerns of the farmers.

The data presented in this thesis will serve as baseline cover crop research in USDA growing zone 9b and 10a, and has contributed to cover crop guide for farmers in the LRGV (Duncan et al., 2016 unpublished data). As an initial exploration of the feasibility and utility of cover crops, this work will hopefully inform future research in the LRGV pertinent to the sustainability of agriculture in this region.

Restoration of Ecosystem Services Through Cover Crops

Robert Constanza and Gretchen Daily's seminal work (1998) on the quantification of ecosystems services (ES), or the benefits derived from ecosystems, is directly applicable to agriculture, the largest users of ecosystems and its benefits. According to Wratten et al (2013) there are several types of ES, including (1) *provisioning services* such as the production of food, fuel, and fiber, (main service from functioning agroecosystems), (2) *regulatory services* such as rainwater retention, energy savings, and pollutant sequestration, (3) *cultural services* like aesthetic, service learning, and spiritual health, (4) *supporting services* like pollination, habitat, nutrient cycling, and biodiversity (De Groot et al 2002; Wratten et al, 2013, Cantu 2015). In this thesis, I focused on the supporting ecosystems services associated with cover crops and explored the implications of warm season cover crops on weed suppression and biodiversity of soil mycorrhizae, in the context of supporting the provisioning services of subtropical organic farms in south Texas.

Cover crops are non-cash crops that is typically grown during the fallow season in agroecosystems. For thousands of years, cover crops have been used as a tool to improve soil conditions in agricultural land (Groff, 2015; White, 2014). They provide ecosystem services such as retain top soil, addition of organic matter to soil, addition or conservation nitrogen in the soil, improve soil structure and water penetration, enhance pest management, attract pollinators, and suppress weeds (Clark 2012). Incorporating cover crops into a farm system increases levels of biodiversity by adding an additional crop species to the environment. This is also referred by Landis et al. (2000) as functional agricultural biodiversity, which enhances all of the ecosystem services listed above. For example, the use leguminous cover crops in a system adds biodiversity that supports the addition of nitrogen at a value of $40 per hectare/year by saving the farmer money on oil-based fertilizers (Vitousek et al. 2009). If cover crops are managed by farmers to go to flower, then they provide habitat for beneficial insects, which aid in controlling pest populations in crops and pollinators. These functions translate into savings for farmers in the following ways: cut fertilizer costs, reduce the need for herbicides and other pesticides, improve yields by enhancing soil health, prevent soil erosion, conserve soil moisture, protect water quality, and help safeguard personal health (Clark, 2007). In effect, food production depends greatly on ecosystem services such as nitrogen fixation, biological control, pollination, mycorrhizae diversity in the soil, weed suppression and biodiversity. As this research demonstrates, incorporation of cover crops as an agroecological method to enhance these ecosystem services can help moves the needle towards sustainability in agriculture.

Additional cover crop research is vital to explore whether this technology is appropriate to address the modern and future challenges of agricultural production. According to a recent report commissioned by the United Nations, sustainable agriculture and agroecological methods have been deemed a necessary path to insure adequate food production in the face of climate change, limiting resources, and an ever increasing human population's nutritional needs (Giovannucci et al. 2011). Recent research suggest that cover crops are a useful tool to improve farm sustainability by reducing the amount of inputs needed to grow crops, increasing soil retention and fertility, and reducing farm pollutants to surrounding water systems and beyond. However, despite the accumulation of evidence of proven benefits of cover crops in general, the farmer needs to know how to tailor the use of these technologies to the needs of his/her farm—how the cover crop interacts with and modifies the crop system and the organisms that live within (Gliessman, 2007). In addition, cover crops can be a costly endeavor with additionally costs of seeds, watering, etc., and thus should be a net contributor to the productivity of the farm.

Table 1.1: Potential Benefits of Cover Crops (modified from Gliessman, 2007).

	Interferences	**Benefits to Crop Community**
Impacts of soil structure	Enhanced root penetration root penetration in upper soil layers; shielding of soil surface from sunlight wind, and the physical impact of raindrops; addition of organic matter to soil; enhanced biological activity in root zone	• Improved water infiltration • Reduced soil crust formation • Decreased runoff • Less soil erosion • More stable soil aggregates • Increased percentage of macropores • Decreased soil compaction • Decreased bulk density
Impacts on soil fertility	Creation of cooler, moister surface and subsurface habitat; fixation of nitrogen by *Rhizobium* bacteria; carbon fixation (greater biomass); capture of nutrients by roots	• Increased organic matter content • Retention of nutrients in system • Prevention of leaching loss • Increased nitrogen content • Greater
Impacts on pest organisms	Addition of allelopathic compounds; removal of resources (light and nutrients) needed by weeds; creation of habitat for beneficial predators, parasites, and parasitoids; modification of microclimate	• Inhibition of weeds by allelopathy • Competitive suppression of weeds • Control of soil pathogen by allelochemicals • Increased presence of beneficial organisms • Suppression of pest organisms

Traditionally, cover crops have been used for centuries to maintain soil fertility, and were an essential part of crop rotation. With the advent of conventional and industrial technologies associated with the Green Revolution (aforementioned above), agrochemicals have replaced this traditional practice because chemicals quickly and easily met the needs of the next cash crop and allowed for continuous growth of cash crops, which increased yields to larger and more frequent harvests. However, inorganic chemicals due not return crop residues or conserve soil and water, and they leave the soil vulnerable to erosion and increase the likelihood of pollutants running down stream. The UN Millennium Project (2005) declared that mineral and organic fertilizers, green manures, tree planting, returning crop residues, and better methods of soil and water conservation are essential to increase and retain soil health. Cover cropping is a method that could contribute to all of these goals.

Cover Crop Varieties

The main plant families used for cover crops include Fabaceae (legumes), Poaceae (grasses), and Brassicaceae (mustards). Each of these different families specializes in different beneficial functions. Cover crops in the Fabaceae family are important to farmers because they fix nitrogen from the atmosphere and add it to the soil profile to ensure efficient nutrients for the subsequent crop, reduce or prevent erosion, produce biomass and add organic matter to the soil, and attract beneficial insects. The way the legume cover crop is managed can greatly affect the amount of N content of the cover crop and the contribution of N to the following cash crop. Experiments have been conducted to optimize the kill date of the legume to harness the maximum amount of nitrogen a legume can contribute to the system. A study in North Carolina showed that allowing an additional two weeks of growth significantly increased the amount of N by 41% (Wagger 1989). This shows the importance of understanding when to plant, when to terminate, and what type of cover crop to chose.

Members of the Poaceae family (grasses) grow to have a large biomass and are more lignified than other cover crops and contribute to increasing soil organic matter and increasing soil carbon crucial in sustaining fertile soils, with implications of sequestering carbon associated with anthropogenic-driven climate change (Lal, 2004). Grass cover crops are most useful for scavenging nutrients (especially N) left over from a previous crop, reducing or preventing erosion, producing large amounts of residue and adding organic matter to the soil, and suppressing weeds (Clark, 2007).

The Brassicaceae family (including cabbages, kale, radish etc.) is often used for multiple benefits: flowering attracts beneficial insects to the farm, associated allelopathic effects diminish above- and below-ground pests, and the network of roots are known to reduce soil compaction (Williams & Weil 2004; Snapp et al 2005). These allelopathic compounds reduce nematodes, fungi, and some weeds (Collins 2006, Matthiessen and Kirkegaard 2006, Larkin et al. 2006).

