Fall 2022

Intercropping Grain Sorghum Into Established Rhizoma Peanut: Greenhouse and Field Studies

Erika HM Cooperman
Missouri State University, Cooperman965@live.missouristate.edu

INTERCROPPING GRAIN SORGHUM INTO ESTABLISHED RHIZOMA PEANUT: GREENHOUSE AND FIELD STUDIES

A Master's Thesis

Presented to

The Graduate College of

Missouri State University

In Partial Fulfillment

Of the Requirements for the Degree

Master of Science, Agriculture

By

Erika Helen Marie Cooperman

December 2022

INTERCROPPING GRAIN SORGHUM INTO ESTABLISHED RHIZOMA PEANUT:

GREENHOUSE AND FIELD STUDIES

Agriculture

Missouri State University, December 2022

Master of Science

Erika Helen Marie Cooperman

ABSTRACT

Land degradation and urbanization are among the top factors pushing the Kenyan Maasai community into an unstable future, with food insecurity and poverty amidst the most fragile components. Implementing conservation agricultural techniques into the Maasai nomadic lifestyle could potentially lead to a diversification of finances and food security. Intercropping is one technique of conservation agriculture that could provide the Maasai both. The main objective of this study is to evaluate the effects of creating an intercropped environment between rhizoma peanut and grain sorghum. A greenhouse study was conducted from late 2020 to 2021 in an effort to investigate the effects of the rhizoma peanut, a perennial living mulch, on the growth of grain sorghum, in three different soil types (soil loam (SL), clay (CY), and sand (SA)) and fertilization methods (fertilized pots without rhizoma peanut (FN), fertilized pots with rhizoma peanut (FP), and unfertilized pots with rhizoma peanut (UP)). Sorghum plant height, leaf collar number, and relative chlorophyll SPAD estimates were collected throughout the study. SL and FP units produced taller sorghum plants and the most leaf collars at 35 days after planting (DAP). This significance could mean that starter fertilizer at time of planting helped increase the growth rate of the seedlings. However, FN units produced higher SPAD estimates which could mean that the rhizoma peanut acts as more of a competitor for nitrogen (N) than the sorghum. Alternatively, a field study was conducted in 2021 to explore the effects of intercropping grain sorghum into an established plot of rhizoma peanut. Differing mowing methods (mowed, scalped, and unmowed) to simulate grazing of the rhizoma peanut and starter fertilization post-planting of the grain sorghum were applied as treatments. There was no significance difference between mowed and scalped treatments, which could imply that any level of rhizoma peanut mowing would benefit young grain sorghum seedlings. All fertilized mowed treatments produced taller sorghum seedlings which could be a result of decomposing rhizoma peanut clippings at time of planting. Future studies with a longer timeframe would be needed to evaluate the possible effects of this intercropped environment.

KEYWORDS: intercropping, rhizoma peanut, Ecoturf, grain sorghum, sustainable agriculture, Kenyan agriculture, cover cropping, perennial intercropped systems, perennial forage

INTERCROPPING GRAIN SORGHUM INTO ESTABLISHED RHIZOMA PEANUT: GREENHOUSE AND FIELD STUDIES

By

Erika Helen Marie Cooperman

A Master's Thesis
Submitted to the Graduate College
Of Missouri State University
In Partial Fulfillment of the Requirements
For the Degree of Master of Science, Agriculture

December 2022

Approved:

Michael G. Burton, Ph.D., Thesis Committee Chair

Benjamin M. Onyango, Ph.D., Committee Member

Jason D. Streubel, Ph.D., Committee Member

Julie Masterson, Ph.D., Dean of the Graduate College

ACKNOWLEDGEMENTS

I would like to thank the following people for their support during the course of my graduate studies. Dr. Michael Burton served as my advisor throughout the entirety of my academic career and without his constant encouragement to step out of my comfort zone, I would not be where I am today. Dr. Burton also taught me how to drive my first tractor, in which increased my confidence in the agriculture field tenfold. Thank you for finding the time to invest in me throughout my academic career and cultivating my passion for international agriculture.

I would also like to thank Dr. Benjamin Onyango and Dr. Jason Streubel for sitting on my graduate committee, especially as we navigated the pandemic confusion. Dr. Onyango was a constant source of encouragement throughout this process, always leaving me with a smile. Dr. Streubel not only taught one of my favorite classes as a graduate student, but also gave excellent insight to the world of international agricultural development. His authentic passion to help global agriculturalists is a source of inspiration.

I could not have completed this graduate program without the sincere love and help of friends – especially the "non-agriculture" friends who were eager to help, no matter how bewildered they were with each new task. A sincere thanks to my parents for always encouraging me first and asking questions second. I cannot thank either of you enough for always encouraging me to follow my dreams, wherever it may take me.

Lastly, a special thanks to Dr. Alice Kosgei of Machakos University; Jerry Stageman and Hans Kreig of Sunset Specialty Groundcover; and the staff at the IFAS North Florida Research and Extension office. Without them, this research would not have come together as it did.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Soil is the simultaneously the backbone and future of agriculture. The genesis of modern agriculture was a way to secure food security for early civilizations, but it also began the steady trickle of soil nutrient depletion, decreased vegetative biomass productivity, and overall collapse of soil health throughout the years (Melakeberhan et al., 2021). The loss of these ecological systems is not privy to choosing between economic or political status – the breakdown of farmable land has been seen across the seven continents since the agriculture's beginning. Certain green, sustainable movements (ie. The Green Revolution, organic/localized farming (Pingali, 2012)) have pushed their way to the forefront of progressive government subsidies and farmers looking to follow the trends. Every new movement has been laced with the hope to help those who suffer from food insecurity, chronic hunger and malnutrition while battling political and societal systems of greed.

Sub-Sahara Africa has arguably seen the worst of the loss of soil functions in natural agroecosystems due largely to years of misuse, but also cultural and political factors (Moebius-Clune et al., 2011). Evaluating all factors involved in the occurrence of land degradation is essential in the journey to help rebuild the soil we all depend on. This literature review will oversee the way land degradation has shaped the past and future of African agriculture and the ways global agriculturalists can continue to support one another. We also aim to identify agricultural practices that could potentially help build confidence among smallholder farmers and conservation agriculture.

African Soil Degradation

The population of the sub-Sahara Africa (SSA) reached a benchmark of over one billion in 2020, with an estimated one in every three Africans living below the poverty line (Kirui et al., 2021). Land degradation has been defined as the steady decline of the lands ability to meet human needs (Conway et al., 2019). Population pressures will only continue pushing city boundaries, concurrently creating a domino effect of farmable land loss and escalating the number of Africans who suffer from food insecurity. Factors behind long term soil degradation go further than agriculture techniques, including a combination of poor land management, population pressures, climate change, insecure land tenues, and varying historical political and economic issues (Bjornlund et al., 2020; Conway et al., 2019).

Land Use and Management. A study conducted by Kirui et al. (2021) oversaw an analysis of the rate of land degradation of four East African countries, including Kenya. Through remote sensing techniques that measured the decline of biomass productivity and ground-based measurements, the study found that "104,994 km^2 or 25 million acres of land in Kenya experiences soil fertility issues", which encompasses nutrient depletion and soil erosion [statistics from 1981-2003] (Kirui et al., 2019). The study results suggest that most of Kenya's land degradation came from deforestation, with the assumption that the new land use would switch to urban landscape or farmland (Kirui et al., 2021; Kirui et al., 2019). Throughout the study years, land use policies changed, not atypical in developing countries. Using a focus group discussion survey to observe the changes, the authors found that the testing sites in Kenya had net reduction changes in forests, shrub-land, bare land, and water within the testing years; with only slight increases in grassland and woodlands (Kirui et al., 2020). This study in land use shows the complex ways land degradation can change the outcome of optimal farmland or show

the attempts of reforming the soil biome with agroforestry, conservation agriculture, and other sustainable processes.

Access to Markets. One driver of land degradation that has the potential to get overlooked is the lack of access to profitable markets and services. Vibrant markets are available in Central Kenya, yet Western Kenya views high-quality markets from afar, not able to depend on common dirt roads for reliable transportation during the rainy season (Place et al., 2006). Subsequently, another study by Place et al. (2007) states that Western Kenya sees the densest rural population, yet high poverty rates. This area also sees the largest amount of small-scale farming, balancing between being self-sufficient and food insecure. This disconnect might come from the lack of diversified crops, as staple crops such as rice and maize are easier to obtain and grow yet lack severely in robust vitamins (Usman and Callo-Concha, 2021). Smallholder farms make up the majority of farming systems in rural communities, with "475 million of the world's farms managed on less than two hectares" (Fan and Rue, 2020).

Smallholder farmers not only have to navigate physical barriers like poor infrastructure, but without access to markets, they fall behind problems that that larger, industrial farms can easily overlook. Larger farms tend to be closer to markets, have financial safety nets in terms of loans, and have an easier time expanding their farming operation (Fan and Rue, 2020). Lack of access to markets can have a direct correlation to smallholder farmers missing out on improved agriculture technologies, including seed varieties and fertilizers (Ariga et al., 2019). Zeng et al. (2015) reports that obtaining improved varieties of seeds can create a reduction in poverty, boosting the overall productivity of agriculture in the SSA, nutrients, and incomes for farmers. Accessing fertilizer and, more importantly, fertilizer education is also essential to smallholder success (Ariga et al., 2019). These improvements essentially help farmers take one step closer to

better land management, which leaves many smallholders drowning, or not caring, to maintain the bare minimum requirements of soil health.

Climate Change. The complex narrative of land degradation includes the new and changing climate conditions of an already harsh climate in SSA. Climate change affects farmers globally; however, the people of SSA are among the most vulnerable, lacking the financial and technical resources to withstand unpredictable natural disasters (Adhikari et al., 2015). Changes in precipitation, including disastrous droughts and floods, are one of the major climate events that not only effect the citizens of SSA, but also important staple crop yields (Adhikari et al., 2015; Chepkoech et al., 2018). According to personal communication between partners at Kenya Assemblies of God (KAG), East University, longer wet seasons have been seen in recent years, creating longer or, respectively, shorter wet and dry seasons, changing long-known planting and harvest dates.

These varied seasons can create new vulnerabilities, especially among drought-intolerant crops, or crops that might be in vulnerable planting stages. According to Barron et al. (2003), only “3.5% of total cultivated land in SSA is irrigated”, leaving farmable land vulnerable to low production and potentially exposed to soil erosion events. Uneven distribution of rainfall can also lead to fertilizer discrepancies, subjecting the soil to even more of an upheaval of important soil nutrients (Adhikari et al., 2015). Studying the impact of climate change on agriculture, Adhikari et al. (2015) evaluated the climate impact on important cash crops that smallholders depend on in SSA, appraising 160 studies on the current climate trends on wheat, maize, rice, millet, sorghum, and beans. Current literature suggests that most of the crops listed above will be moderately impacted; however, wheat yields are the most in danger, “decreasing by 72% by 2080” (Adhikari

et al., 2015). Future projected yields of sorghum are surprisingly the least impacted, as sorghum is known to be drought resistant and can withstand variable temperatures (Taylor, 2003). Continued land degradation matched with the estimated climate trends leans towards debilitating, especially in extreme cases of established desertification and soil nutrient loss. However, African agriculture has intercepted far more struggles than any other farming system to date. Rebuilding degraded soil structure and increasing crop yields are within reach with movements towards conservation agriculture and other sustainable methods. Studies that provided detailed reviews of the factors that enable land degradation and hinder smallholder success are needed as policymakers and constituents are the true driving factor behind the forward movement of African agriculture.

Conservation Agriculture

Conservation agriculture (CA) is an improved farming movement that has spread across the globe as continued land degradation and the advancement of climate change threatens food security in developing countries. The improvement comes from the balance between those looking to maximize yields and those wanting to optimize the environment that food security is dependent upon. Rebuilding the soil index, optimizing labor and profit, and improving crop yield are just a few of the major concepts behind the CA movement (Dumanski et al., 2006). Popular methods of CA include adopting no-tillage farming systems, integrating agroforestry, rotating crops, and introducing legumes through a cash crop or a cover crop (Hobbs, 2005; Ndah et al., 2012). More significantly, Knowler and Bradshaw (2007) found that adoption can help reestablish a depleted soil by adding natural process back into the soil.

A study conducted between 2004 and 2006 by Chessman et al. (2015) sought to evaluate the differences between conventional agriculture systems and CA improved systems in Southern Africa. Their experimental study found that soil carbon improvements under conservation agriculture were subtle when measured against the conventional methods (Chessman et al., 2015). Results were inconsistent throughout the trial sites as they found that some of the testing sites had been minimally tilled longer than newer locations (Chessman et al., 2015). Despite minor differences between conventional and conservation locations, reduced tillage was seen as a major characteristic in plots where the soil carbon was increased. This study also found a resistance towards leaving crop residue on the field when not encouraged by monetary incentives, which could have led to the insignificant increases of carbon inputs found in the study (Chessman et al., 2015). Leaving crop residues on the soil surface could potentially raise the soil carbon input altogether (Giller et al., 2009).

Alternatively, Tian et al. (2000) facilitated two trial tests in West Africa that observed improved nitrogen uptake in maize following a legume cover crop. They sought to measure maize yield after a cover crop and similarly, if cover crop residues could provide an adequate substitute for applied nitrogen fertilizer (Tian et al., 2000). Results showed an increase in nitrogen uptake in maize following a cover crop when compared to urea-N applications and grain yield was higher following a cover crop than the control treatment [no-N] (Tian et al., 2000). The study found a possible considerable weakness, as each year of the study had varied rainfall, with significant rainfall in 1995. Tian et al. (2000) concluded that this could have presented an inflation of the results; however, this also showed that cover crops residues have undisclosed benefits (mulching, soil erosion control) that chemical nitrogen applications do not have. Results of implementing conservation agriculture vary throughout the literature which may be the result

of low adoption rates among poor farming communities, yet situational factors such as weather conditions and soil history should be considered.

International Adoption Rates of CA

Despite the proven benefits of conservation agriculture, there have been low adoption rates throughout developing countries, including Sub-Saharan Africa (SSA). Less than 1% of total cropland in Africa is under CA practices – a stark difference when compared to South American countries which sees about 50% of cropland under CA (Corbeels et al., 2013). Smallholder farmers can have complete access to all the material resources needed to increase their yields, yet if the soil they are working with is lacking in soil organic matter or other important nutrients, the system needs to change in order to secure a better future.

