Crop Rotation Effects on Soil Properties and Cotton (*Gossypium hirsutum L.*) Yield in Semi-Arid Texas

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NOMENCLATURE

SHP, Southern High Plains

RP, Rolling Plains

THP, Texas High Plains

OA, Ogallala Aquifer

BNF, biological nitrogen fixation

N, nitrogen

NO_3^--N, nitrate-N

NH_4^+, ammonium

USDA, United States Department of Agriculture

C-C, cotton to cotton

GS-C, grain sorghum to cotton

GR-C, guar to cotton

GR-GS, guar to grain sorghum

EC, electrical conductivity

$GDD_{15.6}$, growing degree days

MIC, micronaire

Rd, reflectance

+b, yellowness

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ABSTRACT

The Southern High Plains (SHP) and Rolling Plains (RP) of Texas are semi-arid regions, residing at the lower end of the Great Plains of the U.S. Due to decreasing aquifer levels, rainfed acreage within the region has increased. On rainfed acres, cropping systems must be designed to capture and store precipitation and enhance resiliency of the system to withstand prolonged drought events. The implementation of a crop rotation within a management system can potentially improve water dynamics, soil chemical, and physical parameters. Other potential benefits include the decrease of insect pressure, weed pressure, and wind erosion. The inclusion of drought hardy alternative crops with the ability to complete biological nitrogen fixation (BNF) have been reported to increase plant available inorganic N and cotton (Gossypium hirsutum L.) lint yield.

Guar (*Cyamopsis tetragonloba* L.), a drought hardy legume, has the ability to biologically fix nitrogen (N). Guar is a minor crop in the U.S. The main product of guar is galactomannan gum, extracted from the seed endosperm. Galactomannan gum is used in numerous industries ranging from food and fiber to oil and gas extraction. The implementation of guar in management systems in the U.S has been hindered due to no access to guar-specific commercial *Rhizobium* inoculant, lack of federal crop insurance, and the recent hiatus of the only U.S. based processing plant. However, guar can potentially offer many benefits in a rotation by increasing the availability of inorganic N within the soil, increasing soil organic matter by leftover crop residue, and improving soil water dynamics (Rose et al., 2022).

The objective of this study was to evaluate and compare the impact on soil chemical parameters, specifically inorganic N availability, and cotton lint yields when including alternative crops in rotation with cotton versus a cotton monoculture. To address these objectives, sites in Lubbock and Chillicothe, TX were selected, and experiments conducted in 2020 through 2022. Two-year crop rotations (cotton (*Gossypium hirsutum* L.)-cotton, guar-cotton, grain sorghum (*Sorghum bicolor* L.)-cotton, and guar-grain sorghum) were implemented. Blocks were established within a single agronomic field to collect multiple years of rotation in a short time frame.

These short-term crop rotations in 2020 – 2021 increased nitrogen-N (NO_3^--N) availability at the Chillicothe site at a soil depth of 15-60 cm. In the 15-30 cm depth, systems containing guar had greater available NO_3^--N compared to the grain sorghum crop rotation. A similar trend was determined at the 30-60 cm depth, with systems containing guar having greater available NO_3^--N compared to all other crop rotations. The Lubbock site had a similar trend in 2020-2021, at 0-60 cm depth, systems containing guar had greater NO_3^--N compared to the grain sorghum - cotton crop rotation, respectively. Differences in soil chemical parameters in the second block of the two-year crop rotation at the Chillicothe site were not determined.

This study suggests guar in rotation with cotton can increase NO_3^--N amounts but it did not result in increased cotton lint yield compared to a cotton monoculture. Therefore, growers could reduce reliance on synthetic fertilizers and potentially decrease inputs. However, further research is required to better evaluate if guar is economically and agronomically sustainable in semi-arid regions.