Importance of Subtropical Cover Crop Research in the RGV

There is no greater need for an improved understanding of agroecology thatnin the Rio Grande Valley of south Texas. As early as the mid 19th century, settlers came to the RGV for its warm climate, close proximity to the Rio Grande River, and cheap land with rich soils--a perfect place for agricultural endeavors. This drove rapid agricultural development in the region. Currently, the RGV remains one of the most important agricultural areas in the state of Texas. The region ranks among the state leaders in the production of fruits and vegetable specialty crops, especially in citrus, onions, sugar cane, melons, and winter vegetables. In contrast, the Rio Grande Valley only has 5% of the native vegetation covering the land (Leslie & Jahrsdorfer, 1988), and much of the agricultural land is being transitioned to urban development (Huang and Fipps 2006). As the patchwork of agricultural, structured and natural environments in the RGV continues to evolve, the importance of the social and environmental sustainability of agricultural systems becomes ever-more evident in the region. The RGV leads the nation in rates of food-related disease such as obesity and diabetes, and in the percentage of residents uninsured (Gallup, 2014). Much of the region is considered as a federally designated food desert (USDA-

ERS, 2016), and more than one seventh of the population live with hunger (Gunderson et al 2015). The evidence of need for informed action in sustainable food systems is abound, grounded in sustainability research such as the work documented here.

In recent years, there has been a resurgence of sustainability oriented practices across farms of the RGV. For example, in the past four years there was a doubling of the number of USDA-certified organic operations in Hidalgo County (the largest county in the RGV) (Morris and Maggiani, 2016). Organic agriculture is one of the fastest growing segments in the agriculture industry, with demand in Texas exceeding supply by more than 10-fold (Morris and Maggiani, 2016). Participatory action research on cover crops and other agroecological approaches is essential to best inform local growers in ways that qualify for organic certification, offering farmers a chance for higher revenue while transitioning to practices that support the sustainability of their farming enterprise.

A farmer must understand cover crops different functions to best pick which type of cover crop or cover crop combination best suits his or her needs. Unfortunately, no research exists that is relevant to the subtropical conditions of the RGV, as most of the published literature is conducted under more temperate conditions. For example, USDA plant Zones 9b-and10a are largely ignored in the cover-crop resources available from the USDA-Natural Resource Conservation Service website.

As a baseline for cover crop research in this region, we chose from various cover crops commercially available, in close consultation with participating farmers. A brief winter trial was conducted using Tillage Radish (*Raphanus sativus*) a member of the Brassicaceae family, as well as Winter Rye (*Secale cereal*) belonging to the Poaceae family. During the summer trials, the focus of my thesis results, I used two legume species from the Fabaceae family Lablab (*Lablab purpureus*) and Sunn Hemp (*Crotalaria juncea*). I also used species from the Poaceae family Sudan Grass (*Sorghum drummondii*) and Pearl Millet (*Pennisetum glaucum*).

Figure1.1-1.6: (1.1) top left sunn hemp, (1.2) top center lablab, (1.3) top right pearl millet (1.4) bottom left sudangrass, (1.5) bottom center tillage radish, (1.6) bottom right winter rye

Tillage Radish

Tillage Radish cultivars have been bred to have large amounts of above ground biomass used for fodder for livestock and have recently been used as a cover crop. The tillage radish roots can extend up to 3 feet deep in 60 days with the thickened storage portion of the root extending 12 inches from the soil surface (Gruver et al. 2016). The large macro-pores left in the soil after the radish decompose improve water and air infiltration into the soil, provide surface drainage, and increase soil porosity into the subsoil. Studies have shown that subsequent crops planted after tillage radish have better root growth and increased access to subsoil moisture resulting in greater resilience under drought conditions (Chen and Weil 2010). Tillage radish is also great at suppressing weeds. A study performed at the University of Maryland looked at the mechanisms of weed control of tillage radish (Lawley et al. 2011). The study found that there were no allelopathic effects and that the weed suppression was due to the rapid competitive fall growth of the tillage radish. Scavenging nitrates deep in the soil to prevent nitrate leaching is another benefit provided by tillage radish and has shown to contribute 170 lb/acre of N for the subsequent crop (Kremen and Weil 2006).

Winter Rye

Winter rye is a popular winter cover crop used throughout the world. Its benefits include erosion control, increase in organic matter, weed suppression, and scavenges nutrients. A study by the University of California showed the extensive fibrous root system can take up 43 lb/acre of excess N left in the field from the previous crop (William 1996). A study in Michigan showed Rye out performing Hairy Vetch at reducing weed emergence in fields (Hayden et al. 2012).

Lablab

Lablab is a tropical legume that originated in South East Asia as a food crop but has recently been developed for use as a cover crop for tropical regions, but is poorly studied for use in the Americas. Growers in Asia and Africa consider lablab one of their most useful tools in controlling soil erosion, increasing soil health, and providing a high protein forage crop for livestock (Murphy & Colucci, 1999). After initial watering via rainfall or irrigation, lablab can withstand drought and can be grown in a wide variety of altitudes and latitudes throughout the tropics and subtropics (Mayer et al., 1986). Lablab has also shown to resist most diseases and harbors few pests, especially when grown in the tropical to subtropical range (Luck, 1965). Depending on the growth rate and quality of the soil, lablab can provide up to 15-40kg N for each 1000 kg of dry matter above ground biomass (Humphreys, 1995). It's deep taproot, that allows for lablab to be drought tolerant, also brings up minerals from deeper in the soil profile and reduces potential nutrient run off from previous fertilizer applications.

Sunn Hemp

Sunn Hemp (*Crotolaria juncea*) has been used extensively in Africa and Asia (and throughout the tropics) as a soil improvement or green manure crop because of its ability to produce large amounts of biomass in high temperatures and humid climates. Because of this, it has the potential to build organic matter levels and sequester carbon. Also, as a legume it can fix large amounts of nitrogen. Certain varieties have also been known to resist to root-knot nematodes (Rotar & Joy, 1983), and as demonstrated in this thesis also are associated with increase mycorrhizal diversity in soil (Soti et al., 2016).

Pearl Millet

Pearl Millet (*Pennisteum typhoides*) is a tall (6-15' in height), erect bunchgrass high in protein, highly digestible, and free of prussic acid and as such is commonly used for hay, pasture, and silage for feeding cattle, horses, goats, and other livestock. According to National Resources Conservation Service (NRCS), it is also a very good green manure, and well adapted to low soil moisture, low fertility, and high temperatures. Pearl millet produces a large biomass and is a good cover crop for trapping residual nitrogen in the cover crop biomass and diverting nitrates from potential run off (Penn State Ext.) The nitrogen is then released back into the soil when the cover crop breaks down and provides nutrients for the subsequent cash crop. No research exists on pearl millet in tropical/subtropical conditions, but is favorable among some growers in the RGV.

Sudangrass

Sudangrass is a cover crop known for its heat and drought tolerance making it a great option for growing in the LRGV. Due to its large root system sudangrass increases SOM (especially carbon) (Björkman & Shail, 2010), suppresses weeds because of its large above ground biomass and allelochemicals (Scott & Weston, 1991; Forney & Chester, 1984), and has shown to reduce harmful nematodes and soil-borne diseases (Bagegni et al., 1994). The large biomass, subsoil root system, and weed and nematode suppression makes sudangrass a great option to restore soils that have been over farmed, or for farmers that are in transition from conventional agriculture to organic agriculture. It is also widely adaptable being able to withstand a large range of pH from 5.0-9.0, can be grown throughout the US, and is heat and drought resistant.