The integration of conservation agriculture in these farming systems can create countless opportunities for farmers who are interested and willing. However, there is a clear uninterest as more farmers report reduced food production and depleted environments each year, even as the access to CA resources spreads (Giller et al., 2009). Corbeels et al. (2013) explains that the main reasons behind the non-adoption are "the lack of immediate increase in farm income, the need to use crop residues as livestock fodder, and the lack of reliable local markets". This is not surprising as many of the same factors are involved in the reasons behind chronic land degradation and poverty rates in Africa.

A study overseen by Van Hulst and Posthumus (2016) used a socio-psychological approach to understand where the disconnect was specifically coming from in Kenya. This study gave a more emotional look into the reasons behind the non-adoption, especially at the social constructs that are placed on the farmers. The study concluded that the initial attitude and

perceived understanding of conservation agriculture are related. Farmers were less likely to adopt a certain technique if they (i) failed to understand the method from the introduction; (ii) felt that the techniques were too expensive to implement; and (iii) felt more comfortable with what they knew to be true about farming from a cultural and historical background (Van Hulst and Posthumus, 2016). Change without security is difficult to accomplish in any environment, but especially one with perceived undisclosed risks.

Implementing CA is also seen as a risk to small-scale farmers especially for those that struggle from harvest to harvest (Knowler and Bradshaw, 2007). Rebuilding the soil profile can be gradual, without an immediate expression of benefits seen. Quality, increased crop yields is the only physical element seen, which would only be observed at the harvest date. A major takeaway from the literature is that rural African farmers are more likely to embrace conservation agriculture methods if there is an outside organization or extension office within the area (Corbeels et al., 2013; Ndjeunga and Bantilan, 2005). Van Hulst and Posthumus (2016) recommend implementing educational programs that suggest individual practices may be the answer to the escalating non-adoption rates. Exposure to individual methods can lead to a greater chance of implementation for a multitude of reasons. This process gives farms of any size the freedom to explore the methods on their own unique timeframe and an opportunity to see what methods will be the most profitable (Corbeels et al., 2013). Farmers of SSA want to see their yields increase and closing the gap between non-adoption and implementation can provide support, both economically and socially.

Cover Cropping

The research behind adopting conservation agriculture shows that changing long-learned ways of farming brings forth risks farmers in Sub-Saharan Africa are not willing to take when their food security depends on their regular yields, even if those yields are minimal. The literature also shows that farmers are more likely to implement individual CA practices if they clearly understand the advantages (Van Hulst and Posthumus, 2016). Cover crops are an effective management practice that have been in the agricultural sector for decades, although one often discounted when compared with synthetic or conventional practices that have shorter turnaround on benefits (Clay et al., 2020; Hartwig and Ammon, 2002). Cover crops help increase soil health by managing soil erosion, serve as a central source of organic matter from decaying residues that can rehabilitate soil biological activity, and limit nutrient leaching (Clay et al., 2020; Almeida et al., 2018; Kaye and Quemada, 2017).

Chosen cover crops should ideally benefit the soil in some way of management or, in some cases, act as a trap crop for pests and disease (Clark, 2015). Examples include grasses and cereals such as rye (*Secale cereale*) and buckwheat (*Fagopyrum esculentum*) that are helpful in aiding as nutrient sinks and weed suppressant due to their extensive root systems (Flood and Entz, 2018; Magdoff and Es, 2021). Legumes are a popular option for cover crops, primarily due to their ability to fix nitrogen from the atmosphere and most options provide dense coverage on the soil surface (Abdalla et al., 2019). Examples include sun hemp (*Crotalaria juncea*) and various clover varieties (*Trifolium*) (Magdoof and Es, 2021). Understanding individual soil conditions and selecting a cover crop that can directly benefit the key issue is imperative in a sustainable farming system.

Cover crops can also provide more benefits below the soil as they do above. Almeida et al. (2018) evaluated the effects of tillage and land cover on water soil infiltration and found that infiltration is more regulated by coverage and land use than by varying tillage systems. Similarly, Oliveria et al. (2019) observed how different cover crops (sunn hemp, sorghum, millet, and common peanut) and contrasting tillage events (no till, minimum tillage, and minimum tillage with deep subsoiling) can affect the least limiting water range (LLWR) and soil compaction in sugarcane cropping systems. The study also noted the effects on physical soil characteristics such as bulk density and macroporosity, two important features when conditions are optimal for the LLWR (Oliveria et al., 2019). The study found that sunn hemp and millet were overall better candidates for regulating the LLWR, as they performed best in areas such as soil water content and bulk density, even with minimum tillage events. Oliveria et al. (2019) expressed that the legume (sunn hemp) was potentially successful due to the prolonged decomposition and ability to fix nitrogen, providing an extended protection for the soil. A past study on sunn hemp found that aggressive root system of the sunn hemp was also able to expand through four compaction levels (Oliveria et al., 2019; Rosolem et al., 2002). Choosing cover crops based on current soil productivity levels and characteristics is key to implementing significant positive changes in soil management systems.

Both forementioned studies are just a few examples of how using cover crops can benefit a cropping system. One other added benefit of cover crops is the automatic reduction in soil movement as other concepts of conservation agriculture are included as a result. Fertilizer and chemical usage can be significantly decreased, tillage events are either minimum or nonexistent in the new system, and studies have even found that water quality is improved (Clay et al., 2020; Hobbs, 2007). Kaye and Quemada (2017) sought to optimize cover crop benefits, reviewing the

potential for climate change mitigation with the increase in cover crop usage. Their study did not find any outstanding results in terms of diminishing the effects of climate change; however, they did validate the benefits of cover cropping for a farming system and the surrounding environment (Kaye and Quemada, 2017).

Intercropping. Cover crops have historically been labeled as green manure, as they are often tilled into the soil before they mature (Martens and Entz, 2011). Echtenkamp et al. (1989) argue that terminating cover crops by tillage events continues the advancement of soil erosion, reducing their overall effect. They propose that a living mulch, a semi-permanent established cover crop, could help reduce the potential risk of soil erosion, as the farmer would not need to till the crop into the soil (Echtenkamp et al., 1989). They hypothesized that establishing a grass or leguminous cover crop before planting maize could be beneficial for soil management and maize yields, by selecting a cover that could help with soil compaction and suppress weeds (Echtenkamp et al., 1989). The study found that while some aspects of their chosen cover helped the soil profile, the cover crops competed with the maize if not completely terminated (Echtenkamp et al., 1989). However, Echtenkamp et al. (1989) references other studies that had similar cropping systems that saw little to no competition between maize and legumes. They concluded that varying rates of rainfall and other potential environmental factors could have negatively swayed their results (Echtenkamp et al., 1989). This study is important as it serves as a reminder that each farming system is unique and all environmental, economic, and social aspects should be considered when implementing a cover crop.

Rehabilitating degraded soil while also providing a crop yield has challenges. Most farmers cannot afford the potential economic risk and crop loss of waiting for soil nutrients and soil organic matter to be built back into the soil profile to sustain higher yields (Corbeels et al.,

2014). One aspect of the previously mentioned Echtenkamp et al. study is the possibility of extending the foundation of the living mulch concept and creating a fully permanent cover within a farming system, one that has the characteristics to be harvested - otherwise known as intercropping (Asbjornsen et al., 2014). Intercropping incorporates two or more harvestable crop species in a single farming environment (Fan et al., 2020; Fung et al., 2019).

Common intercropped systems include legumes such as cowpeas and maize in Africa and beans and potatoes in Latin America (Brooker et al., 2014). Intercropping is possible on a larger scale as well, as vegetables can grow under the trees in orchards and wooded grasslands (Brooker et al., 2014; Meijer et al., 2014). Regardless of scale or species, there is an inherent risk of competition between two harvestable crops in one system. If environmental conditions and planting dates are not jointly considered for either crops, the intercropped system could negatively impact one or both crops involved (Brooker et al., 2014). These systems are also built to maximize space, as urbanization continues to push city boundaries towards rural farming communities (Fung et al., 2019).

Brooker et al. (2014) states that farmers utilizing a small amount of land can see an "increase in yields per unit per input" when under an intercropped system (Brooker et al., 2014). Ngwira et al. (2012) supports this with a study focused on the short-term benefits of a maize and legume intercropped system in Malawi, Africa. They compared the effects of monocropped maize under a conventional tillage system (CT) with different CA systems, including an intercropped trial (Ngwira et al., 2012). The major takeaway from this study are the positive effects the intercropped trial had in drier study years on the maize crop, as the CA plots in both sections produced a higher amount of vegetative biomass than the conventional plots (Ngwira et al., 2012). There were no negative effects seen on crop yield throughout the entire study (Ngwira

et al., 2012). Farmers on site also spent less time producing the maize in the CA trials, "47 days compared to the 65 days spent on the conventional system" (Ngwira et al., 2012). The culmination of this study was that the margin income for the CA systems doubled while CT systems remained stagnant (Ngwira et al., 2012). Similar economic observations were found in a study by Fung et al. (2019) when evaluating the effects of an intercropped system in various farming regions in China.

Perennial Intercropped Systems. One variation of intercropping is the idea of a perennial living mulch – planting a grain or cereal into a long-established cover. Perennial intercropped farming systems explore the possibilities of improving soil conservation with minimal management or chemical inputs, reducing labor and upkeep costs (Schlautman et al., 2021). Perennial cover can aid in water purification and soil compaction, as the undisturbed roots of the perennial cover can increase the size of macropores in the soil and increase the overall water uptake via evatranspiraton, especially in humid climates (Asbjornsen et al., 2014).

Successful perennial intercropped systems include grass-legume combinations, as the crops can mimic natural systems while also existing as forage for animals (Bybee-Finley and Ryan, 2018). As previously stated in this text, legumes provide many benefits within a cropping system. Legumes are maximized as a perennial cover, as seen in studies by Ryan et al. (2018) and Picasso et al. (2008). There is limited literature on perennial groundcover within cropping systems; however, Moore et al. (2019) suggests that this practice will become more relevant in the agricultural industry as the sector moves towards sustainable longevity in the face of impending environmental changes and rapid food insecurity.

Exploring a perennial intercropped environment is precisely what our research hopes to achieve. We believe that additional extensive research on perennial groundcover in cropping

systems is needed for the future of rural agricultural communities. We are hopeful our research will bridge the gap between conservation agriculture non-adoption rates and cultural ties that might hold smallholder farmers back from experimenting with new conservation practices.

Crops of Interest: Rhizoma Peanut and Grain Sorghum

Two potential cash crops utilizing the same space and alternating harvest seasons could provide more than double the amount of harvest yield, forage options, and overall income. Our research will aim to examine the interactions between a perennial peanut *(Arachis glabrata)* groundcover interseeded with a hybrid grain sorghum *(Sorghum bicolor)* variety. Perennial peanut, or sometimes referred as rhizoma peanut, is a non-seeding, leguminous groundcover that was first introduced in the Unites State from Brazil in the 1930s (Bodrey, 2016; Wang et al., 2019). This cultivar spreads by underground stems, performing much like a thick sod and is long-lasting in alternative landscaping solutions and grazing systems (Debeux et al., 2016; Silva et al., 2021).

Florigraze and Arbrook were the original cultivars introduced, developed for groundcover in roadway medians (Bodrey, 2016). Other cultivars have a history of being used as living mulch in orchards, as seen in a study conducted by Radovich et al. (2009). The authors found that there was initial competition for nitrogen between crop species; however, their review of the literature found that past studies showed a decrease in competition the longer the study continued [past 24 and 30 months] (Clement and DeFrank, 1998; Radovich et al., 2009). Debeux et al. (2016) found that other varieties might be more suited for grazing or hay options for livestock. These cultivars include UF Peace, UF Tito, and Ecoturf (Debeux et al., 2016).

Grain sorghum, or forage sorghum, is the "fifth most important grain crop" in the world and ranks as second-most important grain crop in Africa (Abunyewa et al., 2016; Taylor, 2003). Sorghum is widely used as food and feed for humans and livestock despite low-adoption rate in recent years (Okeyo et al., 2020). Sorghum is an excellent crop for African smallholder farms, especially as weather patterns continue to vary season to season. It has been observed to thrive in any climate type in Africa, from arid Africa to subtropical Africa (Taylor, 2003; Vendramini et al., 2019).

Research on rhizoma peanut is surprisingly limited, with research mostly focused on livestock forage. Introducing a rhizomatous peanut variety as an established living mulch for grain crops is just the first step in observing the possible short-term benefits of conservation agriculture and would provide further insight in how rhizoma peanut could benefit the agricultural world. Our research will investigate the possibilities of using rhizoma peanut as a living mulch in a grain sorghum production, a forage option for livestock, and a nitrogen source for soil.

MATERIALS AND METHODS

Introduction

Food insecurity persists throughout Sub-Saharan Africa (SSA), following a domino effect of land degradation, varied climate change, and an increasing population in both rural and urban SSA. The Maasai are a semi-nomadic ethnic group who live primarily in southern Kenya and northern Tanzania and, as pastoralists, they face some of the most prominent vulnerabilities in the SSA, including land conflicts, urbanization, and chronic land degradation (Lawson et al., 2014). This community makes up a large portion of those who are food insecure in Kenya, as they rely mainly on their livestock for their dietary needs (Lawson and James, 2014). Per cultural boundaries, cattle are the primary focus of the Maasai. However, as drought conditions continue to increase each year in this area, the search for pastures widen (Hart, 2012). Additionally, their livelihood is threatened as urbanization continues to encroach on the already dwindling territory of the Massai. Diversifying their livelihood can help the Maasai move towards a more secure future in terms of food security, economic gain, and generational health.

A review of the literature shows that conservation agriculture could help relieve some aspects of Maasai food insecurity – not only for themselves, but their livestock as well. Conservation agriculture (CA) is defined as an improved approach to managing agroecosystems sustainably by strengthening food security, increasing soil nutrients, and rehabilitating soil structure through new management practices (Kassam et al., 2018; FAO, 2019). The Maasai do have a history of implementing agriculture into their way of life; however, due to their nomadic lifestyle, transitioning to a life of cultivating the land versus roaming the land has its challenges

(McCabe et al., 2010). Choosing a practical method of CA that can be personalized for the Maasai is key to the success of developing a sustainable future.

One method of conservation agriculture that can be customized based on the unique needs of the Maasai involves intercropping. Intercropping involves establishing two of more harvestable crops in a single farming environment, usually including a legume groundcover and a staple cash crop (Echtenkemp and Moommaw, 1989). Intercropping provides the typical cover crop benefits of soil conservation, while also: (i) maximizing space by providing two (or more) harvestable crops, (ii) aiding in water purification and efficient use of limited nutrients, and (iii) providing a possible forage option for livestock, especially if a perennial groundcover is chosen (Fan et al., 2020; Fung et al., 2019). We propose that establishing a perennial groundcover as a forage crop and intercropping a staple grain crop after forage harvest could provide the Maasai a way of building a sustainable cropping system that could diversify their economic livelihood while also honoring their historical association with cattle.