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CHAPTER I

LITERATURE REVIEW

History of crop production in the Southern High Plains of Texas

The Texas Southern High Plains (SHP) consists of nineteen counties with extreme, unpredictable weather and varying soil textures of sandy to clayey. Residing within the southern portion of the Great Plains the SHP is classified as Bsk by the Koppen-Geiger climate class; an arid climate, steppe precipitation, and cold arid temperature (Allen et al., 2008; Peel et al., 2007). The area is notorious for high destructive winds, hot summers, cold winters, and precipitation events that are intense and sporadic (Allen et al., 2008). By the late 1800s and early 1900s cultivated land increased dramatically and the population within the area doubled. The cost of managing large cattle operations during the winter months and overgrazing increased the transition to farmland upon the SHP. Crops first produced on the SHP include corn (*Zea mays* L.), oats (*Avena* spp.), alfalfa (*Medicago sativa*), pearl millet (*Pennisetum glaucum*), and grain sorghum (*Sorghum bicolor L.*). Ranches in the area started growing these crops to supplement the decreasing grazing capabilities. (Gibson, 1932; Gordon, 1961) Similar to the SHP, the Rolling Plains (RP) is also classified as a Bsk (Peel et al., 2007). While a semi-arid region, the RP receives on average 100 mm more precipitation annually. The region is similar to the SHP and produces multiple crops, such as cotton (*Gossypium hirsutum* L.), wheat (*Triticum aestivum* L.), peanuts (*Arachis hypogaea*), and grain sorghum. A cotton-wheat rotation is common in the RP (DeLaune et al., 2020; Tripp et al., 1982).

Innovative technology improved grower practices and increased the amount of land one could manage. Increased demand for wheat led to monocultures and increased tillage. Intense drought led to the worst weather event to plague the Great Plains (Baumhardt, 2003; Gibson, 1932; Gordon, 1961; Hayter, 1981). The dust bowl left inhabitants in poor health and bankrupt. To combat this epidemic the government created policies in the 1930s to decrease overuse of land. Conservation practices were paramount in combatting erosion with cultivated land being transitioned back to grassland. Alternative crops, such as grain sorghum, better suited for the area were planted, in rotation with traditional crops. (Hornbeck, 2012).

Furrow irrigation became a tool to combat soil erosion within the area, and for that reason irrigation wells increased. The main irrigation source for this area is the Ogallala Aquifer (OA) (Baumhardt, 2003). The OA is the largest aquifer in North America and provides irrigation water to multiple states from South Dakota to Texas. Discovered in Nebraska this “underground lake” transformed agriculture within the Great Plains (Green, 1992; Terrell et al., 2002; Zivkovic & Hudson, 2014). The SHP relies on the OA as its main irrigation source with an estimated saturated thickness in our region of 16 m (HPWD, 2021). Due to diminishing water levels, estimated to have a varying decline of 10 m to more than 150 m since the 1950’s, within the OA, dryland acreage has increased on the SHP. (Amosson et al., 2009; McGuire, 2017). Studies predict 54% of irrigated land will be transitioned to rainfed systems in the SHP by 2100 (Deines et al., 2020). Growers within the SHP will have to adopt management practices to overcome these challenges.

Cotton and crop rotation overview

Cotton production in the SHP preceded the mid 1890's. One of the first cotton crops recorded in the area was produced in Crosby County and ginned in Childress, TX. Growers within the area started to plant patches of cotton. People in the region learned how well suited the crop was to the area it slowly spread across the SHP into the 1900s (Gordon, 1961). Texas is the leading producer of cotton in the U.S. Texas growers harvested 2,246,005 ha of cotton in 2021, the SHP produced half of that acreage (Plains Cotton Growers, 2021, 2022; USDA, 2021).

Cultivated as an annual in the SHP, cotton planting dates range from late April to mid-June. Planting by June 5th or June 10th is required for growers to qualify for full-coverage federal insurance and minimize exposure of cool weather that can hinder fiber quality during boll maturation (Mauget et al., 2019). Emergence can take up to 14 days after planting. Soil moisture and temperature are pivotal in emergence, a soil temperature <10 °C can hinder emergence and seed viability (Sansone et al., 2002). Ideal moisture accumulation (rainfall or irrigation) in-season for an economically viable cotton crop within the SHP is about 74 cm (Wanjura et al., 2002). Typically, fully mature productive cotton crops require 1444 heat units (Ritchie et al., 2007). General recommendations suggest 56 kg of nitrogen (N) a bale ha^{-1} (Lemon et al., 2009). However, recent studies conducted in New Deal, TX from 2018-2020 concluded that varying rates of N fertilizer (0, 45, 90, 135, and 180 kg N ha^{-1}) did not significantly impact cotton lint yield, due to residual NO_3^--N within the soil profile (Pabuayon et al., 2021). It is imperative fertilizer recommendations are based upon soil elemental concentration and target yield potential, rather than repetitive blanket applications year to year.

Cotton monocultures have become standard SHP practice due to economic benefits apart from crop rotations (Reeves, 2017). A study conducted by Allen et al. (2008) from 1997 to 2005 in northeast Lubbock County evaluated the economic return of cotton monocultures to integrated systems. The study concluded integrated systems utilizing cotton, forage, and livestock have a greater profitability up to 90% compared to conventional continuous cotton system. (Mauget et al., 2020).