CHAPTER II

WEED SUPPRESSION PROVIDED BY COVER CROPS

Introduction

Agricultural soils contain a high number of weed seeds, which if left unmanaged cause a significant reduction in the cash crop yield and quality by competing for light, nutrients and water (McErlich & Boyston 2014). In addition, weeds also harbor pests (nematodes, insects, and pathogens) causing the reduction in the potential yields and quality of crops (Capinera, 2005; Boydston et al., 2008). Farmers rank weeds as the number one barrier to organic production (Walz, 1999), and organic farmers cite weed management as their number one research priority (Monks et al., 2008). For organic growers, managing weeds with acceptable techniques is a major challenge and potentially requires the highest labor input (Center for Agroecology & Sustainable Food Systems, 2015; Bàrberi, 2002). Using cover crops, a traditional farm management method, has regained its popularity among organic growers seeking to reduce farm inputs and maximize yield quantity and quality. Cover crops have several benefits including protection from soil erosion, weed and pest suppression, reduction of nutrient leaching, and soil carbon sequestration. If seeded well in the right conditions a cover crops are known to suppress weeds up to 100% while planted and significantly reduce weeds in subsequent crop seasons (Schonbeck, 2011). Cover crops are known to suppress weeds in several ways by direct competition for nutrients, light, and water, allelopathy, blocking stimuli for weed seed germination, and altering the soil microbial communities (Teasdale, 1993, Hartwig, 2002; Seigies & Pritts, 2006). Altering the availability of limiting resources such as light and nutrients is an important approach in weed control leading to sustainable weed management (Perry and Galatowitsch, 2006).

Effects of light quality and quantity on crop/weed growth has been documented by several researchers (Holt, 1995; Jones, 2013; Yelverton & Coble, 1991) The high density of crop plantings causes high light competition amongst crop individuals and increases with the presence of weeds (Beuerlein & Pendleton, 1971). It has been shown that when weeds become taller than the intended crop light penetration and the growth of the crop are reduced (Cudney et al. 1991). Shading by cover crops during cover crop growth, causes the reduction in the ratio of red to far-red light reaching the soil surface thus resulting in the inhibition of weed seed germination (Holt, 1995). The physical light barrier that a cover crop canopy provides inhibits the establishment of weeds in crop fields making cover crops a viable option for reducing weeds.

Cover crops for weed-suppression is a key technological option for farmers in tropical and subtropical regions that face tremendous weed pressures characteristic of these regions. For example, farmers in the southern-most region of Texas and often cite weed management as one of their major constraint, especially in organic agriculture (Racelis, unpublished data). However, despite the building evidence for cover crops and their potential in weed management, there is very little information the performance of cover crops in the subtropical United States (US Zone 9b). In this study, we analyzed the potential of several cover crops to suppress weeds by limiting light resource for the weeds in an on-farm trial in Harlingen, TX. We also determined the best seeding rate and seeding method to achieve maximum weed suppression by the cover crops.

Methods

Site Description

We tested four different cover crops to analyze their ability to suppress weed density at a 14-acre certified organic working farm in Harlingen, Texas (26°09'20.89" N 97°42'19.74" W). As for much of the region, this site is considered subtropical, with annual average rainfall of 69.9 cm and an annual average temperature of 23.3°C. July and August are the warmest months, with average daily high temperatures of 35°C and 35.6°C respectively. Most of the rainfall falls between May and September, with September having the highest average precipitation of 13.4 cm. In general, soils at the site are characterized as deep calcareous soils that are level to nearly level (heavy-textured Harlingen clay, average pH 7.6). Based on weather data from the regional airports (National Centers for Environmental Information, 2016), the monthly average precipitation during this study did not differ significantly from twenty year averages. Although total rainfall during the study period was lower than the interannual average, there was considerable (above average) rainfall in the month of May 2015 preceding the planting date, which is typically when RGV region plants their summer crops. Average rains in June 2015 delayed our planting until July 2015.

Cover Crops

We selected four different cover crops (2 legumes and 2 grasses) for this study: lablab (*Lablab purpureus*), sunn hemp (*Crotalaria juncea*), pearl millet (*Pennisetum glaucum*), and sudan grass (*Sorghum drummondii*). The cover crops were planted on a 2-acre field divided into 16 plots, allowing for two replicates of each cover crop and two control plots measuring 7.3x30.5 m. Three of the four cover crops: lablab, sunn hemp, and sudangrass were planted 1.5 times and 3 times the recommended seeding rate. After three planting attempts, pearl millet did not grow to provide a good cover crop stand and was determined to be unsuccessful if planted during the summer months in the RGV. The seed source, seeding rates and temperature tolerance for each cover crop is given in Table 1. The cover crops were planted on 7/9/16 due to excessively wet soils that did not allow field access to plant. Half of the field was planted using a hand broadcast seeder and the other half was planted with a drop seeder attached to a walk behind tractor (BCS, city ST), and immediately tilled in by the farmer using a disk implement attached to a tractor. The cover crops were flood irrigated two times during the study period: two days after planting (DAP) and 28 DAP. After 8 weeks the plants were tilled on September 3rd 2015, and the cover crop biomass was measured.

Cover Crop Height and Biomass Measurement

To estimate the standing biomass of cover crops, height of the cover crops was measured every two weeks. Height of the cover corps was measured in 0.25m^2 in five randomly selected quadrats in each cover crop treatment. At the end of the eight-week trial period above ground biomass from 5 random quadrants was collected for each cover crop treatment. These biomass samples were transported to the lab and weed and cover crops were sorted and dried in an oven at 55^oC for 72 hours. The dry cover crop and weed weight in each cover crop treatment was measured.

Light readings

Light readings, measuring the photosynthetic photon flux density (PPFD), were collected every two weeks after planting the cover crops. A Licor Quantom Line Sensor (LI-COR, INC. Lincoln, NE USA) and data logger (LI-1400, LI-COR, Lincoln, NE, USA) were used to measure PPFD at the soil surface below the cover crop canopy and at the top of the cover crop canopy at clear conditions at 12:00pm-1:00pm.

Data analysis

Analysis of the different cover crop heights and the light readings were analyzed using Sigma Plot 12.5. Data that did not meet assumptions of normality were log-transformed. Analysis of variance (ANOVA) was done to compare the height of the above ground biomass of the different cover crops, and an ANOVA was done to compare the amount of light penetration through the cover crop canopy that reached the ground in each cover crop treatment. Pearson correlation analysis was used to look at the relationship between cover crop height and the amount of cover crop biomass. A correlation analysis was also performed to relate the biomass of the cover crop and the PPFD at the soil surface. Statistics were performed using SigmaPlot 13.

Results

In this study, we compared the performance of four different summer cover crops and two different seeding methods and seeding rates. Seeding method did not have any significant difference on cover crop performance (data not shown). However, there was a significant difference in the growth and weed suppression potential among the different cover crops in the growth of varying degrees of cover crop and weed growth among the different cover crop treatments. (Table 1). Sudangrass planted 1.5 times the recommended rate produced the highest amount of biomass (2910 kg/ha) followed by sudangrass planted at 3times the recommended rate, while lab lab planted at both rates 1.5 times and 3times produced the lowest cover crop biomass (94.4kg/ha and 107 kg/ha respectively).

As expected, the biomass cover crops was negatively correlated with the weed biomass ($r(14) = -0.53$, $p = .05$). The weed to cover crop biomass in the different cover crop plots ranged from 434 kg/ha of weeds in a plot of lablab 1.5 times recommended with a biomass of 944 kg/ha to 220 kg/ha of weeds in a plot of sudangrass 3 times recommended rate with a biomass 1950 kg/ha. The control treatment of 570 kg/ha had the highest above ground biomass of weeds when compared to all of the cover crop treatments at all seeding rates. Weed to cover crop ratio was lowest in the sudangrass treatments at all seeding ratings.

The correlation between plant height and the PPFD of the different cover crops show that sudangrass grew vigorously and blocked the most of the light from reaching the soil surface. While there is a possibility that PPFD could have been affected by the weeds our results show a strong negative correlation between the cover crops' height and the PPFD at the soil surface.

A two-way ANOVA of cover crop type and seeding rate on height of the biomass was conducted to compare the effect the cover crop type and seeding rate had on the height of the above ground biomass in lablab, sudangrass, and sunn hemp. A significant main effect of cover crop type on above ground biomass height was found, $F(2,56) = 175.071$ p=<0.001. The main effect of seed rate on biomass height was not significant. The cover crop type and seeding rate interaction was significant $F(2,56) = 7.084$ $p=0.002$. Of the four different cover crops, sudangrass at both the seeding rates had the highest heights followed by pearl millet. The 1.5 times the seeding rate in sudangrass grew taller than the 3 times the seeding rate sudangrass plots. On the other hand, sunn hemp at 1.5 times the seeding rate had the lowest height growth (Figure 3).