Our research will explore the possibilities of creating an intercropped environment between rhizoma peanut (*Arachis glabrata* Benth*)* and grain sorghum (*Sorghum bicolor* (L.) Moench*)* in way of greenhouse and a field studies. Establishing an intercropped environment brings together a multitude of benefits, but also the risk of crop competition. Both studies aim to examine the effects of a perennial living mulch in a no-till grain cropping system.

Objectives and Hypotheses

Greenhouse Experiment. The greenhouse study investigated potential effects of a forage crop, effectively serving as a perennial living mulch, on grain sorghum in an intercropped and controlled environment, treatments included differing soil types, fertilization, and

presence/absence of rhizoma peanut. We hypothesize (i) that the grain sorghum will produce differences in growth among the soil treatments; (ii) fertilization treatments will increase growth and chlorophyll estimates in both crops; (iii) the grain sorghum monoculture treatment (FN) will have higher sorghum biomass compared to the other treatments; and (iv) the rhizoma peanut will increase grain sorghum growth or N nutrition (chlorophyll as measured by SPAD meter).

Field Experiment. The field study aimed to explore the effects of intercropping grain sorghum into a long-established plot of rhizoma peanut. Simulated "grazing" (i.e., mowing) and fertilization were treatment factors. Treatment effects were imposed on either whole plots, which evaluated row widths and mowing methods, or as split plot treatments that examined interactions between mowing heights and fertilization. We hypothesize that (i) mowing height of the rhizoma peanut will influence emergence and stand counts of grain sorghum; (ii) row width of grain sorghum may influence yield of both crops, and (iii) fertilization of sorghum at planting will increase sorghum stand counts, growth, and grain yield.

Crop Selections Shared in Both Intercropped Experiments

The crops chosen for this study were rhizoma peanut, 'Ecoturf' (*Arachis glabrata* Benth) and a hybrid grain sorghum variety, 'DKS40-76' (*Sorghum bicolor (*L.) Moench). Rhizoma peanut is a known high-quality forage and ornamental groundcover for subtropical and warm temperate environments (Rouse, 2019). This crop was chosen for this study because of its high resistance to drought and perennial, nitrogen-fixing characteristics (Debeux et al., 2016). The variety 'Ecoturf' was chosen for its hardiness and generative productivity, as it is a prolific producer of roots and rhizomes in grazing systems (Debeux et al., 2016). 'Ecoturf' is a newer variety compared to 'Florigraze' and 'Arbrook' yet retains the same opportunities for animal

forage (Lemus, 2018). Grain sorghum is the second most important grain crop in global food-insecure regions, with an “average mean yield of 0.8 t/ha from approximately 24 million hectares of arable cropland in Africa” (Msongaleli, 2017; Taylor, 2003). Sorghum is a staple crop in these regions because of its natural drought and heat tolerance. A hybrid grain sorghum variety (DKS40-76) with medium maturity and sugarcane aphid resistance was selected as the grain crop in this study.

Overview of Intent

The original intent was to conduct research near Nairobi, Kenya, at two separate trial sites during May through September 2020 and 2021 through a partnership among Missouri State University, Convoy of Hope, Kenya Assemblies of God, East African University (KAG), and Machakos University. In response to the widespread Coronavirus pandemic, domestic locations were identified to simulate conditions in Kenya. This work included a greenhouse study and a field experiment. The greenhouse study was conducted in Missouri State University’s agricultural greenhouse in Springfield, Missouri (N37.19738, W93.27838) from Fall 2020 to Fall 2021. The field experiment was conducted June to August 2021 near Live Oak, Florida, (N30.15200, W82.96947) at Sunset Specialty Ground Cover, a rhizoma peanut nursey and landscaping solutions company. Although generally warmer than the intended Kenyan locations, the Florida site provided an area of established rhizoma peanut on a coarse textured soil.

GREENHOUSE EXPERIMENT

Soil Selection

Missouri soils with characteristics similar to soils identified at the KAG and Machakos locations were selected to parallel the original proposed research plan. Black Cotton soil is common near the KAG campus; Kikuyu soil is found near in the Machakos campus. Black Cotton is a shrink-swell clay, formed of fine clayey material and has a high moisture retention (Sindhu 2019). Kikuyu is a red loam sandy soil that is known in Kenya for its high moisture storage capacity and has good structural stability within cultivated cropping systems (Muchena and Gachene, 1988).

Selected substitute Missouri soils included: Sharkey clay (very fine, smectitic, thermic Chromic Eqiaquerts) and Bosket fine sand (fine-loamy, mixed, active, thermic Mollic Hapludalfs) (USDAa, 2013; USDAb, 2018). Sharkey clay was obtained from a crop production field at the University of Missouri Fisher Delta Research Center in Portageville, Missouri, (N36.41468, W89.70135). Bosket fine sand was obtained from Rhodes Farm, property of the Fisher Delta Research Center, in Clarkton, Missouri, (N36.49153, W89.97053).

A third soil, Cedargap silt loam (loamy-skeletal, mixed, superactive, mesic Cumulic Hapludolls), was chosen to provide an intermediate texture between the extremes of the other two selections (USDAc, 2006). Cedargap silt loam was obtained from a tilled field near Turners, Missouri, (N37.16006, W93.12222). Stones were removed.

Soil Test Analysis. Standard soil tests were completed at the University of Missouri Soil and Plant Testing Laboratory in Columbia, Missouri. The results showed that the silt loam sample was low in potassium relative to the other two soil types (Table 1). To provide similar

potassium availability across soil types, 1.0-g of wood ash was mixed into the surface of each silt loam pot at the time of rhizoma peanut transplanting in November 2020.

Experimental Design

The greenhouse experiment was designed as a 3x3 full factorial experiment, including soil type and cover treatments. Cover treatments were randomly assigned to soil-filled pots and included: unfertilized rhizoma peanut (UP), fertilized bare soil (FN), and rhizoma peanut that was fertilized at time of sorghum planting (FP). The experiment was established in a randomized complete block design with four replications. Each replication was re-randomized weekly (after sorghum planting) to alleviate potential edge effects as the peanut canopy grew, and differences in light level and ventilation along the greenhouse bench.

Greenhouse Conditions

The experiment took place in the research bay (Bay 2) of the Karls Hall greenhouse at Missouri State University. Steps to mimic the climate of South Kenya were taken, such as monitoring the temperature in the greenhouse bay and the outside temperatures. All temperature measurements were taken in the research bay using a Fisherbrand Traceble Digital Alarm RH/Temperature Monitor that continuously monitored temperature and reported daily minimum and maximums (Appendix A-1). The monitor was placed in a shaded location near the greenhouse bench. Greenhouse vents and cooling systems were manipulated in an attempt to maintain temperatures within the range of 23 – 26 °C (75 – 80 °F) (Appendix A-2).

Rhizoma Peanut

Rhizoma peanut rhizomes were transplanted from 0.5-L (4-in) pots into 11.5-L (11 x 9-in) pots beginning November 6, 2020. Transplanting methods included soaking the root-bound plants for 10-15 minutes in water and then separating the rhizomes from the pine bark media. Two transplanting methods were attempted. For replicate 1, rhizomes were cut into 8 to 15-cm lengths and placed at a depth of 5-cm below soil level on the left and right sides of the pot, creating parallel lines. For subsequent replicates, the method was altered to include longer rhizomes. Rhizomes were completely disentangled from the pine bark media and then transplanted in a circle near the pot wall at a depth of 5-cm. A 7-cm wide, 1-cm deep depression in the soil was left in the middle of each pot to allow space for the later-planted grain sorghum and promote irrigation infiltration through the pot center. Rhizoma peanut was allowed to establish from November 2020 to August 2021, when the experimental treatments were imposed.

Transplant dates were from November 6th to November 13th and then from November 17th to January 11th, 2021. There was a gap in transplanting (November 17th to December 16th) to allow the clay soil to air dry completely after a second trip to Portageville, Missouri was taken on November 16th to obtain more of the Sharkey clay soil. Rains prior to the second trip left the clay soil excessively wet. The wet clay soil was air dried completely and then powdered by hammering, until it was suitable to transplant the rhizomes of the rhizoma peanut. All pots were regularly irrigated, and stems were periodically trimmed during the 9-month establishment period. See Appendix B for an overview of the initial preparation of the rhizoma peanut for the grain sorghum planting.

Rhizoma Peanut Measurements

To compare peanut vigor across experimental units (pots), rhizoma peanut was trimmed to 5-cm 30 days before sorghum planting. Rhizoma peanut regrowth was cut to a height of 1-cm above the soil on the day of sorghum planting and fresh weight was estimated by pot using an electronic balance. Harvest clippings were then dried at 60 °C (140°F) in a Cascade TEK's Model TFO-28 forced air lab oven. Dry weight measurements were taken after constant dry weight was observed for a randomly selected group of samples.

At 14, 21, 28, and 35 DAP (days after planting), rhizoma peanut canopy height was measured from soil level, taking one measurement at a representative location in each pot (Uchino et al., 2011). Indirect chlorophyll estimates were also collected using a Konica/Minolta Soil Plant Analysis Development (SPAD) meter. Four recently fully-expanded compound leaves were randomly selected in each pot. SPAD readings were taken on the top right leaflet only (Figure 1) (Marques da Silveira and Cesar de Oliveira Gonzaga, 2017). Measurements were taken in the middle of the leaflet, excluding the midrib to obtain reproducible readings. Any potential selective bias (choosing leaf clusters that were large enough to achieve a reading) stemmed from the effort to minimize reading errors from the SPAD device and excluding extensive spider mite damage (Figure 2, Appendix A-3).

Final canopy height and SPAD measurements were taken 35 DAP (October 8), and the rhizoma peanut was clipped to a height of 5-cm and retained for fresh and dry canopy biomass estimates using the same methods as the September 3rd clipping.

Grain Sorghum Planting and Fertilization

On September 3rd, immediately after clipping the rhizoma peanut canopy, six seeds (treated with a proprietary blend of insecticide and herbicide safeners) of DKS40-76 were planted in the center of each pot, 2.5-cm deep, 2-cm from the nearest neighboring seed (Ciampitti, 2013). Pots randomly assigned a fertilized cover treatment each received 1.74-g of ammonium nitrate (reagent grade) dissolved in 10-mL of tap water. This fertilizer rate approximated 27-kg N/ha (24#N/A) on a land area basis. All pots were then irrigated normally to move the solution into the soil. Seedlings were thinned 10 DAP, leaving two uniform plants per pot. Total seedling emergence was noted for each pot at the time of thinning.

Grain Sorghum Measurements

Non-destructive sorghum measurements were taken 14, 21, 28, and 35 DAP and included typical staging assessments such as plant height, number of fully emerged leaf collars (excluding the coleoptile "leaf"), and indirect chlorophyll estimates, using a SPAD meter (Abunyewa et al., 2016). SPAD measurements were taken from the middle of the sorghum leaf with the most recently emerged leaf collar, excluding the midrib (Abunyewa et al., 2016). Plant height was determined by measuring from soil surface to the highest height of the most fully emerged leaf, held vertically (Masaka et al., 2021). Fully emerged collars of true leaves (excluding coleoptile) were counted as a measure of the plant's developmental stage (Abendroth et al., 2011).

Other observations taken at this time included degree and location of spider mite damage on sorghum leaves. Minor damage from spider mites occurred between the 28 and 35 DAP assessments and was observed on the bottom leaves (typically third and fourth leaves) of the

grain sorghum in all replications and across all treatments, with more severe damage (discoloration on all sorghum leaves with active infestation) on a few plants within the third and fourth replications.

Grain sorghum seedlings were cut at soil level 35 DAP, placed into sample bags, and weighed using a portable electronic balance. Fresh weights were recorded, and samples were placed in the forced air lab oven to be dried at 60 °C (140°F). Five randomly selected samples were weighed on October 14th and October 15th to assess constant dry weight. Constant weight was observed on October 15th and all dried samples were weighed.

FIELD EXPERIMENT

Site Selection

A rhizoma peanut/grain sorghum intercropping experiment was conducted in an established rhizoma peanut crop, on a Bonneau-Blanton-Padlock complex (Bonneau: loamy, siliceous, subactive, thermis Arenic Paleudults; Blanton: loamy, siliceous, semiactive, thermic Grossarenic Paleudults; Padlock: fine, mixed, active, thermic Aquic Paleudults) (USDAd, 2007; USDAe, 2019; USDAf, 2018). The selected site has an average daily temperature above 30°C (85°F) from May to September (Weather Spark). On average May to July has a 41% chance of precipitation, increasing to 67% after July 30th (Weather Spark). The experiment site (Figure 3) was approximately 0.2-ha (0.6-acres) of the 32.4-ha (80-acres) present on the farm.

The rhizoma peanut in this field was a uniform stand of the 'Ecoturf' variety that was first established on this field 10-12 years ago. The specific area in use for this study was cut for sod two years earlier. Mowing was intermittently performed since the 2019 sod cutting. The most recent herbicide application was flumioxazin (Valor ®) in February 2021. The elapsed interval greatly exceeded the 30-day label restriction for planting sorghum (Currie et al., 2018). The field experiment was conducted approximately 150 days after the herbicide application, eliminating concern of crop injury. No herbicide or insecticide applications were applied post sorghum planting.

Field Experimental Details

Three separate experimental studies, each with three replicates, were implemented to study the interaction between intercropped grain sorghum and rhizoma peanut. Experiments

included: (i) effect of sorghum row widths (whole plot) and rhizoma peanut mowing height (split plot), (ii) effect of alternative mowing methods (whole plot) and fertilization (split plot), and (iii) effect of alternative mowing methods on sorghum recruitment in hand-sown plots.

Site Preparation

The experimental treatments were established on June 29th, 2021. The 9.1-m x 60.7-m (30-ft x 200-ft) site was divided into two separate 9.1-m x 27.4-m (30-ft x 90-ft) sections (whole plots). Whole plots measured 3.1-m x 9.2-m (10-ft x 30-ft) and split plots were 3.1-m x 4.6-m (10-ft x 15-ft). Two 3-m x 9.1-m (10-ft x 30-ft) sections were utilized as buffers: one separated the two larger experiments and served as the location for the grain sorghum recruitment experiment and the other buffered the entire experimental site from the farms production areas.

Equipment

Mowing treatments were imposed using a rotary riding lawnmower (Grasshopper) or a gasoline powered string trimmer. Planting width was achieved by coulter removal and blading seed units to achieve 38 and 57-cm (15 and 22.5-in) row spacing, using a 606 NT Great Plains seed drill. A Monosem NG+3 two row planter was used for the 76-cm (30-in) treatment. Planting widths were modified between treatment plots by blocking the seed path for unused drill units.