Crop rotation is an option for growers to decrease economic inputs, lower disease potential, control weeds, and improve soil chemical, physical, and biological properties. Crop rotation is a sequence of crops grown in succession on a particular field (Castellazzi et al., 2008). A study conducted in Halfway, TX from 2003 to 2008 evaluated the impact of a cotton – grain sorghum crop rotation on cotton lint yield. Annual precipitation varied throughout the study and had a large impact upon results. Precipitation accumulation was below the annual average of 460 mm a year in 2003 and 2008, 303 mm and 376 mm, respectively. These years cotton – grain sorghum rotation increased cotton lint yields 18% and 44%. Cotton lint yield was not impacted by the rotation in years of excessive precipitation, 2004 and 2007 with 876 mm and 559 mm respectively (Bordovsky et al., 2011).

Introducing alternative crops considered drought tolerant and better suited for the environment, into management systems within the SHP, can potentially better help growers use diminishing water resources. Prior research conducted in New Deal, TX, by Pabuayon et al. (2019, 2022) from 2017 to 2018 suggests alternative crops such as sesame (*Sesamum indicum* L.), safflower (*Carthamus tinctorius* L.), and sunflower (*Helianthus annuus* L.) were able to support productive growth with precipitation accumulation of 345 mm, whether rainfed or irrigated. In the same study, guar (*Cyamopsis tetragonoloba* L.), had the ability to support productive vegetative and seed growth with precipitation accumulation of 345 mm, whether rainfed or irrigated (Pabuayon et al., 2022). Acosta-Martínez et al. evaluated from 2002 to 2007 long-term effects of non-leguminous cropping systems and tillage practices on cotton lint yields and total soil N, in New Deal, TX, in a rainfed setting. Cropping systems include grain sorghum–cotton, cotton- rye (*Secale cereale*)-grain sorghum, and grain sorghum-rye. Tillage treatments included no tillage and conventional tillage. Limited rainfall during this research led to crop failure during multiple years of this study. However, total soil N was not impacted by any cropping system until the fifth year of research. The grain sorghum-rye cropping system had an increased amount of total soil N. Cotton lint yield was not significantly impacted by any cropping rotation or tillage practice.

Implementing a leguminous crop with biological N fixation (BNF) capabilities can improve soil chemical properties if successful rhizobial nodulation and fixation occurs. Tripp et al. (1982) indicated a guar-to-cotton crop rotation increased cotton lint yield up to 15%. Summer legumes can be utilized for grazing, as a cover crop, and reduce biotic and abiotic pressures. A study conducted in El Reno, OK from 2003 to 2006 evaluated water efficiency of adding alternative summer legumes in a cropping system with winter wheat (Rao & Northup, 2009). The legumes included pigeon pea (*Cajanus Cajan* L.), guar, cowpea (*Virginia unguiculata* L.), mung bean (*Vigna* *radiate* L.), and soybean (*Glycine max* L.). Mung bean, cowpea, and guar were best suited to add to a summer legume – winter wheat cropping system. The study concluded those crops use less soil water and had a lower water deficit most years the study was conducted compared to monoculture wheat.

Summer legumes have the potential capability to fix N in the soil therefore potentially reducing the amount of N a grower would need to apply. Prior research evaluates the impact of adding legumes into cropping systems. A study conducted from 2004 -2007 near Florence, SC, evaluated the impact of a summer legume-cotton crop rotation at different nitrogen rates on soil and plant chemical attributes (Bauer et al., 2009). Soil samples were collected the winter after the first year of the cropping system. To a depth of 90 cm soil nitrate-N (NO_3^--N) was greater in sun hemp (*Crotolaria juncea*) than cowpea or fallow treatments in 2006. However, in the second year there was not a significant difference in soil NO_3^--N at the time of cotton planting. Cotton lint yield was not significantly different in any year the study was conducted.

A dryland study conducted in Queensland, Australia on a vertisol soil, from 1996 to 2004, evaluated the impact on soil chemical properties of adding legumes and non-legumes to a cropping system. Cropping systems included continuous cotton, cotton-grain sorghum, cotton-wheat (double cropped), cotton-chickpea (*Cicer arietinum*), and cotton-wheat were evaluated. Cropping systems did not impact soil pH and organic carbon (Hulugalle et al., 2007). Though amounts did differ among sampling depths they were not significantly different. Crop rotations may not impact soil chemical properties quickly. Long-term studies are required to better understand impacts on soil chemical and physical properties.