My results show that light penetration to the soil surface decreased significantly over time (Figure 2). Among the seven treatments, sudangrass with seeding rate 1.5 times the recommended rate and 3 times the recommended rate resulted in the lowest light penetration along with pearl millet 2times the recommended rate. ($F(3,66) = 3.12$ $p=0.0319$)

Discussion

Cover crops are a fundamental component of organic farm management. Cover crops have the potential to produce large amounts of biomass and contribute to the maintenance and/or improvement of the physical, chemical and biological characteristics of the soil, including adaptation of effective soil depth through their roots which help in weed suppression and promote soil quality in short period of time. This is the first study documenting the potential for cover crops to suppress weeds during the summer season in the Lower Rio Grande Valley. Without the option to use chemical herbicides, weed management is a challenge for organic growers, and they need to use several biological, chemical, and cultural practices (Liebman and Davis 2000). Our results indicate that, in addition to other soil health benefits (Soti et al 2016), cover crops could serve as a successful weed management tool in organic farms.

Cover crops emergence and ground coverage (represented by the light reading) varied significantly among the cover crops selected and their seeding rates. This could be the result of the seed temperature tolerance, field conditions etc. Sunn hemp performs best on well-drained soils with a pH from 5.0-7.5 (USDA NRCS). The soil at this location had a pH of 8.00 and had very high clay content. This may account for the poor performance of Sunn Hemp. Sudan grass followed by pearl millet had faster growth and biomass accumulation these results are similar to previous studies (Bicksler & Masiunas, 2009; Creamer & Baldwin, 2000; Teasdale, 1993; Ong & Monteith, 1985; Maiti & Bidinger, 1981).

The weed species growing in the control plots parthenium (*Parthenium hysterophorus*), pigweed (*Amaranthus palmeri*), and johnsongrass (*Sorghum halepense*) represent the major problematic weeds in the region. Parthenium is an annual weed that causes major problems in rangelands and cropping systems throughout the southern US and other subtropical regions. It can cost up to $22 million dollars a year in reduced crop production and increased management costs (CRC Weed Management, 2003). Pigweed an annual weed which causes serious problems for farmers throughout the southern US can cost $60-$80 per acre for farmers to manage in their fields (Thompson, 2016). Johnsongrass is a perennial weed and is very difficult to control with a single cultural methods or herbicide application (Johnson et al 1997). Johnson grass is one of the most costly weeds that farmers encounter and costs millions of dollars a year in lost crops, poor quality grain, and lower crop yield (Shawnee Co. Weed Department). Our study indicated that the grass species of cover crop, sudangrass and pearl millet, with faster growth and higher biomass accumulation, were more successful in weed suppression and growth compared to the, legume species used, lablab and sunn hemp. Potential of grass cover crops to suppress weeds is well documented (Teasdale, 1996; Teasdale et al., 2007; Burgos & Talbert, 1996; Yenish, J. P., Worsham & York 1996.) Cover crops with faster growth rate and above and below ground biomass accumulation rates can suppress weeds by competition for resources such as light, water, and nutrients. Additionally, the reduction of weed biomass could be in part due to the allelopathic effects. Sudangrass is known to have allelopathic compounds and exudes sorgoleone which is very active at very low concentrations and has been shown to suppress weeds and may have been a factor in the low amount of weeds (Scott, 1991).

With the growing market demand for organic produce, there is also a growing demand to find practices that reduce the amount of weeds in crop fields in an environmental and economically sound manner. This study showed encouraging results for the use of sudan grass as a cover crop to suppress weeds through physical competition for light, nutrients and space. Future research is needed to better understand the mechanism of weed suppression. In the subtropics with constant high weed pressures, it is also important to study more varieties of cover crops during different times of the year to see which perform best when. This could then be translated into a yearlong crop rotation between cover crops and vegetable production to ensure the greatest amount of weed suppression throughout the year.

Conclusion

This is the first study documenting the potential for cover crops to suppress weeds during the summer season in the Lower Rio Grande Valley. Organic farmers constantly deal with weeds on their farm due to USDA organic standards that forbid the use of chemical herbicides on their land. With the growing market demand for organic produce, there is also a growing demand to find practices that reduce the amount of weeds in crop fields in an environmental and economically sound manner. This study showed encouraging results for the use of sudan grass as a cover crop to suppress weeds through physical competition as a smother crop. Sudan grass also has allelopathic compounds and exudes sorgoleone which is very active at very low concentrations and has been shown to suppress weeds and may have been a factor in the low amount of weeds (Scott, 1991). There was no statistical difference between the other cover crops and their ability to suppress weeds. Some factors that may have influenced the development of the stands are the placement in the field, soil type, and time of planting. Future research is needed to better understand how these factors may affect the success of the cover crop creating biomass because the height of the cover crop may have only had such a strong correlation to standing biomass because of the poor performance of the shorter cover crops. In the subtropics with constant high weed pressures, it is also important to study more varieties of cover crops during different times of the year to see which perform best when. This could then be translated into a yearlong crop rotation between cover crops and vegetable production to ensure the greatest amount of weed suppression throughout the year.

Tables & Figures

Table 2.1: The Seed Source, Seeding Rates, & Temperature Tolerance for Each Cover Crop

Cover Crop	Source	Recommended Seeding Rate lb/acre*	Cost/Acre	Optimum Temperatures
Sudan Grass	Johnny's Selected Seed Co.	40	$108.80	Soil temp at least 18.3°C
Pearl Millet	Johnny's Selected Seed Co.	10	$16.40	Soil temp at least 18.3°C
Lablab	Hancock Seed Co.	25	$70.25	13-30°C Can tolerate light frosts
Sunn Hemp	Hancock Seed Co.	25	$65.50	Warm temperatures with no frost dates

Table 2.2: Cover Crop Above Ground Biomass : Weed Biomass
Average cover crop biomass and weed biomass measured (kg/ha) at the end of the experiment for different cover crops at different seeding rates. Converted to kg/ha.

Cover Crop	Seeding Rate	CC Biomass (kg/ha)	Weed Biomass (kg/ha)
Pearl Millet	2X	639	339
Lablab	1X	94.4	434
Lablab	3X	107	314
Sunn Hemp	1X	587	334
Sunn Hemp	3X	344	230
Sudangrass	1X	2910	430
Sudangrass	3X	1950	220
Control		0	570

Table 2.3: Average Cover Crop Above Ground Biomass Height.