Experimental Design

Treatment details of each experiment are as follows: (i) split plot randomized complete block experiment as a 3x2 factorial design examining effects of row widths (38, 57, and 76-cm / 15, 22.5, and 30-in) [whole plot] and rhizoma peanut mowing height (short, 4-5 cm; tall, 13-15

cm) [split plot], (ii) a split plot randomized complete block 3x2 factorial design that studied the effects of alternative mowing methods (string trimmer: "scalped" to level soil; Grasshopper: mowed to 4-cm above soil; not mowed (control): 10-13 cm) [whole plot] and with or without fertilization (ammonia sulfate prills), and (iii) a randomized complete block design with three replications was conducted, observing the effect of rhizoma peanut mowing height (short: scalped to soil; medium: 4-5cm; tall: 13-15cm (string trimmer was used for both)) on recruitment (50 planted seeds per 1-m row) when hand sown.

Mechanically and hand-sown seeds were planted 2.5-cm (1-in) deep and at a rate of 50,000 seed per acre (Bean and Noland 2019). Row width treatments varied in row numbers per plot. For example, 76-cm (30-in) plots had three rows per plot, whereas plots with 38-cm (15-in) rows had twice as many rows but half as many seeds/m (ft). Fertilization application was completed the same day as sorghum planting. To assure seed to soil contact, the entire experimental site was rolled perpendicular to the direction of planting using a 2.4-m x 1.2-m (8-ft x 4-ft) commercial tractor roller the following day.

21-DAP Measurements

Non-destructive measurements of the grain sorghum and rhizoma peanut were taken 21-22 DAP. Plot rows were thinned to uniformity using a plants per foot (PPF) calculation using a 10-foot rigid plastic PVC pipe marked by every foot: 38-cm (15-in): 1 PPF; 57-cm (22.5-in): 2 PPF; and 76-cm (30-in): 3 PPF. It was observed during this process that the 57-cm (22.5-in) row widths had a disproportional germination rate of the grain sorghum, varying in emerged seedlings among each row. The number of rows within these plots also varied, possibly caused by seed remaining in the drill units, which should have been cleaned out of blocked off when

row width was changed between the coulters and seeding disks. It was observed that the 57-cm (22.5-in) plots seemed to have both 57-cm (22.5-in) and 38-cm (15-in) row spacing within treatment plots. Unnecessary rows were terminated, reducing potential effects from sorghum neighbor present.

Grain Sorghum. Five randomly selected grain sorghum plants were chosen out of each row for the non-destructive measurements, which included plant height (measured from ground level to the most fully emerged leaf tip, held to its highest height), most recently emerged leaf collar number (counted from lowest true leaf up to the most recently fully emerged collar), and unitless chlorophyll estimates (one SPAD reading taken from the middle of the most recently fully emerged leaf) (Zandonadi et al., 2016; Nielsen, 2019; Abunyewa et al., 2016). Measurements were later averaged to obtain the row average of each plot. Future data analysis would include only the middle two rows of the 76 -cm (30-in) subplots and the second and fourth rows of the 38 and 57-cm (15 and 22.5-in) plots.

Rhizoma Peanut. Five non-destructive SPAD estimates were taken at least 7.6-cm (3-in) from the previously chosen grain sorghum plants. Readings were taken on the middle of the leaflet, excluding the midrib to obtain the most uniform reading, following the same method performed in the greenhouse experiment (Marques da Silveira and Cesar de Oliveira Gonzaga, 2017). Readings were then averaged to find the row average. Varying canopy height was observed during this process, largely due to the mowing treatments imposed at planting. Five random canopy height (cm/in) measurements were taken throughout the experiment site, excluding row space, to identify the whole plot average canopy height.

Statistical Analyses

Minitab 19.1 (Minitab Inc, State College, PA, USA) was used for our analyses of the greenhouse and field experiments. All effects and interactions were considered significant when $P < 0.05$.

Greenhouse. The greenhouse experiment was performed as a randomized complete block (RCB) design, consequently analyzed as a mixed effects model within Minitab. Statistical significance and potential interactions between treatments were tested using repeated measures (per harvest/DAP dates), including fixed factors: soil and cover. Species were analyzed separately across the analysis. Comparison means among effects were identified using Fisher Pairwise comparisons.

Field. The field experiment was analyzed as three separate experiments using a general linear model. Treatment effects and possible interactions were analyzed within the split plot RCB experiments as follows: (i) fixed effects: rhizoma peanut mowing height (split plot) and sorghum row widths (whole plot) and (ii) fixed effects: rhizoma peanut alternative mowing methods (whole plot) and starter fertilization (split plot). A one-way ANOVA model was used for the third experiment (iii) to evaluate the effect of rhizoma peanut alternative mowing methods on hand sown sorghum recruitment. Analyses were performed separately on either grain sorghum or rhizoma peanut across all field experiments. All effects and interactions were considered significant when $P<0.05$. Where significant effects were identified, means were compared using Tukey Pairwise comparisons.

RESULTS AND DISCUSSION

Greenhouse Analyses

Soil type and cover/fertilization effects on growth (nondestructive measures such as height, leaf collar number, and SPAD) and biomass were evaluated using a repeated measures method. Multiple covariance types were compared for each fixed factor, including heterogeneous autoregressive (ARH (1)), heterogeneous compound symmetry (CSH), compound symmetry (CS), and autoregressive (AR (1)). Selected covariances gave lower AICC values than those also evaluated. ARH (1) was used to evaluate the relationship between grain sorghum plant height, leaf collar number, rhizoma peanut canopy height and the respective experimental treatments. Covariance AR (1) was used to evaluate the relative chlorophyll SPAD estimates for both grain sorghum and rhizoma peanut.

Plant Height. Grain sorghum plant height was influenced by both soil *($P<0.0001$)* and cover fertilization *($P<0.0015$)* treatments, although there was no significant interaction between treatments (Table 2). Silt loam (SL) pots produced nearly 23% taller plants than sand (SA) pots and 4% taller plants than clay (CY) pots, which was vastly insignificant when compared to total means for the other soil types. SA produced nearly 18% smaller plants than CY (19 vs. 22.4). Figure 4 displays the influence of soil on sorghum plant height as it progresses through each data collection, measurements taken 14, 21, 28, and 35-DAP.

Fertilized pots without rhizoma peanut (FN) produced 10% taller plants than unfertilized pots with rhizoma peanut (UP) while the fertilized pots with rhizoma peanut (FP) produced roughly 15% taller plants than the UP pots (Table 2). Although marginally significant, FP also produced 4% taller plants than FN pots (22.9 vs. 22). This quantitative observation could be the

result of a delay in growth of the freshly de-foliated rhizoma peanut, allowing the grain sorghum seedlings to competitively access the mineralized nutrients first available after starter fertilizer was applied. However, with FP producing taller plants than either FN and UP, this could show that supplemental starter fertilizer is needed with or without the presence of rhizoma peanut, as it might balance the potential competitiveness of the rhizoma peanut and the inherent depletion of soil nutrients when planting on bare soil. Figure 5 shows the trend of cover fertilization influence on sorghum plant height throughout the experimental growth period.

ARH (1) was also used to examine the relationships the experimental treatments had on the canopy growth of the rhizoma peanut. Soil types were marginally significant *($P<0.0595$)* (Table 2). SL produced 13% taller canopy heights than SA. Other soil type comparisons were considerably insignificant.

Leaf Collar Numbers. Soil type and cover fertilization effects were both nominally significant *($P<0.0005$; $P<0.0006$)* (Table 2). SL outperformed both SA and CY, producing nearly 12% and 6% more collar numbers than SA (5.4 vs. 4.8) and CY (5.4 vs. 5.1). SA produced 6% less leaf collar numbers than CY (4.8 vs. 5.1). Figure 6 shows the influence soil types had on sorghum leaf collar numbers over the course of the experiment. Additionally, FN units seemed to produce faster growing seedlings than the other two pots during the first two weeks after planting. FN produced a marginal 2% more leaf collar numbers than FP (5.3 vs. 5.2) and 10% more than UP (5.3 vs. 4.8). FP outproduced UP by nearly 8% which could mean that the starter fertilizer at sorghum planting helped increase the growth rate of the seedlings within the first two weeks of development. See Figure 7 to observe the influence cover treatments had on grain sorghum leaf collar numbers 14 through 35-DAP.

Relative Chlorophyll SPAD Estimates. Soil and cover fertilization treatments influenced grain sorghum SPAD estimates *(P<0.0003; P<0.0002)* (Table 2). SL produced 10- and 13% higher SPAD estimates than both SA and CY (35.8 vs. 32.6; 35.8 vs. 31.6). Although marginal, SA produced nearly 3% higher SPAD estimates than CY (32.6 vs. 31.6). Figure 8 shows the influence of soil type on sorghum SPAD estimates throughout the experiment. Estimates increased almost immediately after initial growth before leveling as the experiment continued.

Higher SPAD estimates were found in FN when compared to both FP and UP cover fertilization treatments, with nearly 9-and 5% difference between them respectively. This result could mean that the rhizoma peanut possibly acts as a competitor for N, especially as UP did not have supplemental application of N. If the rhizoma peanut was a N donor, we could have expected FP to have similar SPAD levels as FN. Figure 9 shows the gradual incline of sorghum SPAD estimates and the steady dip of estimates between 28 and 35-DAP. This decrease in estimates might represent spider mite damage found at this time.

Furthermore, soil was the only significant effect *(P<0.0016)* for the relative chlorophyll SPAD estimates of the rhizoma peanut canopy (Table 2), while the cover fertilization treatments were only marginally significant *(P<0.0733).* SL units produced nearly 13% higher SPAD estimates than CY (34.3 vs. 30.4). Differences found between SL and SA and SA and CY were marginally significant, with roughly a 6% difference between both interactions (34.3 vs. 32.4; 32.4 vs. 30.4).

Testing for Sorghum Senescence

Relative chlorophyll content (SPAD) estimates were collected on the third leaf of the sorghum plants to provide an objective measure of senescence and translocation among treatments 35-DAP. No difference in senescence should be observed if rhizoma peanut is adequate doner of N. Cover fertilization treatment (*P<0.001*), but not soil type, affected relative chlorophyll content. Cover treatment FN had third leaf SPAD readings nearly 50% greater than UP and FP treatments. UP and FP treatments were not different based on pairwise comparisons, with means of 15.4 and 15.1, respectively (Table 3). The mean for SA third leaf SPAD estimate was numerically 27% greater than CY estimates (20.1 vs. 15.8). This was potentially unexpected as SA was outperformed by the other soil treatments in most of the measurements.

SPAD meter readings confirmed the visual observation (yellowing of third leaves) of senescence. In the absence of the peanut cover (FN), the grain sorghum achieved higher SPAD estimates at 35-DAP. This result likely indicates that rhizoma peanut was not a prolific donor of N in our experiment setup, but rather a competitor. We believe that we would not have seen senescence occurring in the peanut units if the rhizoma peanut was more of a donor.

Sorghum Biomass

The sorghum seedlings were collected and kept to take Fresh and Dry biomass measurements. Standard ANOVA was conducted on the harvest date (35-DAP). The pre-harvest data (before the official start of the experiment) is in the Appendix (Appendix C-1). All factors were found to be significant (*P<0.001*) in both fresh and dry measurements.

Fresh Biomass. Grain sorghum plants in SL produced nearly 50% more fresh vegetative biomass than sorghum plants in the CY pots, while the sorghum in the CY pots produced nearly

70% more biomass than the SA pots (Table 4). Cover treatments also had a significant effect; however, pairwise comparisons found that two treatments did not differ. Sorghum in the FN pots produced nearly 70% more biomass than FP and UP treatments (Table 4). FP and UP did not differ despite an apparently large numerical difference (50%). The greater fresh biomass of FN suggests competitive release relative to the other two cover fertilization treatments, as the presence of the rhizoma peanut seemed to reduce sorghum seedling growth even when supplemental N was given at time of planting.

Dry Biomass. Sorghum plants in the SL pots produced nearly 40% more dry biomass than sorghum in the CY pots (4.6 vs. 3.3), which produced nearly 60% greater weight than the sorghum in the SA pots (Table 4). Cover fertilization treatments also presented significant effects. FN produced nearly 47% more dry biomass than FP (4.7 vs. 3.2), while FP produced just over 50% more dry biomass than UP (Table 4).

Rhizoma Peanut Shoot Biomass

The aboveground biomass of the rhizoma peanut was determined for fresh and dry biomass following the same procedure as the sorghum biomass. Pre-harvest data is located in Appendix C-2. Soil type influenced the fresh biomass rhizoma peanut *($P= 0.023$).* With a mean of 46.6-g, SL produced about 45% more fresh biomass than SA and CY (32.3 and 31.8-g respectively) (Table 4). See Figure 10 to examine the biological aboveground biomass of the rhizoma peanut cover. Cover fertilization treatments did not differ despite a nearly 30% numerical difference between FP and UP means (41.6 vs. 32.7). Alternatively, both soil type and cover fertilization treatments were found to influence the dry biomass of the rhizoma peanut *($P<0.05$)* (Table 4). There was nearly 47% more dry biomass from SL than SA and CY (11.6 vs.

8.1/7.8). Cover fertilization treatment FP produced nearly 25% more dry biomass than UP (10.2 vs. 8.2).

Field Analyses: Grain Sorghum

Nondestructive measurements taken 21-DAP included similar growth measurements as the greenhouse experiment: plant height, collar number, and SPAD estimates (only experiment (ii)). There was significance found within the sorghum row width data; however, after analyzing the raw data, we believe that the significance found within the row widths came from the 57-cm (22.5-in) rows, as that data set was lacking adequate samples 21-DAP. As a result, the 57-cm (22.5-in) row data was discarded.

Experiment (i): Sorghum Row Width x Mowing Height

Sorghum Row Width (Whole Plot). As mentioned above, sorghum plant height was influenced by sorghum row widths *(P=0.041)* (Table 5). However, when the 57-cm (22.5-in) row data was excluded, plant height did not differ between the 38-cm (15-in) and 76-cm (30-in) rows. Sorghum height in 38-cm (15-in) rows was numerically, not but statistically higher, than the 76-cm (30-in) rows by a negligible 1% (9.6 vs. 9.5). Likewise, sorghum row width also influenced sorghum collar number *(P=0.037)* (Table 5). Pairwise comparisons found no difference among factors. However, 38-cm (15-in) rows did produce about 3% more collar numbers than the 76-cm (30-in) rows. No interaction of row width x mowing height was detected for neither sorghum plant height *(P<0.361)* or collar number *(P<0.837)*. No difference was expected at 21-DAP because no intraspecific interference between cover was anticipated early in crop growth in wide row spacings.

Rhizoma Peanut Mowing Height (Split Plot). Rhizoma peanut mowing height did not show an influence on sorghum plant height *($P<0.676$)*, with a negligible <1% numerical difference between short and tall mowing heights (Table 5) (23.9 vs. 23.6-cm). Alternatively, sorghum collar number was influenced by the mowing height treatments *($P<0.012$)* (Table 5). The short mowing height treatments resulted in nearly a 7% greater sorghum collars than the tall mowing treatment (3.2 vs. 3.0), which could suggest that mowing provided sorghum a brief release from peanut competition.

Experiment (ii): Mowing Method x Starter Fertilizer

Rhizoma Peanut Mowing Method (Whole Plot). The alternative mowing methods (string trimmer) of the rhizoma peanut influenced sorghum plant height *($P<0.039$)*. However, pairwise comparisons found mowing treatments similar (Table 6). Mean sorghum height in mowed treatments was numerically greater than in the unmowed treatment (28.2 vs. 26.4-cm). The scalped treatment was similar to both mowed and unmowed treatments, resulting in sorghum plants that were less than 1% shorter than the mowed treatment (28.2 vs. 28-cm) and nearly 6% taller sorghum plants than the unmowed treatment (28 vs. 26.4-cm). A lack of difference between mowed and scalped treatments could indicate that any level of mowing or "grazing" of the rhizoma peanut before grain crop planting could provide significant results in grain crop development.

Mowing methods of the rhizoma peanut appeared to have a larger effect on sorghum collar number *($P<0.001$)* (Table 6). Scalped and mow treatments were similar, resulting in a negligible 3% difference of sorghum collar means (3.6 vs. 3.5). The unmowed treatment differed

from the other two mowing treatments combined, producing nearly 12% fewer leaf collars (3.6 vs. 3.2).

Sorghum SPAD estimates were also influenced by rhizoma peanut mowing treatments *($P<0.001$)* (Table 6). Similar to the effect on leaf collar numbers, scalped and mowed treatments were not different, with a negligible 3% difference in SPAD estimates (27.3 vs. 26.5). The unmowed treatment was lower in relative chlorophyll, producing nearly 8% lower SPAD estimates from the other two treatments combined (26.9 vs. 24.8). Overall, the unmowed treatment might have suffered a disadvantage from the competiveness of the uninjured rhizoma peanut canopy.

Starter Fertilization (Split Plot). Starter fertilization influenced sorghum mean plant height *($P<0.001$)* when compared to the non-fertilized treatment, producing nearly 10% taller plants than the non-fertilized plots (29 vs. 26.2-cm) (Table 6). This could mean that the presence of supplemental N application at time of sorghum planting could benefit seedling competitiveness of grain sorghum. Likewise, starter fertilizer influenced sorghum leaf collar number *($P=0.014$),* producing 6% higher mean of leaf collar numbers than the non-fertilized plots (3.5 vs. 3.3) (Table 6). The presence of starter fertilizer *($P<0.001$)* also produced 10% higher SPAD estimates than non-fertilized sorghum seedlings (27.4 vs. 25.0) (Table 6).

Sorghum Interactions. Starter fertilization and the rhizoma peanut mowing methods were evaluated together to identify interactions between treatments. Sorghum plant height was influenced by fertilization and mowing methods *($P<0.049$)* (Figure 11). However, when analyzed further, groupings were not statistically different. The fertilized, mowed treatment resulted in taller sorghum seedlings overall, with a mean of 12. Additionally, the presence and absence of the starter fertilizer remained level in the scalped mowing treatment (Figure 11), with

all fertilized mowing treatments producing taller sorghum seedlings than the non-fertilized mow treatments (excluding non-fertilized, scalped). This could possibly be due to added decomposing organic matter from the clipped rhizoma peanut, which was a result of use of the string trimmer in the scalped treatment and the mower in the mowed treatment. Clipped debris would have decomposed throughout each plot in various placements.

There were no plot interactions found in the sorghum leaf collar means *(P=0.216)* or SPAD estimates *(P=0.067)*, although the latter is negligibly significant. However, it was noted that the tall mowing treatment remained consistently less than the other treatments when compared to the fertilization treatments, for all three measurements. Fertilized unmowed and non-fertilized unmowed (3.5 vs. 3.3) remained level when analyzing sorghum leaf collar numbers. This could mean that even starter fertilization does not have an influence on the competition from rhizoma peanut, especially when rhizoma peanut is uninjured before grain sorghum planting.

Rhizoma Peanut Analyses. SPAD estimates were taken on the rhizoma peanut within the sorghum rows. Fertilization *(P<0.001),* but not mowing treatment, affected relative chlorophyll content (SPAD). Fertilized plots produced nearly 8% higher SPAD estimates than untreated plots (37.2 vs. 34.5) (Table 6). Rhizoma peanut mowing methods did not affect relative chlorophyll readings *(P<0.082)*, with treatments producing similar means of 36.7 (mowed), 35.7 (scalped), and 35.2 (unmowed). The mowed treatment might have outperformed the scalped treatment as a result of a delayed competitive response time of the scalped rhizoma peanut, although it did seem that the clippings of the rhizoma peanut might have helped the non-fertilized scalped treatment plots.

Experiment (iii): Recruitment on Hand Sown Sorghum x Rhizoma Peanut Mowing Height

A one-way ANOVA was performed for the alternative rhizoma peanut mowing methods on hand-sown sorghum recruitment experiment. No differences in sorghum seedling recruitment were observed among the mowing treatments *($P<0.559$)*. Means of mowing height were similar: 44% (scalped), 42% (mowed), and 40% (unmowed). This result indicates that seedling emergence among mowing treatments will likely be similar but does not address subsequent potential interference from rhizoma peanut.

CONCLUSIONS

Grain sorghum plant height, number of fully emerged leaf collars, and relative chlorophyll SPAD estimates all responded significantly to the greenhouse soil and cover-fertilization treatments; although, some were only nominally significant. Increased growth and biomass of the grain sorghum were observed in the silt loam and clay soils. The grain sorghum responded well to the supplemental starter fertilizer, namely influencing both plant height and leaf collar numbers. Interestingly, senescence was observed 35-DAP, which prompts the theory that the rhizoma peanut may not be a reliable source of N within this experiment. The greenhouse study also prompted the idea that the grain sorghum (or any secondary grain crop) should be planted concurrently with any grazing or cutting of the rhizoma peanut. This would allow the sorghum seedlings the opportunity to establish before the rhizoma canopy regrows.

Benefits of injuring the rhizoma peanut canopy before planting were also seen in the field experiment. There was no observational difference between sorghum plant height or leaf collar numbers in the mowed and scalped rhizoma peanut plots in the second experiment (ii). This may mean that any level of grazing injury to the rhizoma peanut before planting would be beneficial. Sorghum SPAD estimates for the unmowed rhizoma peanut plots further demonstrated this as the unmowed plots produced lower SPAD estimates, possibly from competing with the uninjured rhizoma peanut. Likewise, the application of supplemental starter fertilizer had a significant effect on sorghum plant height and leaf collar numbers. The study results suggest the recommendation to apply starter fertilization at time of planting when intercropping with rhizoma peanut.

A few considerations could be made for future research. Reapplying fertilizer after sorghum seedling emergence in the field study might have given the seedlings the extra boost of nutrients needed to compete with the rhizoma peanut across any of the mowed treatments. It is also recommended to possibly eliminate the FN treatment to see if the monoculture would still yield the same results without the presence of the rhizoma peanut. Extended research on perennial intercropped systems should be considered, as the overall importance of these systems could help restore degraded soil structure and optimize the continued growth of sustainable agricultural options.

REFERENCES

Abdalla, M., A. Hastings, K. Cheng, Q. Yue, D. Chadwick, M. Espenberg, J. Truu, R.M. Rees, and P. Smith. 2019. A critical review of the impacts of cover crops on nitrogen leaching, net greenhouse gas balance and crop productivity. Glob. Chang. Biol. 25(8):2530-2543.

Abendroth, L.J., R.W. Elmore, M.J. Boyer, and S. K. Marlay. 2011. Corn growth and development. PMR 1009. Iowa State Uni. Ext, Ames, Iowa.

Abunyewa, A.A., R.B. Ferguson, C.S. Wortmann, and S.C. Mason. 2016. Grain sorghum leaf reflectance and nitrogen status. Afr. J Agric. Res. 11(10):825-836.

Adhikari, U., A.P. Nejadhashhemi, S.A. Woznicki. 2015. Climate change and Eastern Africa: A review of impact on major crops. Food and Energy Secur. 4(2):110-132.

Ariga, J., E. Mabaya, M. Waithaka, and M. Wanzala-Mlobela. 2019. Can improved agricultural technologies spur a green revolution in Africa? A multicountry analysis of seed and fertilizer delivery systems. Agric. Econ. 50(1):1-12.

Asbjornsen, H., V. Hernandez-Santana, M. Liebman, J. Bayala, J. Chen, M. Helmers, C.K. Ong, and L.A. Schulte. 2014. Targeting perennial vegetation in agricultural landscapes for enhancing ecosystem services. Renew. Agric. Food Syst. 29(2):101-125.

Barron, J., J. Rockstrom, F. Gichuki, and N. Hatibu. 2003. Dry spell analysis and maize yields for two semi-arid locations in east Africa. Agric. For. Meteor. 117(1-2):23-37.

Bean, B. and Noland, R. 2019. Georgia grain sorghum production quick guide. Uni. Ga. Ext. Sorghum Checkoff. <https://site.extension.uga.edu/colquittag/files/2018/04/Georgia-Grain-Sorghum-Production-Quick-Guide.pdf>

Bjornlund, V., H. Bjornlund, and A.F. Van Rooyen. 2020. Why agricultural production in sub-Saharan Africa remains low compared to the rest of the world – a historical perspective. Intl. J. Water Res. Dev. 36(S1):S20-S53.

Bodrey, R. 2016. Perennial peanut, a great choice for Panhandle pastures and landscapes. IFAS Ext. Uni. Fl. <https://nwdistrict.ifas.ufl.edu/phag/2016/09/16/perennial-peanut-a-great-choice-for-panhandle-pastures-and-landscapes/>

Brooker, R.W., A.E. Bennett, W-F Cong, T.J. Daniell, T.S. George, P.D. Hallett, C. Hawes, P.P.M. Iannetta, H. G. Jones, A.J. Karley, L. Li, B.M. McKenzie, R.J. Pakeman, E. Paterson, C. Schob, J. Shen, G. Squire, C.A. Watson, C. Zhang, F. Zhang, J. Zhang, and P.J. White. 2014. Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology. New Phytol. 206(1):107-117.

Bybee-Finley, K.A. and M.R. Ryan. 2018. Advancing intercropping research and practices in industrialized agricultural landscapes. Soil and Crop Sci. 8(6):1-24.

Cheesman, S., C. Thierfelder, N.S. Eash, G.T. Kassie, and E. Frossard. 2015. Soil carbon stocks in conservation agriculture systems of Southern Africa. Soil Till Res. 156(11):99-109.

Chepkoech, W., N.W. Mungai, S. Stober, H.K. Bett, and H. Lotze-Campen. 2018. Farmer's perspectives: Impact of climate change in African indigenous vegetable production in Kenya. Intl. J. Cli. Change Strateg. Mngt. 10(4):551-579.

Ciampitti, I. 2017. Sorghum management considerations: planting practices. Kans. State Uni. <https://eupdate.agronomy.ksu.edu/article_new/sorghum-management-considerations-planting-practices-496>

Clark, A. 2015. Cover crops for sustainable crop rotations. SARE Outreach. <https://www.sare.org/resources/cover-crops/>

Clay, L., K. Perkins, M. Motallebi, A. Plastina, and B.S. Farmaha. 2020. The perceived benefits, challenges, and environmental effects of cover crop implementation in South Carolina. MDPI. Agric.10:372.

Clement, C.R. and J. Defrank. 1998. The use of ground covers during the establishment of heart-of-palm plantations in Hawaii. Hort. Sci. 33(5):814-815.

Conway, G., O. Badiane, and K. Glatzel. 2019. Food for all in Africa. Sustainable intensification for African farmers. Cornell Uni. Press. 3(1):61-84.

Corbeels, M., J. de Graff, T.H. Ndah, E. Penot, F. Baudron, K. Naudin, N. Andrieu, G. Chirat, J. Schuler, I. Nyagumbo, L. Rusinamhodzi, K. Traore, H.D. Mzoba, and I.S. Adolwa. 2013. Understanding the impact and adoption of conservation agriculture in Africa: A multi-scale analysis. Agric. Ecosyst. Environ. 187(2014):155-170.

Currie, R.S., P.W. Geier, W. Keeling, and B. Bean. 2018. Weed control and injury with non-labeled herbicides in grain sorghum. Kans. Agric. Exp. Station Res. Rep. 4(8): 1-6.

da Silveira, P.M. and A.C. de Oliveira Gonzaga. 2017. Portable chlorophyll meter can estimate the nitrogen sufficiency index and levels of topdressing nitrogen in common bean. Pesq. Agropec. Trop. 47(1):1-6.

de Almeida, W.S., E. Panachuki, P.T.S. de Oliveira, R. de Silva Menezes, T.A. Sobrinho, and D.F. de Carvalho. 2018. Effect of soil tillage and vegetal cover on soil water infiltration. Soil and Till Res. 175(2018):130-138.

de Oliveira, I.N., Z.M. de Souza, L.H. Lovera, C.V.V. Farhate, E. De Souza Lima, D.A.A. Esteban, J.A. Fracarolli. 2019. Least limiting water range as influence by tillage and cover crop. Agric. Water. Mgmt. 225:105777.

Dubeux, J. 2016. Perennial peanut provides opportunities and challenges. Hay and Forage Grower. <https://hayandforage.com/article-552-perennial-peanut-provides-opportunities-and-challenges.html>

Dumanski, J., R. Peiretti, J.R. Benites, D. McGarry, and C. Pieri. 2006. The paradigm of conservation tillage. Proc. World Assoc. Soil and Water Conserv. 1:58-64.

Echtenkamp, G., and R.S. Moomaw. 1989. No-till corn production in a living mulch system. Weed Technol. 3(2):261-266.

Fan, Y., Z. Wang, D. Liao, M.A. Raza, B. Wang, J. Zhang, J. Chen, L. Feng, X. Wu, C. Liu, W. Yang, and F. Yang. 2020. Uptake and utilization of nitrogen, phosphorus and potassium as related to yield advantage in maize-soybean intercropping under different row configurations. Sci. Reports. 10(9504):1-10.