TREATMENT	2 WAP		5 WAP		8 WAP	
LL1	13.07	± 1.67	14.87	± 2.52	23.11	± 5.04
LL3	16.38	± 2.23	19.20	± 3.72	32.78	± 11.32
SG1	28.30	± 5.72	76.28	± 21.34	137.48	± 29.17
SG3	30.26	± 4.22	61.66	± 13.23	107.50	± 31.81
SH1	20.18	± 2.59	35.70	± 9.24	61.73	± 13.04
SH3	19.65	± 3.46	33.33	± 8.34	55.56	± 9.05

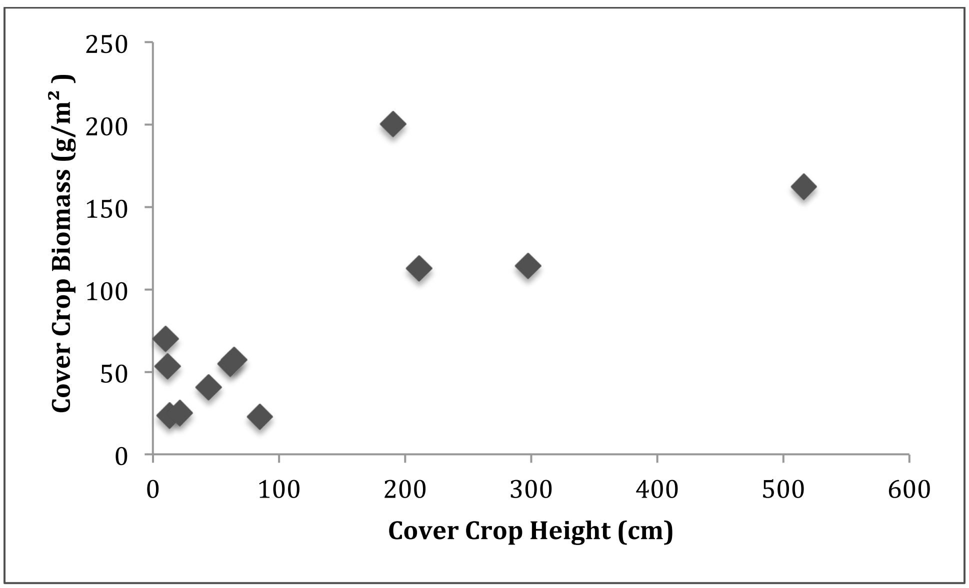

Figure 2.1: Correlation of Cover Crop Above Ground Biomass and Cover Crop Height: Relationship between cover crop height and biomass recorded at the end of 8 weeks. There was strong positive correlation between the cover crop biomass and the average height of the cover crops (r (14) = 0.94, p < .00001.)

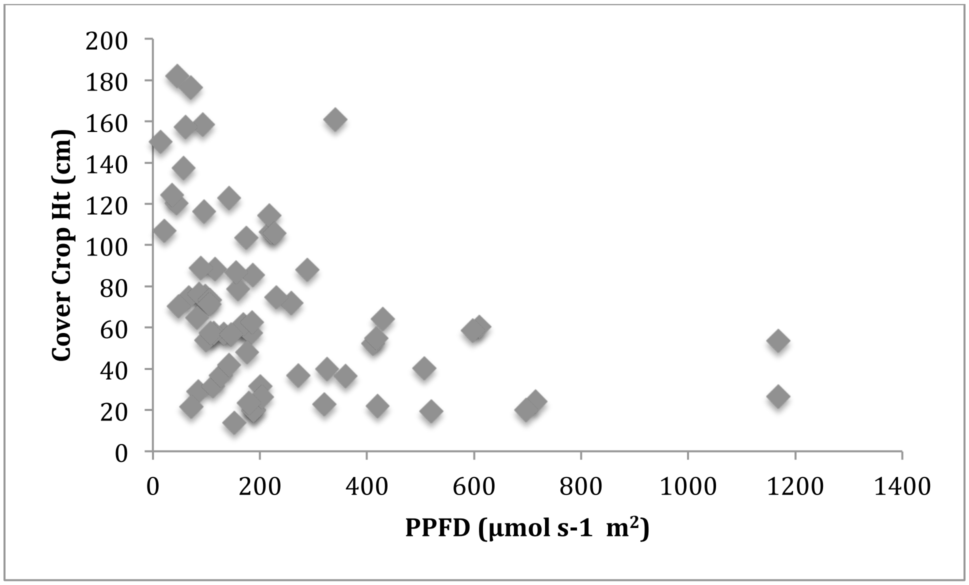

Figure 2.2: Correlation between Cover Crop height and Light Readings at Soil Surface: Negative correlation between plaint height and PPFD readings at soil surface. (r(67) = -0.38, p=0.001)

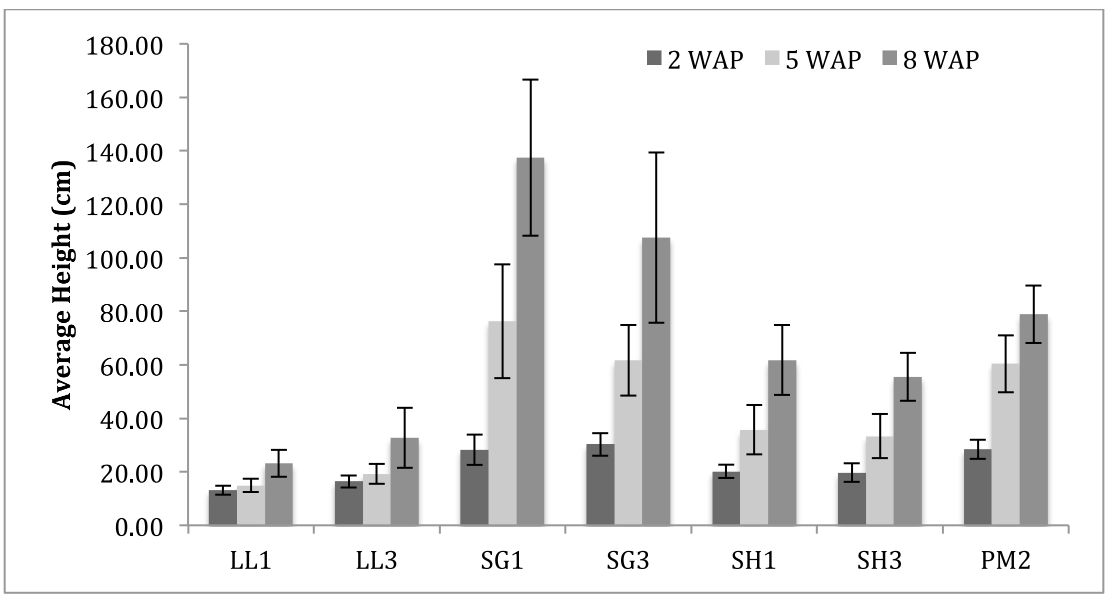

Figure 2.3: Difference in above ground biomass height amongst cover crop treatments. The height difference of the above ground biomass at of the cover crop treatments at 1.5x recommended seeding rate and at 3x recommended seeding rate.

CHAPTER III

MYCORRYZHAE DENSITY OF DIFFERENT COVER CROPS

Introduction

Soil microbial communities play a very important role in improving soil health and plant productivity through recycling of nutrients and increasing nutrient availability in agroecosystems. For example, mycorrhizal fungi and plant growth-promoting rhizobacteria can enhance plants' tolerance to adverse environmental stresses via plant growth promotion and induced resistance (Pineda et al., 2010). Mycorrhizal fungi are especially important in organic farming as they act as natural fertilizers enhancing nutrient up take and providing resistance against drought and soil pathogens. Various studies have demonstrated that mycorrhizal symbiosis is crucial in nutrient deficient soils (Marschner & Dell, 1994; Johnson et al., 2010; Soka & Ritchie, 2014), where for examplemycorrhizal fungi can contribute to up to 90% of plant P demand (Van Der Heijden et al., 2006). As a result, agroecosystems with high diversity and abundance of mycorrhizal fungi often result in better crop performance and increased productivity (Khade & Rodrigues, 2009) and improved agroecosystem services such as soil aggregation, improved soil structure and carbon sequestration (Barrios, 2007; Van Der Heijden & Scheublin, 2007). Mycorrhizal fungi are formed at the interface between soil and plant roots and highly sensitive to changes in the plant or soil conditions. Thus, fallow periods are especially detrimental to mycorrhizal fungi as they depend on the host plants for their nutrition Cheeke et al. (2012).

Improvement of crop growth by mycorrhizal fungi association can be enhanced by increasing the effectiveness of indigenous fungi (Miller et al., 1995) (Kabir & Koide, 2000). However, there has been relatively little attention given to understanding how to enhance mycorrhizal fungi to benefit cash crops, especially in the southern US, where farmers deal with warmer climates associated with high rates of decomposition. In the Lower Rio Grande Valley of deep south Texas, farmers have to also contend with highly calcareous soils with low organic matter and high soil pH (Table 1). While indigenous mycorrhizal fungi may be prevalent, the availability of macro and micro nutrients is low. As such, finding ways to increase fungi colonization in this region may help increase farm productivity and sustainability.