Fan, S. and C. Rue. 2020. The role of smallholder farms in a changing world. Springer Cham. 2(9):13-28.

Flood, H.E. and M.H. Entz. 2018. Effects of a fall rye cover crop on weeds and productivity of *Phaseolus* beans. Can. J. Plant Sci. 99(1):22-33.

Fung, K.M., A.P.K. Tai, T. Yong, X. Liu, and H-M. Lam. 2019. Co-benefits of intercropping as a sustainable farming method for safeguarding both food security and air quality. Environ. Res. Lett. 14(4):1-12.

Giller, K.E., E. Witter, M. Corbeels, and P. Tittonell. 2009. Conservation agriculture and smallholder farming in Africa: The heretics' view. Field Crops Res. 114(1):23-34.

Hart, N. 2012. Maasai pastoralists make crops thrive despite drought in Kenya. IAEA. <https://www.iaea.org/newscenter/news/maasai-pastoralists-make-crops-thrive-despite-drought-in-kenya>

Hartwig, N.L. and H.U. Ammon. 2002. Cover crops and living mulches. Weed Sci. 50(6):688-699.

Hobbs, P.R. 2005. Conservation agriculture: What is it and why is it important for future sustainable food production? J. of Agric. Sci. 145(2):127-137.

Kassam, A. and H. Brammer. 2013. Combining sustainable agricultural production with economic and environmental benefits. Geogr. J. 179(1):11-18.

Kaye, J.P. and M. Quemada. 2017. Using cover crops to mitigate and adapt to climate change. A review. Agron. Sustain. Dev. 37(4):1-17.

Kirui, O. 2019. The agricultural mechanization in Africa: Micro-level analysis of state drivers and effects. Afric. Assoc. of Agric. Econ. 272(1):1-47.

Kirui, O.K., A. Mirzabaev, and J. von Braun. 2021. Assessment of land degradation 'on the ground' and from 'above'. SN Appl. Sci. 3(318):1-13.

Knowler, D. and B. Bradshaw. 2007. Farmer's adoption of conservation agriculture: A review and synthesis of recent research. Food Policy. 32(1):25-48.

Lawson, D.W., M.B. Mulder, M.E. Ghiselli, E. Ngadaya, B. Ngowi, S.G.M. Mfinanga, K. Hartwig, and S. James. 2014. Ethnicity and child health in Northern Tanzania: Maasai pastoralists are disadvantaged compared to neighbouring ethnic groups. PLOS ONE. 9(10):e110447.

Lemus, R. 2018. Perennial peanuts as a forage crop. Miss. State Uni. Ext. <https://extension.msstate.edu/sites/default/files/publications/publications/p2624.pdf>

Magdoff, F. and H. van Es. 2021. Building soils for better crops. SARE Outreach. 3(10):137-157.

Masaka, J., C. Chohunoita, and E. Mupfiga. 2021. Soil moisture, dryland sorghum (Sorghum bicolor L.) growth and grain yield responses to in-field rainwater harvesting tillage methods. Soil & Crop Sci. 7(1):1-16.

Martens, J.T. and M. Entz. 2011. Integrating green manure and grazing systems: A review. Can. J. Plant Sci. 91(5):811-824.

McCabe, J.T., P.W. Leslie, and L. Deluca. 2010. Adopting cultivation to remain pastoralists: The diversification of Maasai livelihoods in Northern Tanzania. Hum. Ecol. Interdiscip. 38(3):321-334.

Meijer, S.S., D. Catacutan, O.C. Ajayi, G. W. Sileshi, and M. Nieuwenhuis. 2014. The role of knowledge, attitudes and perceptions in the uptake of agricultural and agroforestry innovations among smallholder farmers in sub-Saharan Africa. Int. J. Agric. Sustain. 13(1): 40-54.

Melakeberhan, H., Z. Maung, I. Lartey, S. Yildiz, J. Gronseth, J. Qi, G.N. Karuku, J.W. Kimenju, C. Kwoseh, and T. Adejei-Gyapong. 2021. Nematode community-based soil food web analysis of Ferralsol, Lithosol and Nitosol soil groups in Ghana, Kenya and Malawi reveals distinct soil health degradations. Divers. 13(3):1-19.

Moebius-Clune, B.N., H.M. van Es, O.J. Idowu, R.R. Schindelbeck, J.M. Kimetu, S. Ngoze, J. Lehmann, and J.M. Kinyangi. 2011. Long-term soil quality degradation along a cultivation chronosequence in western Kenya. Agric. Eco. Envir. 141(2011):86-99.

Moore, K.J., R.P. Anex, A.E. Elobeid, S. Fei, C.B. Flora, A.S. Goggi, K.L. Jacobs, P. Jha, A.L. Kaleita, D.L. Karlen, D.A. Laird, A.W. Lenssen, T. Lubberstedt, M.D. McDaniel, D.R. Raman,

and S.L. Weyers. 2019. Regenerating agricultural landscapes with perennial groundcover for intensive crop production. MDPI. 9(8):458-474.

Msongaleli, B.M., S.D. Tumbo, N.I. Kihupi, F.B. Rwehumbiza. 2017. Performance of sorghum varieties under variable rainfall in Central Tanzania. Hindawi. 2017(2506946):1-10.

Muchena, F.N. and C.K.K. Gachene. 1988. Soils of the highland and mountainous areas of Kenya with special emphasis on agricultural soils. Mnt. Res. Dev. 8(2/3):183-191.

Ndah, H.T., J. Schuler, S. Uthes, P. Zander, B. Triomphe, S. Mkomwa, and M. Corbeels. 2012. Adoption potential for conservation agriculture in Africa: A newly developed assessment approach (QAToCA) applied in Kenya and Tanzania. Land Degrad. Dev. 26(2):133-141.

Ndjeunga, J. and M.S.C. Bantilan. 2005. Uptake of improved technologies in the semi-arid tropics of West Africa: Why is agricultural transformation lagging behind? J. Agric. Dev. 2(1):85-102.

Ngwira, A.R., J.B. Aune, S. Mkwinda. 2012. On-farm evaluation of yield and economic benefit of short term maize legume intercropping systems under conservation agriculture in Malawi. Field Crops Res. 132(14):149-157.

Nielsen, R.L. 2019. Determining corn leaf stages. Purdue Uni. Ext. <https://www.agry.purdue.edu/ext/corn/news/timeless/VStageMethods.html>

Okeyo, S.O., S.N. Ndirangu, H. N. Isaboke, L.K. Njeru, and J.A. Omenda. 2020. Analysis of the determinants of farmer participation in sorghum farming among small-scale farmers in Siaya County, Kenya. Sci. Afric. 10:e00559.

Picasso, V. D., E.C. Brummer, M. Liebman, P.M. Dixon, and B.J. Wilsey. 2008. Crop species diversity affects productivity and weed suppression in perennial polycultures under two management strategies. Crop Sci. 48(1):331-342.

Pingali, P.L. 2012. Green Revolution: Impacts, limits, and the path ahead. PNAS. 109(31):12302-12308.

Place, F., J. Njuki, F. Murithi, and F. Mugo. 2006. Agricultural enterprise and land management in the highlands of Kenya. Int. Food Res. Inst. 8(1):191-215.

Place, F., M. Adato, and P. Hebinck. 2007. Understanding rural poverty and investment in agriculture: An assessment of integrated quantitative and qualitative research in Western Kenya. World Dev. 35(2):312-325.

Radovich, T., L.J. Cox, J. Sugano, and T. Idol. 2009. Benefits and costs of using perennial peanut as living mulch for fruit trees in Hawai'i. Coll. Trop. Agric. Hum. Resour. SCM-27:1-10.

Rosolem, C.A., J.S.S. Foloni, and C.S. Tiritan. 2002. Root growth and nutrient accumulation in cover crops as affected by soil compaction. Soil and Till. Res. 65(1):109-115.

Rouse, R.E., E.M. Miavitz, and F.M. Roka. 2019. Guide to using rhizomal perennial peanut in the urban landscape. IFAS Ext. HS960. <https://edis.ifas.ufl.edu/pdf%5Carchived%5CEP%5CEP135%5CEP135-5668806.pdf>

Ryan, M.R., T.E. Crews, S.W. Culman, L.R. Dehaan, R.C. Hayes, J.M. Jungers, M.G. Bakker. 2018. Managing for multifunctional in perennial grain crops. BioSci. 68(4):294-304.

Schlautman, B., C. Bartel, L. Diaz-Garcia, S. Fei, S. Flynn, E. Haramoto, K. Moore, and D.R. Raman. 2021. Perennial groundcovers: An emerging technology for soil conservation and the sustainable intensification of agriculture. Emerg. Topics in Life Sci. 5(2):337-347.

Sindhu, M.M., P.M. Shanmugavadivu, and G.K. Makilan. 2019. Stabilization of black cotton soil using fly ash. Indian J. of Res. 8(1):44-45.

Silva, L., K. Mullenix, L. Dillard, and D. Russell. 2021. Rhizoma perennial peanut. Alabama A&M and Auburn Uni. Ext. <https://www.aces.edu/wp-content/uploads/2021/06/ANR-2737-Rhizoma-Perennial-Peanut_052821L-G.pdf>

Taylor, J.R.N. 2003. Overview: Importance of sorghum in Africa. Dep. Food Sci. 1(2003):1-21.

Tian, G., G.O. Kolawole, B.T. Kang, and G. Kirchhof. 2000. Nitrogen fertilizer replacement indexes of legume cover crops in the derived savanna of West Africa. Plant and Soil. 224(2):287-296.

Uchino, H., K. Iwama, Y. Jitsuyama, K. Ichiyama, E. Sugiura, and T. Yudate. 2015. Stable characteristics of cover crops for weed suppression in organic farming systems. Plant Prod. Sci. 14(1):75-85.

UGA Peanut Entomology. 2014. Spider mites in peanut. UGA Coop. Ext. <https://site.extension.uga.edu/peanutent/2014/07/spider-mites-in-peanut/>

USDAa. 2013. Sharkey series. Natl. Coop. Soil Surv. <https://soilseries.sc.egov.usda.gov/OSD_Docs/S/SHARKEY.html>

USDAb. 2018. Bosket series. Natl. Coop. Soil Surv. <https://soilseries.sc.egov.usda.gov/OSD_Docs/B/BOSKET.html>

USDAc. 2006. Cedargap series. Natl. Coop. Soil Surv. <https://soilseries.sc.egov.usda.gov/OSD_Docs/C/CEDARGAP.html>

USDAd. 2007. Bonneau series. Natl. Coop. Soil Surv. <https://soilseries.sc.egov.usda.gov/OSD_Docs/B/BONNEAU.html>

USDAe. 2019. Blanton series. Natl. Coop. Soil Surv. <https://soilseries.sc.egov.usda.gov/OSD_Docs/B/BLANTON.html>

USDAf. 2018. Padlock series. Natl. Coop. Soil Surv. <https://soilseries.sc.egov.usda.gov/OSD_Docs/P/PADLOCK.html>

Usman, M.A. and D. Callo-Concha. 2021. Does market access improve dietary diversity and food security? Evidence from Southwestern Ethiopian smallholder coffee producers. Agric. Food Econ. 9(18):1-21.

Van Hulst, F.J. and H. Posthumus. 2016. Understanding (non-) adoption of conservation agriculture in Kenya using the reasoned action approach. Land Use Policy. 56(2016):303-314.

Vendramini, J., J. Erickson, W. Vermerris, and D. Wright. 2019. Forage sorghum. IFAS Ext. SS-AGR-333. <https://edis.ifas.ufl.edu/publication/AG343>

Wang, X-B., C-M. Hsu, J.C. Dubeux, C. Mackowiak, A. Blount, X-G. Han, and H-L. Liao. 2019. Effects of rhizoma peanut cultivars (Arachis glabrata Benth.) on the soil bacterial diversity and predicted function in nitrogen fixation. Ecol. Evol. 9(22):12687-12687.

Weather Spark. Temperature histories. Weather Spark.

Zandonadi, C.H.S., C.J.B. Albuquerque, and R.S. Freitas. 2016. Chlorophyll index (SPAD) and macronutrients relation and productive performance of sorghum hybrids in different sowing dates. Aust. J. of Crop Sci. 10(4):546-555.

Zeng, D., J. Alwang, G.W. Norton, and B. Shiferaw. 2015. Ex post impacts of improved maize varieties on poverty in rural Ethiopia. Agric. Econ. 46(4):515-526.

Table 1. Soil test results of alternative soil types used in our greenhouse experiment. The analysis showed silt loam was low in potassium.

Soil Types	phs	N.A meq/100g	%OM	P Bray I lb/A	Ca lb/A	Mg lb/A	K lb/A	CEC meq/100g
Silt Loam	6.1	2.5	4.1	56	3352	182	302	12
Sandy	5.4	1.5	0.7	94	631	101	198	3.8
Clay	5.8	3	2.7	87	7646	1947	440	30.8

Table 2. Repeated measures total means of sorghum plant height, leaf collar number, rhizoma peanut canopy height, and SPAD estimates for both species.

	Sorghum			Rhizoma Peanut		
Soil						
	Silt Loam	Sandy	Clay	Silt Loam	Sandy	Clay
Plant Height (in)	23.4	19	22.4	5	4.4	4.8
Collar #	5.4	4.8	5.1	*	*	*
Mean SPAD	35.8	32.6	31.6	34.3	32.4	30.4
Cover						
	FN	FP	UP	FP	UP	
Plant Height (in)	22	22.9	20	4.8	4.7	
Collar #	5.3	5.2	4.8	*	*	
Mean SPAD	35.7	32.9	31.3	33.1	31.6	

Table 3. Soil and cover influence over the third leaf of grain sorghum at time of termination. All values were deemed significantly different (P<0.005, Fisher Pairwise comparisons). Cover was found to show the only influence among fixed factors.

Soil			Cover		
Silt Loam	Sandy	Clay	FN	FP	UP
18.2	20.1	15.8	23.5	15	15.4

Table 4. Soil and cover influence on sorghum and rhizoma peanut fresh and dry biomass weight 35-DAP.

	Sorghum			Rhizoma Peanut		
	Soil					
	Silt Loam	Sandy	Clay	Silt Loam	Sandy	Clay
Fresh	40.6	16	26.8	46.6	32.3	31.8
Dry	4.6	2.1	3.3	11.6	8.1	7.8
	Cover					
	FN	FP	UP	FP	UP	
Fresh	41.8	25	16.8	41.6	32.3	
Dry	4.7	3.2	2.1	10.2	8.2	

Table 5. Sorghum row width and rhizoma peanut mowing height influence on sorghum plant height and leaf collar numbers 21-DAP. 57-cm (22.5-in) data is not included in the overall analysis but was included in table to compare alongside 38-cm (15-in) and 76-cm (30-in) row width data.