The LRGV frequently grow crops highly dependent on mycorrhizal fungi such as peppers and corn, following non mycorrhizal dependent brassica crops (Storz, 2011). Thus, growing mycorrhizal cover crops in rotation with these cash crops may help promote mycorrhizal fungi, so they can form associations with corps that depend on them. Cover crops are known to improve the mycorrhizal inoculum of the soil (Kabir & Koide, 2000). However, there is very little information on cover crops in the LRGV. Furthermore, the USDA does not have any recommendations on cover crops for subtropical areas (Plant Zones 9-10). Given their benefits in nutrient uptake, mycorrhizal fungi can be of high value for the functioning and sustainability of agroecosystems, particularly in organic farms where choices of external inputs are limited. There are several commercial inoculants available, but generally are limited in diversity. In addition, and since commercial inoculants are usually not native to specific areas (especially in the southern US where there is a lack of options), these commercial varieties might not be well adapted to the farm conditions where they are applied. Thus, cover crops can be a cost effective and easy method to harness the benefits of extant mycorrhizal fungi. The objectives of this study were: to assess the effects of four different warm season cover crop candidates--lablab (*Lablab purpureus*), sunn hemp (*Crotalaria juncea*), pearl millet (*Pennisetum glaucum*), sudangrass (*Sorghum drummondii*)-on the spore density and diversity of mycorrhizal fungi, soil organic carbon and nutrient status, and soil organic matter and nutrients.

Materials and Methods

Research Site

We tested four different cover crops to analyze their ability to increase mycorrhizal fungi density certified organic farm in Harlingen, Texas (26^{o}09′20″N, 97^{o}42′19″W). We created ten 48 × 110 ft plots for the experiment in completely randomized design. The soil nutrient status of the farm at the beginning of the experiment (July, 2015) is given in Table 1. Initially, this site had high levels of calcium concentration ranging from 18913 ppm to 22511 ppm, high soil pH and very low organic matter content, an environment not conducive for the microbial activity (Naidu & Rengasamy, 1993). The soil texture was silty loam with very poor drainage, which is a common characteristic of soils in this region. The nutrient distribution along our field varied considerably, likely a result of the variation in the water drainage pattern in the field.

Table 3.1: Soil Nutrient Status (in ppm) Prior to Experiment

	Pearl millet	Lablab	Sunn hemp	Sudangrass	Control
Boron	1.60	1.80	1.55	1.90	1.60
Calcium	20344	21024	20410	22511	18913
Copper	0.50	0.50	0.70	0.70	3.40
Iron	0.20	0.25	0.20	0.25	0.30
Magnesium	139	145.50	140	155	130
Manganese	15	17.25	15.95	21.70	20.40
Nitrate	25	19.50	17	19.50	18
OM%	2.68	2.51	2.25	2.43	3.08
pH	8.00	8.05	8.10	8.05	8.00
Phosphorus	7	7.75	7.45	9.05	8.1
Potassium	442	512.50	479.50	554.50	350
Sulfur	196.20	211.95	218.95	220.25	236.80
Zinc	0.60	0.55	0.55	0.75	6.20

Cover Crops

We selected four different cover crops (two legumes and two grasses, respectively) for this study: lablab (*Lablab purpureus*), sunn hemp (*Crotalaria juncea*), pearl millet (*Pennisetum glaucum*), and sudangrass (*Sorghum drummondii*).. Seeds were purchased from different vendors and were approved for use in organic farms (SG, PM from Johnny's Select Seeds Winslow, ME; LL and SH were purchased from Hancock Farm Seed Co. , Dade City FL). The farm was previously planted with *Brassica oleraceae* (kale, a non-mycorrhizal crop) On July 7, 2015 we planted all the cover crops using a hand broadcaster. The cover crops were flood-irrigated two times the study period: two days after seeding and after four weeks. After 8 weeks the plants were tilled on September 3, 2015.

Soil Sample Collection and Analysis

Four weeks after tilling the cover crops soil samples were collected from the plots and analyzed for mycorrhizal fungi spores and soil organic matter status. Three soil samples were collected from each plot with a soil corer (diameter = 2.5 cm; AMS, American Falls, ID). Soil samples from each plot were mixed thoroughly to create a composite sample for each cover crop. A portion of soil samples were then stored in a 4 ^{o}C refrigerator until analysis. Soil samples for soil chemical analysis were air dried and ground in a mortar pestle and shipped in air tight containers to the Soil and Plant Tissue Testing Laboratory, University of Massachusetts, (Amherst, MA). Soil organic matter was estimated by loss on ignition method and soil moisture was measured by the gravimetric method.

Spore Extraction

Mycorrhizal spores were extracted from soil by using a modified wet sieving and decanting technique Gerdemann and Nicolson (1963). Ten gram of soil was added to 500 ml of water and mixed vigorously to separate the spores from soil aggregates. The soil mixture was then passed through a series of sieves and washed until the water flowing through the sieves was clear. The sievate retained on the sieves was washed and centrifuged with water to remove the organic debris. The pellet in the bottom was resuspended in a 50% sucrose solution, and centrifuged for one minute at 1600 RPM to separate the spores from denser soil components. Immediately after centrifugation, spores in the sucrose supernatant were washed into petri dishes for counting. The spores were counted under ZEISS Discovery V5 stereomicroscope. Spores collected from each treatment were grouped based on the color, size and shape. They were then observed under 100x magnification and identified to genus level following the International

Culture Collection of VA Mycorrhizal Fungi (INVAM) based on the spore morphology (Schenck & Pérez, 1988).

Data Analysis

Data was stored in an excel spreadsheet and analyzed with Statistical Analysis System (SAS, 2003). Difference in the soil nutrient status due to cover crops was calculated by subtracting the soil nutrient concentration at the beginning of the experiment from the soil nutrient concentration at the end of the experiment. Correlations between soil spore density and soil chemical and physical properties were done using Pearson correlations coefficients.

Results

Mycorrhizal Fungi Spores

Overall, all cover crop treatments had a positive effect on the mycorrhizal spore density compared to the control. Total spore density varied significantly among the different cover crop treatments, ranging from 52 to 187 spores per 10 grams of dry soil (Figure 1). Our results indicate that the mycorrhizal spore density was influenced by the cover crop identity. Highest number of spores was found under sunn hemp followed by sudangrass and lablab. Among the four cover crops, pearl millet had the lowest number of spore count.

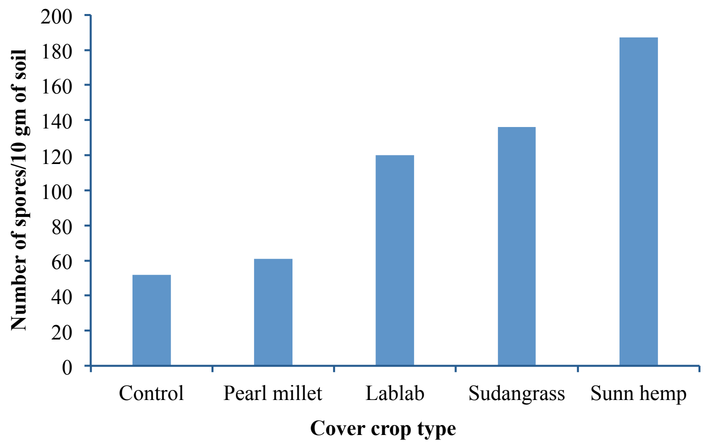

Figure 3.1: Number of mycorrhizal spores per 10 grams of soil under each cover crop

There was also a difference in the spore size among the different cover crops. Sunn hemp and sudangrass had generally bigger spores while the control and pearl millet generally had smaller spores with few large spores. 14 different species of mycorrhizal fungi were identified in the study from three different genera: *Glomus*, *Aculospora* and *Gigaspora*. The distribution of these spores varied among the different cover crops. *Glomus* was most dominant in the sunn hemp and lablab and a high density of *Gigaspora* occurred in the sudangrass treatment.

There was a strong positive correlation between the number of spores and soil magnesium ($r = 0.96$, $p = 0.0095$) and boron concentration ($r = 0.92$, $p = 0.025$). A strong negative correlation was seen between the number of spores and soil moisture ($r = -0.93$, $p = 0.021$) indicating that the number of mycorrhizal spores were higher in dry soils compared to wetter soils. However, there was no significant correlation between the total number of spores and soil organic matter, nitrate, or phosphorus concentration.

Soil Nutrient Status

Our results show that cover crop treatments had mixed results in changing the soil nutrient status (Table 2). All treatments increased soil organic matter, declining only in the control treatment. Similarly, concentration of copper and zinc also went up in the plots with cover crops while their concentration declined in the control treatment plots. Concentration of boron, calcium, magnesium, phosphorus, and potassium increased in all the treatments. Highest increases in boron concentration was observed in the lablab treatment, followed by the sunn hemp trial. Similarly, sunn hemp resulted in the highest increase in the soil magnesium concentrations, followed by lablab and pearl millet.

Table 3.2: Change in the Soil Nutrient Status After Each Cover Crop (in ppm).
Numbers are calculated by subtracting the pre cover crop soil nutrient concentration from the post cover crop nutrient concentration

	Pearl Millet	Lablab	Sunn hemp	Sudan grass	Control
Boron	0.2	0.55	0.9	0.45	0.2
Calcium	1852	1406.5	1427	500	3360
Copper	0.6	0.2	0.4	-0.1	-2.3
Iron	0.1	0.1	0.15	0.15	0
Magnesium	24	28	35.5	13.5	27
Manganese	-1	-0.5	0.65	-2.45	-6.7
Nitrate	2	-3	7.5	0.5	2
OM%	0.45	0.87	1.46	1.08	-0.48
pH	0.1	0.05	0	0	0.1
Phosphorus	9.9	19.2	19.3	15.35	6.8
Potassium	142	205.5	205.5	138.5	143
Sulfur	0.4	-14.25	-18.65	-12.8	-32.9
Zinc	0.6	0.5	0.6	0.25	-5.3

Discussion

The beneficial effects of cover crops on mycorrhizal fungi have been well documented (Galvez et al., 1995; Boswell et al., 1998; Douds et al., 2005). This study confirmed the potential of warm seasoncover crops in promoting native mycorrhizal fungi in subtropical organic farms. Our results indicate that over, cover crops can help improve the density and structure of mycorrhizal fungi. However, of the number of spores was not necesarrily associated with improved soil physical and chemical properties as tested in this study. While the number of mycorrhizal fungi spores was positively correlated with increases in soil magnesium and boron, here was a strong negative correlation between the fungal spore density and soil moisture. In addition, mycorrhizal fungi varied among the different cover crops. *Glomus* spp. was most commonly found in sunn hemp and lablab treatments, where higher densitties of *Gigaspora* occurred in the sudangrass treatment. Similar results of higher density of *Glomus* in soils with high magnesium concentration and high *Gigaspora* density in low soil magnesium concentration has been reported in previous studies (Schenck & Siqueira, 1987; Gryndler, 1992). The overall diversity of mycorrhizal fungi, however, was similar for the different cover crops and was lower in the control treatment.

Soil organic matter is the major component of sustainable agriculture, and when growing vegetables and specialty crops, a soil high in organic matter is very desirable. Cover crops are known to increase soil organic matter and enhance the natural productivity and fertility of soil. In our study all the cover crops increased the soil organic matter compared to the control treatment where it decreased over the course of the experiment.Generally, grass cover crops are known to contribute more soil carbon than legumes (Hoorman, 2009). However, in this study, sudangrass contributed less organic matter compared to sunn hemp when measured after 4 weeks of incorporating cover crops into the soil. A possible reason for this could be the sudangrass had lignified when tilled and may not have fully decomposed in the soil because of its high C:N ratio (Wang & Noite, 2010).

Sunn hemp resulted in highest nitrate concentration in the soil. However contrary to our expectation lablab, caused a decline in the soil nitrate. A possible explanation for this outcome could be the high density of weeds in the lablab plots relative to the other treatments Similarly, sunn hemp also out performed other treatments in the conservation of phosphorous in the soil signaling its potential as a warm season cover crop to improve soil health in subtropical agroecosystems.

While cover-crop selection often depends on specific farm conditions and expected outcomes, this study shows that in this subtropical region, where the soils are alkaline and have high calcium concentration, cover crops can facilitate a diversity of benefits associated with soil mycorrhizal fungi. More detailed analysis is required to calculate the total benefits, but if seed costs are low, soil rehabilitation with cover crops can be beneficial to farmers with only minor additional costs. In addition, in areas where farm rotations include non-mycorrhizal crops (such as kale and other brassicas) with mycorrhiza dependent crops such as peppers or other fruiting plants, incorporating cover crops in rotation could play an important role in increasing mycorrhizal inoculum potential and growth of subsequent mycorrhiza dependent crop.

CHAPTER IV

CONCLUSIONS AND FUTURE RESEARCH

This thesis explored the potential benefits of using summer cover crops in subtropical organic vegetable farms. The following are the major contributions of this research:

(1) Discovery of cover crop varieties that can grow best the summer months in the RGV (Chapter 1),

(2) Cover crops can help suppress weeds, a major challenge faced by organic growers in the RGV and beyond (Chapter 2)

(3) Cover crops can promote soil health and fertility in subtropical farms (Chapter 3)

How To Decide on Which Cover Crop to Plant

When farmers decide to incorporate cover cropping into their farm management plan, they must consider multiple factors that may affect the success of the cover crop and the benefits it provides. First, a farmer should decide what he or she would like to achieve by growing a cover crop i.e. erosion control, soil organic matter, soil fertility, weed suppression etc. (Chapter 1). Many cover crops provide more than one function on the farm, so it is beneficial to use comparison charts to see how different cover crops perform different roles. Next, the farmer needs to know what time during the year makes the most economical and regional sense to plant cover crops and how long the crops will be in the ground. During this step, farmers should consider what was in the field before planting the cover crop and what will be planted after the cover crop. This will help to ensure the subsequent crop has adequate nutrients. Also, the weather during the time of planting should influence what types of cover crops to grow during that time of the year. Lastly, the farmer must consider the region in which they grow to pick a crop that is climatically adapted for that growing zone. All of these factors are pertinent to my research because I assessed the cover crops different functions and how they ranked comparatively to one another; I looked at growing cover crops during the summer season because that is when farmers in this region typically leave their fields fallow and makes the most economical sense; I am also the first person to research different cover crops and their functions on organic farms in this region and provides recommendations for growers in this region that did not exist prior to my thesis research.

Potential Summer Cover Crops Suitable for Subtropic Organic Vegetable Farms

Chapter 1 is a synthesis of the background literature compiled of researching potential cover crops that could perform well during the high temperatures and drought conditions of the Lower Rio Grande Valley (growing zones 9b & 10a). Little to no research has been published on cover crops in this region, underlining the significance this work. Through literature review, I identified various cover crop candidates that were used as cover crops in sub-tropical regions of the world-especially in regions that experience periods of drought. Four varieties that seemed tolerable to the climatic conditions of the LRGV during the summer months: sudangrass, lablab, sunn hemp, and pearl millet. I also found two varieties for the winter months, which included tillage radish and winter rye. In close collaboration with the farmer at Terra Preta Farms, winter trials were planted and had good biomass production, but due to extenuating circumstances on farm, no data was gathered during those trials (Figure 4.1 & 4.2).