	Sorghum Row Width (cm)			Rhizoma Peanut Mow Height	
	38	57	76	Short	Tall
Plant Height (cm)	24.4	22.4	24.1	23.9	23.6
Collar #	3.2	3	3.1	3.2	3

Table 6. Rhizoma peanut mowing method (scalped, mowed/medium, and unmowed) and sorghum starter fertilizer influence on sorghum plant height, leaf collar number, and SPAD estimates for sorghum and rhizoma peanut 21-DAP.

	Rhizoma Peanut Mow Methods			Starter Fertilizer	
	Scalped	Mow	Tall	Short	Tall
Plant Height (cm)	28	28.2	26.4	29	26.2
Collar #	3.6	3.5	3.2	3.5	3.3
Sorghum SPAD	27.3	26.5	24.8	27.4	25
Peanut SPAD	35.7	36.7	35.2	37.2	34.5

Figure 1. SPAD readings were taken on the top right leaflet across all samples.

Figure 2. An example of a leaf cluster that would not be chosen for a SPAD reading due to the extensive spider mite damage.

Figure 3. Top: Aerial photo of Sunset Specialty Groundcover in Suwannee County, Florida. Bottom: Zoomed in photo of the approximate experimental area (blue rectangle). Red rectangles mark the differing experiments; red square is Experiment 3.

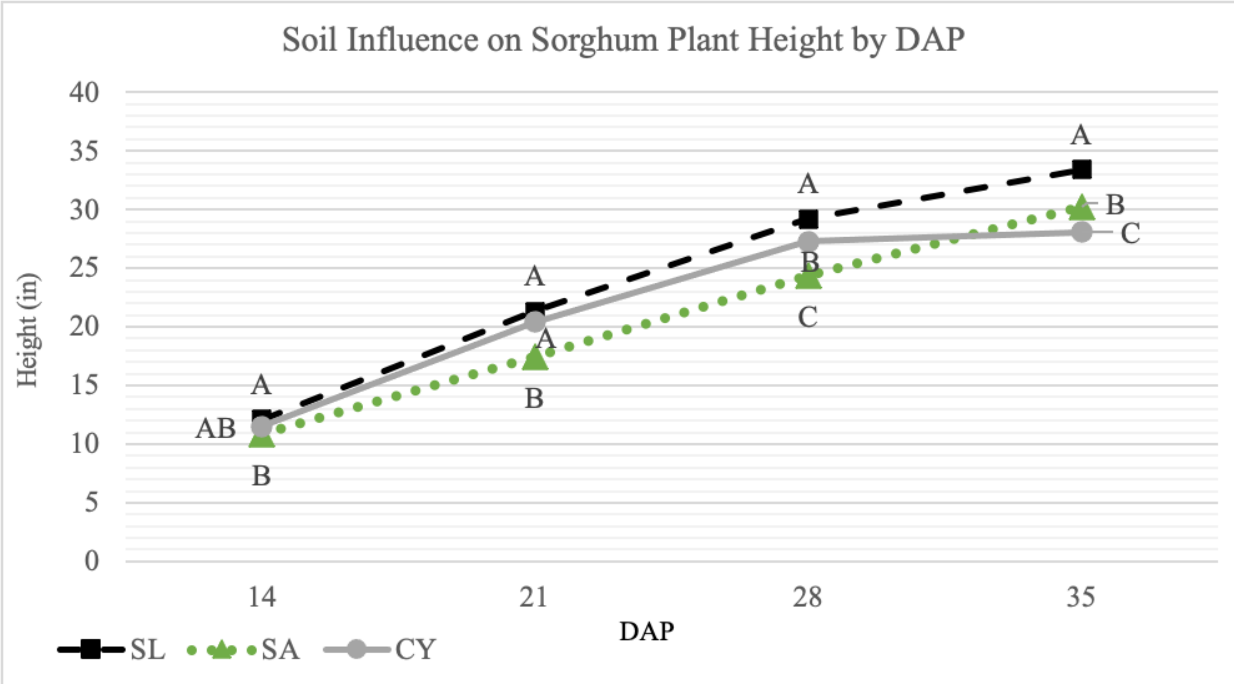

Figure 4. Soil influence on sorghum plant height at 14, 21, 28, and 35-DAP.

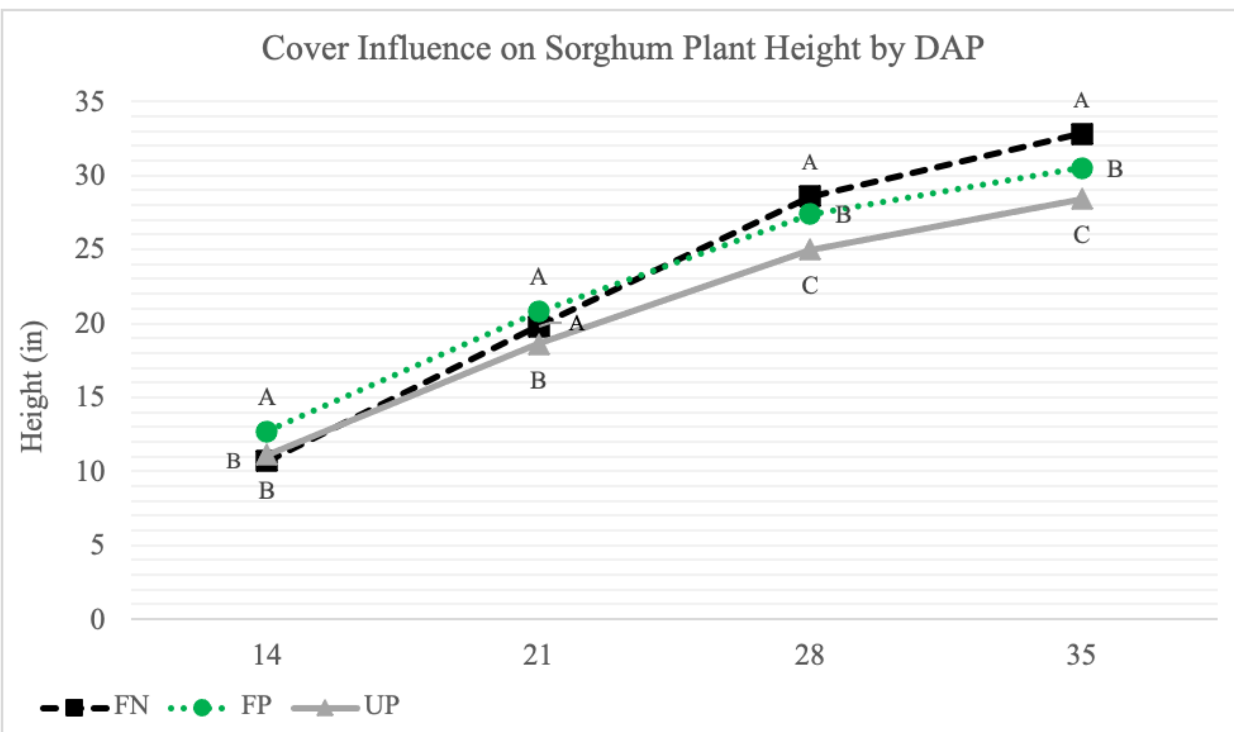

Figure 5. Cover influence on sorghum plant height number 14, 21, 28, and 35-DAP.

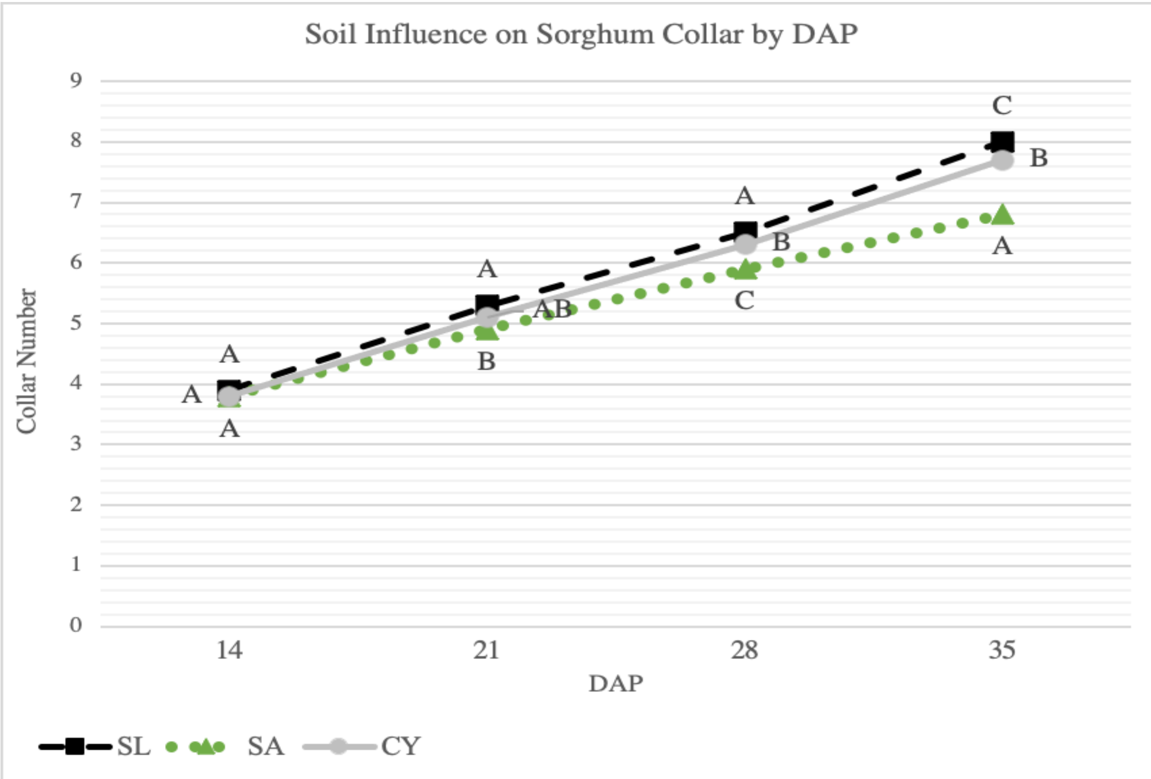

Figure 6. Soil influence on sorghum leaf collar number 14, 21, 28, and 35-DAP.

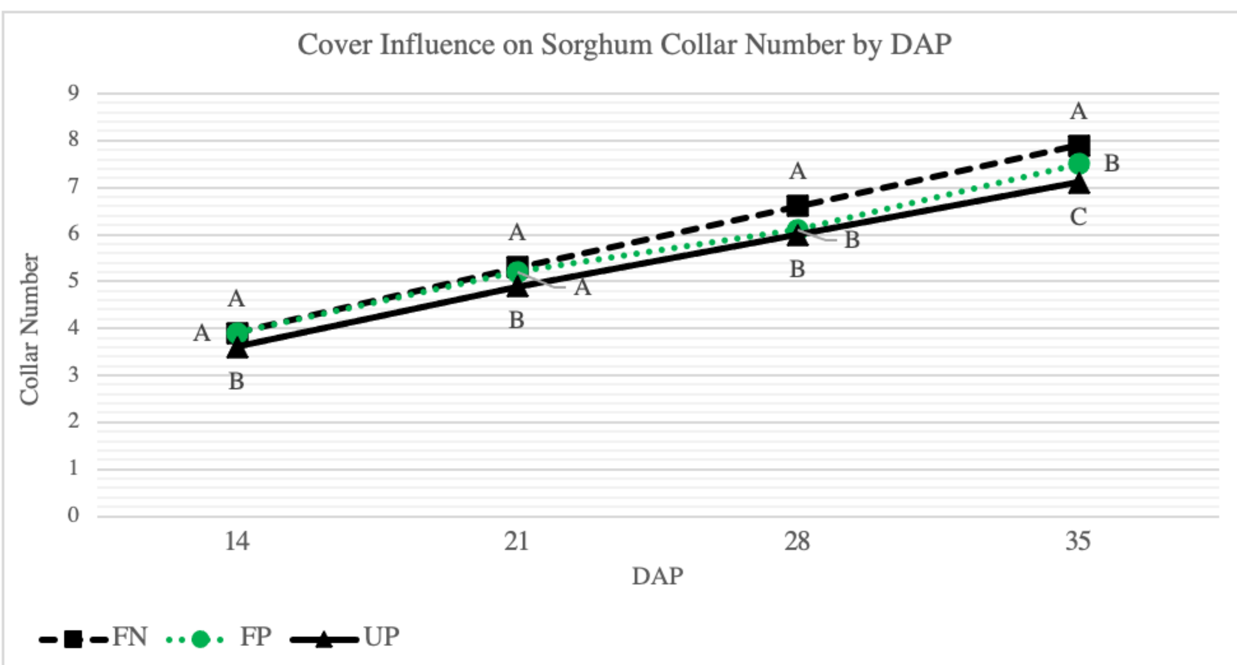

Figure 7. Cover influence on sorghum leaf collar numbers for 14, 21, 28, and 35-DAP.