Figure 4.1 & 4.2: (4.1, right) An example of the size of the tillage radish grown during the winter trials. (4.2, left) Myself in the field flail mowing the above ground biomass from the tillage radish trials.

The cover crops suitable for the summer on subtropical organic vegetable farms, presented here, serve as the experimental trials in this region, and should serve as a useful baseline for future research, especially on soil health and fertility. The information presented in this study will be a useful guide to farmers looking to select warm season cover crops in their farms since cover crops that are often recommended to farmers by seed provider or even the USDA more specifically suitable for other growing regions—for example, on the list provided by Johnny's Seeds Catalog (2016, ME), cover crops candidates are recommended for Zones 3-8—completely avoiding USDA Plant Zones 9 and 10. Lablab is often recommended for the summer months, but in our trials it had poor germination and were out-competed by weeds. But when planted for a demonstration plot during the cooler month of October at the UTRGV research garden these crops grew a nice canopy and suppressed most weeds in the plot (qualitative visual data, no quantitative analysis was performed see Figure 4.2).

Figure 4.3: A Dense Stand of Lablab: planted October 2, 2015 at the UTRGV research garden.

Table 4.1: Recommendations to subtropical growers, especially those in the RGV.

Cover Crops	Benefits ranked in order of decreasing value	Rate (for best results)	Planting time
Sunn-hemp	Nutrient cycling Increasing mycorrhizae spores Increasing soil organic matter Suppressing weeds	120lb/acre (3x recommended)	Year-round
Sudangrass	Suppressing weeds Increasing soil organic matter Nutrient cycling Increasing mycorrhizae spores	40lb/acre (recommended)	Year-round
Lablab	Increasing soil organic matter Nutrient cycling Increasing mycorrhizae spores Suppressing weeds	100lb/acre (4x recommended)	Fall, Winter, & Spring
Tillage Radish	Reducing compaction Suppressing weeds Recycling nutrients Increasing soil organic matter	12lb/acre (2x recommended)	Fall & Winter
Pearl Millet	Increasing soil organic matter Suppressing weeds Nutrient cycling	40lb/acre (4x recommended)	Fall

Cover Cropping To Manage Weed Suppression

The information presented in Chapter 2 is makes recommendations for cover crop seeding rates and method of seeding. As demonstrated in this chapter, different cover crops have different benefits, based on the farming conditions. When evaluating the four different cover crops used in this study in regards to weed suppression, sudangrass was a clear winner as a warm season cover crop. Based on this work, lablab would be poorly recommended for suppressing weeds in the fields during the summer months. Of note, farmers at Yahweh Farm in Harlingen, TX where this was conducted immediately decided to grow sudangrass as cover crop the following summer, largely because of the success during our trials. Further research is needed on the mechanisms of weed suppression (chemical vs. physical), timing of planting , tradeoffs with utility and investment (cost vs. benefits), the amount of irrigation needed to have a successful cover crop stand, the potential to use the cover crop as animal fodder, comparing the economic savings of using a cover crop versus manual labor cost of weeding.

Cover Crops Promote Soil Health

Chapter 3 provides some baseline information on the potential of cover crops to promote soil health and nutrient status in subtropical agroecosystems. Undoubtedly, this warrants further survey of mycorrhizal fungi in the Lower Rio Grande Valley, but this study suggests that cover crops can promote the populations of beneficial soil microorganisms , demonstrated by the increase in spore density in the sunn hemp trials. In addition, sunn hemp provided the most plant accessible nitrate after the incorporation of the cover crops (Table 3.1). This shows promise in using this cover crop as a form of green manure to increase the amount of nitrates in the soil essential for crop growth.

Need For Participatory Action Research In Agriculture

An impediment to modern agricultural research is translating or scaling up research and experimental studies to practice on farm. Often research is led by scientists and university interests, often driven by curiosity and inquiry and these broader implications, not necessarily by practicality and relevance, and local implication. This type of research endeavor infrequently considers the needs and interests of the farmers that would be directly impacted by the results of the study, and would be the ones that could actually scale up the research. Unfortunately, this research do not account for multiple factors that determine on-farm decision-making—factors that don't exist in the lab or can be controlled. That said, if done properly, agricultural research can and should have a tremendous impact on the health and productivity of farms and farmers, but this work should thus be endogenous and participatory. However, rarely are farmers (especially small-scale and underserved minority farmers) involved in research design, and as such, their valid questions are often ignored.

Participatory action research is a framework that attempts to avoid this pitfall. PAR is a multifaceted framework that includes elements of collaborative inquiry and experimentation and strong community engagement. Through the incorporation of local farmer input, and a self-reflective process, stakeholders are empowered through the endogenous exploration of new knowledge. Farmers are involved the decision making and design of the experiment. In my research, the farmers were included in every step of the design and implementation of the study. First, I met with farmers from the Rio Grande Valley to examine what were the primary issues affecting them on their farms. In fact, farmers helped identify the target cover crops, based on information from their peers, what they've read on the internet, etc. They also determined which cover crop benefits they were most interested in (weed suppression and soil health) for me to research and provide them with the most relevant information. Once I had the farmers' inputs, I designed an experiment to provide the farmers with the service of purchasing seeds, planting, and growing the cover crop on their fields in exchange for a place to conduct large scale research on a farm setting. Through this partnership I gained a lot of personal report with the farmers and developed a deeper relationship and understanding of their perspectives and needs. They also respected my dedication of working in the summer heat out in the field, which allowed us to talk about the nuances of farming in a candid manner. At the end of the experiment, the farmers were more inclined to implement my findings because they saw the results with their own eyes and trusted my opinion due to our researcher to farmer relationship.

Figure 4.4: The components that contribute to participatory action research (PAR).

Future Research

This being the first research of its kind in this region there are still a lot of unanswered questions that warrants further research. One aspect that was not addressed in this thesis is the beneficial insect biodiversity provided by the cover crop habitat. Many beneficial insects such as lady beetles, lacewings, parasitic wasps, and syrphid flies can maintain populations in flowering cover crop strips and provide control of pests in surrounding crop fields (Chandler et al., 1998; Altieri, 1999). Research is needed to understand if certain cover crops provide more habitat for beneficial insects than others, or to see if any cover crops are harboring crop pests. This is important because if one of the cover crops hosts similar pests to the subsequent cash crop it would not be a good chose for the farmer.

Long term studies that extend over multiple years (which was not possible for the 2 year master program) are also necessary further research to see how the cover crops may be affected by the different environmental conditions year to year, to see how the benefits of cover cropping change after growing them for multiple years, and to increase accuracy of the initial findings of the study.

Assessing the performance of cover crops when grown in different soil conditions would also help the understanding of what cover crops to use depending on the farmers' soils. Most of the soils in the LRGV are characteristically high in clay content, so trials comparing high sand content soils to high clay content soils could help determine what cover crops do best in different soil types.

A closer look at the benefits to the soil biology of the populations of mycorrhizae spores in the soil would also be necessary to further understand what types of mycorrhizae are being enhanced and what that means in terms of plant health. Research into beneficial nematodes in the soil is also needed because organic growers need an alternative to chemicals to manage their farms' soil health.

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BIOGRAPHICAL SKETCH

Savannah Rugg grew up in the Santa Cruz Mountains on the central coast of California. She recieved a Bachelor's of Arts in Environmental Studies from the University of California Santa Cruz. While studying at UCSC she fell in love with the study of agroecology while working at the Center of Agroecology and Sustainable Food Systems (CASFS). There she became fascinated with the intrinsic relationships amongst all biotic and abiotic forces at the farm level and how the management of those relationships can produce a sustainable system.

She enjoys being outdoors, riding her bike, surfing, and connecting with others over food. She hopes to persue a career in sustainable agricultura and food systems to bring about healthy people leading healthy lives. She completed her Master of Biology in May 2017. She may be contacted at savannahrugg@gmail.com.