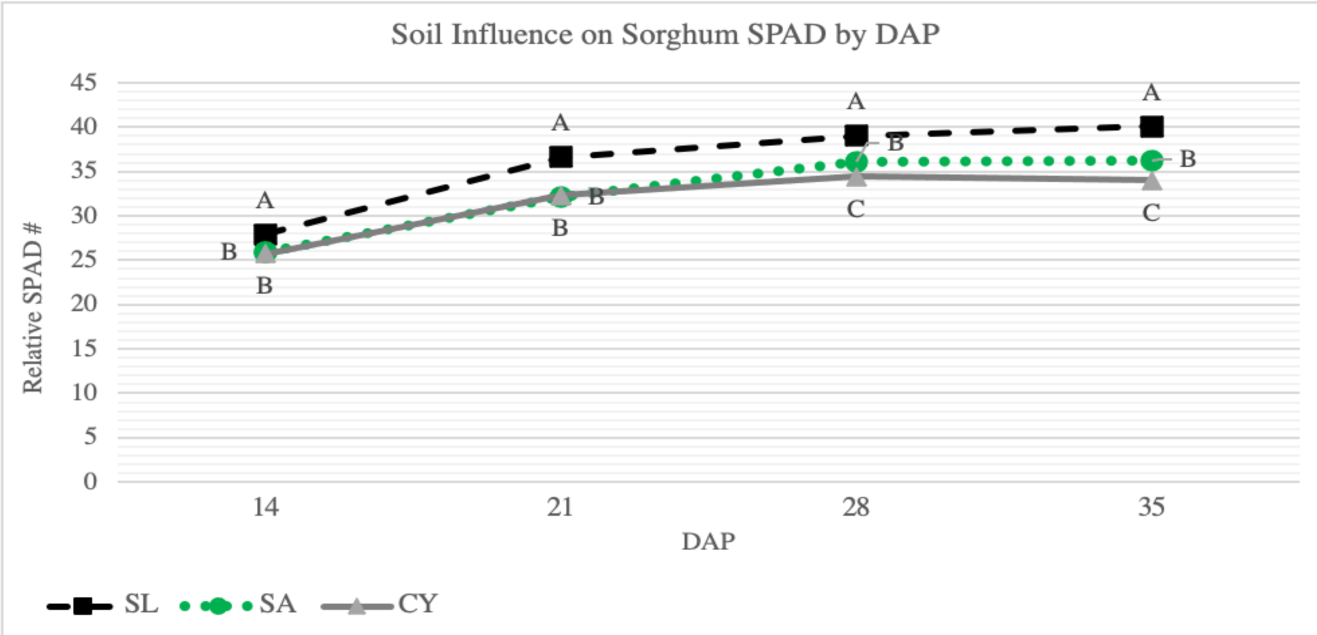

Figure 8. Soil influence on the relative chlorophyll SPAD estimates for sorghum 14, 21, 28, 35-DAP. SPAD estimates measure the "greenness" of leaves, so the observed potential flatline is expected over time. Slight decreases might be due to spider mite damage on sorghum leaves.

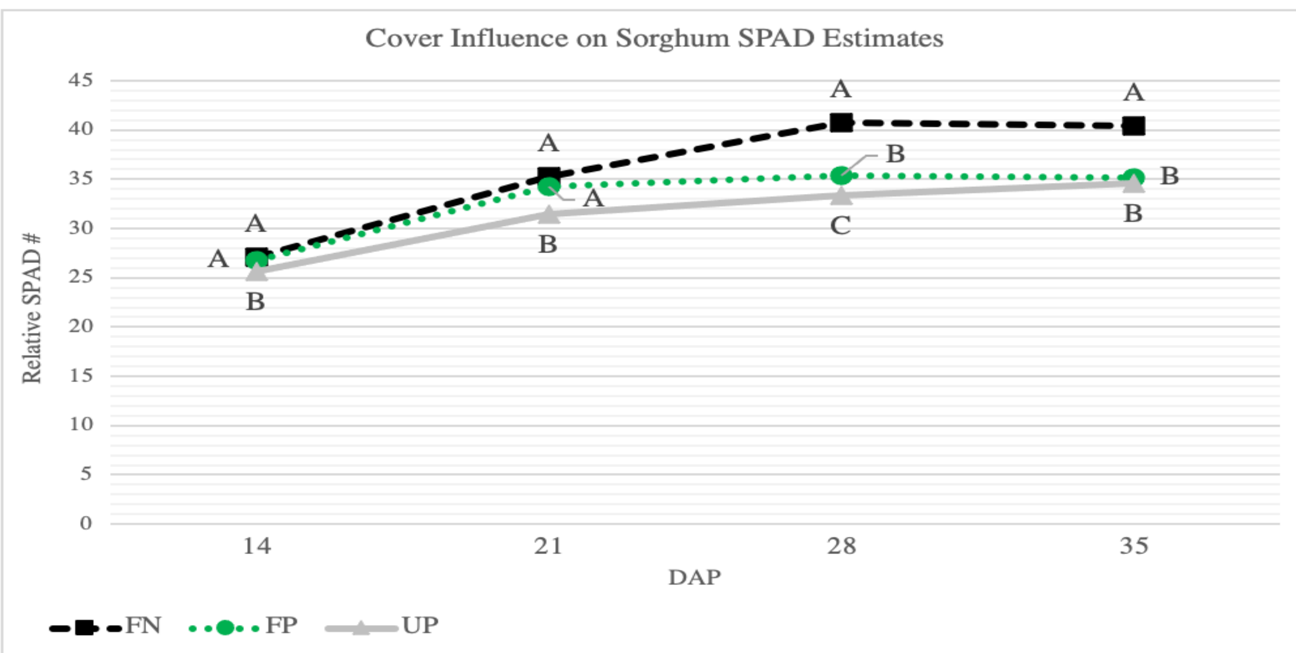

Figure 9. Cover influence on sorghum SPAD estimates for 14, 21, 28, 35-DAP. SPAD estimates decrease after 28-DAP, most likely due to spider mite damage.


SA F 102


SL NF 103

Figure 10. Peanut aboveground biomass by soil types (top: sand, middle: silt loam, bottom: clay)

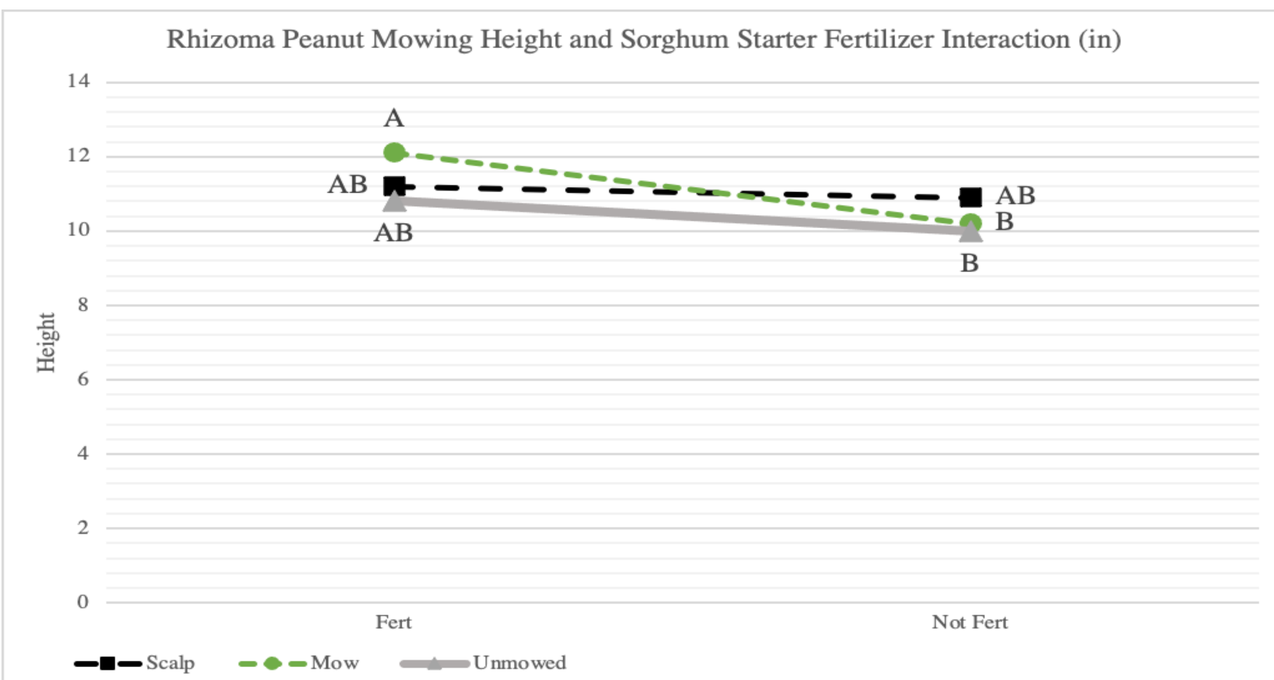

Figure 11. Sorghum plant height was influenced by fertilization and rhizoma peanut mowing methods (scalped, mow, and unmowed).

APPENDICES

Appendix A: Greenhouse Environmental Conditions 2020

Appendix A-1: Greenhouse Temperature. To determine environmental conditions within the greenhouse initial minimum/maximum temperature measurements were taken from November 2nd to November 9th. The minimum temperature averaged 22.9 °C (73.2 °F) and the maximum temperature averaged 29.7 °C (85.5 °F) inside the research bay. According to WeatherSpark, the greenhouse temperature was slightly elevated when compared to Live Oak, Florida (min: 14.2 °C (57.6 °F / max: 25.8 °C (78.4 °F)) and Nairobi, Kenya (min: 15.9 °C (60.6 °F)/ max: 23.9 °C (75 °F)) during this time of year (Weather Spark, 2020).

Appendix A-2: Supplemental Lighting. Beginning in December 2020, supplemental crop lighting was in use to extend the photoperiod of the rhizoma peanut crop, as overall growth and canopy vigor appeared stunted due to the decreased solar angle in Springfield, Missouri at this time. Canopy health increased within days of the supplemental lightening use per increased new growth and prolific flowering. Photoperiods in Springfield were compared against Live Oak, Florida (where the rhizoma peanut pots arrived from), and then cross-referenced with Nairobi, Kenya's typical photoperiod in the same timeframe. Using data from December 2nd-7th across all three locations the photoperiod for Springfield averaged 9.4-hrs from December 2nd-7th; photoperiod for Live Oak averaged 10.2-hrs; and the photoperiod for Nairobi averaged 12.1-hrs. That left a 2.7-hr difference between Nairobi and Springfield and a .8-hr difference between Live Oak and Springfield. While differences between photoperiods seemed minor, the supplemental crop lighting also helped increase the light and heat intensity within the greenhouse bay, as the solar angle decreased along with the photoperiod.

Use of the crop lighting was terminated when outside temperatures in Springfield reached a consistent +26.7 °C (+80 °F) in late June 2021. Photoperiod for this time in Springfield averaged 14.8-hrs, 14-hrs for Live Oak, and 12-hrs in Nairobi.

Appendix A-3: Pest Management. A spider mite outbreak affected the rhizoma peanut pots intermittently from January 2021 to June 2021. Spider mites thrive in dry conditions and is a known pest of rhizoma peanut (UGA Peanut Entomology, 2014). The rhizoma peanut pots were treated with a diluted mixture of Neem Oil and water, per the mandatory control methods of the greenhouse staff. Pots were initially treated mid-day by the greenhouse staff, exposing the plant cuticle to damage under the diluted pesticide and sunlight. This led to discoloration of the old growth. The plants continued to produce new, healthy shoots. Weekly misting after 5pm were enacted to reduce dry conditions.

Appendix B: Preparation for Grain Sorghum Planting

Transplanted rhizoma peanut pots were left to establish for approximately eight months, from January to August 2021. On August 2nd, each rhizoma peanut pot was clipped down to 5-cm (2-in) above soil level to prepare for the first planting of grain sorghum. This process removed elongated peanut canopy coverage and damage from the previous spider mite invasion and treatments. Before planting the grain sorghum, a timespan of two weeks was allotted for time for the rhizoma peanut to regrow. Grain sorghum seeds were planted on August 18th.

Beginning August 23rd, greenhouse temperatures surpassed 32 °C (90 °F). Temperature measurements were taken between 1pm and 6pm from August 23rd to August 27th, approximately averaging 40 °C (105 °F). Alerted by the excessive heat in the greenhouse bay, measures were taken to reduce the heat, including opening greenhouse breezeway vents and headhouse doors to allow building air to circulate through the greenhouse bays. The temperature returned to relative normalcy between August 30th and September 3rd, approximately averaging 31°C (88 °F).

It became apparent in this timeframe that the rhizoma peanut grows back quickly with excessive heat, resulting in a full coverage canopy in less than a month after the first clipping, directly competing with the grain sorghum seedlings planted on August 18th. This first planting was terminated.

Appendix C: 1st Fresh/Dry Biomass of Both Crops

Appendix C-1: Collection and Measurements. The initial planting of grain sorghum on August 18th was terminated on September 3rd, 16 DAP; however, seedlings were kept to take fresh and dry weight biomass measurements. Grain sorghum seedlings were cut at soil level and weighed together as a singular pot. Collective seedling weight of each pot was measured and then later used to find the average weight of each individual seedling within that sample. The rhizoma peanut canopy was also clipped at this time (September 3rd) to 2.5-cm (1-in) above soil level. This allowed canopy space for the second planting of the grain sorghum, which immediately followed the clipping. All samples (sorghum and peanut canopy biomass) were then placed in paper bags, organized by pot number, and then arranged in a Cascade TEK's Model TFO-28 drying oven located in Karl's Hall on the Missouri State University campus.

Samples were dried at a consistent heat of 60 °C (140 °F) from September 3rd to September 9th, measuring random samples in this time to determine when constant weight was met. Drying to a constant weight could mean 0 or negligible change. Constant weight was observed on September 9th, 6 days of drying. Fresh and dry weight biomass measurements were taken using a Fisher Science electric balance.

Appendix C-2: Analysis of Fresh and Dry Vegetative Biomass. Repeated measures were used to analyze the initial harvest of the grain sorghum and rhizoma peanut. Sorghum seedling biomass was not influenced by soil in either fresh or dry weight and soil only showed an influence in dry weight of the rhizoma peanut biomass. Cover was also not influential for the rhizoma peanut, in either fresh or dry weight. However, cover did influence sorghum seedlings in both fresh and dry weights *($P<0.001$).*

Sorghum Analysis. Soil treatments were not significant *(P=0.530)* in the fresh weight analysis of the sorghum, and Fisher Pairwise grouped all soils as one. SL produced a greater fresh biomass weight than SA, which outperformed CY. Cover, however, did have an influence on the fresh weight of the sorghum biomass. Seedlings in the FN pots produced nearly 10% higher fresh weights of the seedlings than either UP and FP. Fisher Pairwise found UP and FP to be significantly similar, with only a 1% difference found between cover treatments.

The dry weight analysis showed similar results, with soil treatments not showing an influence on the dry weight of the sorghum seedlings *(P>0.005)*. Fisher Pairwise ranked the soil treatments in the same order of similar significance. Similarly, cover treatments did significantly influence the dry weight of the sorghum seedlings *(P<0.001)*. Seedlings in the FN treatments produced nearly 10% higher dry weight biomass than those in either UP or FP treatments, which were found to be significantly similar.

Rhizoma Peanut Analysis. The only significant result in the rhizoma peanut analysis of fresh and dry weight biomass was found in influence of soil treatments on dry rhizoma peanut. The fresh weight analysis found that SL outperformed SA and CY, although all were similarly grouped by Fisher Pairwise. Alternatively, cover treatments FP and UP were also similarly grouped. The dry weight analysis found that SL was significantly different than the similarly grouped CY and SA, producing nearly 20% higher dry biomass in the rhizoma peanut. Cover treatments were similarly grouped, with FP producing just barely 1% more than UP.