Guar overview

Guar, a member of the Leguminosae family, is a drought resistant annual. Guar was introduced to the U.S. from India in 1903 but is believed to originate from wild species within Africa (Mudgil et al., 2014; Tripp et al., 1982). Guar has been grown in India, Pakistan, Australia, and the United States. (Gresta et al., 2013). In the U.S. guar has been grown in Texas, New Mexico, Arizona, and Oklahoma (Abidi et al., 2015; Trostle, 2020a, 2020b). India is the largest exporter of guar with the Rajasthan region being the main production area. India produces 80% of the world’s guar. Increased production of crude oil lead to the U.S becoming the largest importer of guar in the world (Hinson & Adams, 2020; Mudgil et al., 2014; Shrestha et al., 2022) Before the industrial uses of guar were capitalized upon, guar was grown for green manure, human, and animal consumption (Abidi et al., 2015; Hinson & Adams, 2020).

Guar is used in the production of textiles, food, cosmetics, explosives, oil, and gas. A major interest of guar production stems from the multiple uses of galactomannan gum. Galactomannan gum is extracted from guar endosperm. Production begins with the separation of the seed from the pod (threshing). Guar seeds are spherical and smaller in size than a cowpea. These seeds vary in color from tan to deep brown. Excessive precipitation late in the growing season can impact guar seed color, seeds can turn dark brown or black (Abidi et al., 2015). Galactomannan gum production is extracted by fracturing the seedcoat and separating it from the endosperm. The resulting “splits,” mostly endosperm, are finely ground and graded by physical and chemical properties. Byproducts of guar gum include guar meal also called korma and is used in cattle feed. Guar gum acts as a binder and thickener. The viscous gel produced has become a staple in oil and gas extraction since the 1950's (Abidi et al., 2015).

Guar does best in semi-arid environments, receiving on average 25-51 cm of precipitation. Establishment and growth are best suited in soil textures that drain well. (Abidi et al., 2015). The planting dates in the SHP range from mid–May to early July, but it can be planted as late as July 5th in the lower regions in the SHP (Trostle, 2023). Guar is an alternative crop to be planted after a failed cotton crop as a late-season catch crop. Planting depth ranges from 3-4 cm in adequate moisture (Abidi et al., 2015; Tripp et al., 1982; Trostle, 2020b). Seeding density varies from 5-7 kg ha^{-1} (or 174,000-243,000 seeds ha^{-1}). However, plant population is heavily affected by row spacing, irrigation, and germination percentage (Tripp et al., 1982; Trostle, 2020b). Fertilizer applications in guar for optimal nodulation production should consider residual elemental soil concentrations prior to application, recommendation suggest little to no N should be applied to guar for optimal nodule production (Hinson & Adams, 2020). This recommendation depends, however, on adequate *Rhizobium* nodulation which is rarely observed in the SHP and RP. Phosphorous (P) fertilizer application can be a tool for nodulation and root growth, if residual concentrations with the soil is not efficient for production (Shrestha et al., 2022; Tripp et al., 1982).

Compared to other crops grown in the SHP guar requires fewer inputs. A recent study, in Las Cruces, NM, evaluated the economic impact of adding guar to cropping systems within a grower's management system on the SHP (Acharya et al., 2020). Three different rotations compared through simulation analysis include cotton-cotton, grain sorghum-cotton, and guar-cotton. Results reiterate guar requires less inputs than cotton and grain sorghum. Guar also had higher net return and a lower probability of loss within the study.

Guar nodule production

Nitrogen is the most limiting nutrient in agricultural systems. Interest has increased in implementing legumes with capabilities of BNF within management systems to reduce reliance on synthetic fertilizers which may not be economically or environmentally sustainable for producers (Neely et al., 2018; Rose et al., 2022). Guar, like other legumes, has the potential to biologically fix N when nodulation occurs. Nodules production occurs on the roots, when species-specific rhizobia bacteria connect with the root hair; when produced, active nodules assimilate atmospheric N_2 into plant available inorganic N (Hinson & Adams, 2020; Peoples et al., 2009). Guar has difficulty producing nodules as effectively as other legumes (Abidi et al., 2015). Many studies have evaluated different strains of specie-specific *Bradyrhizobium* or *Rhizobium* for guar nodule production, currently the only guar species-specific strain available, CB3035, is sourced from Australian Inoculants Research group (MacMillan et al., 2021).

Studies in recent years evaluate biotic factors that impact guar nodule production and conditions that could optimize seed production. A greenhouse study in Vernon, TX in 2017 evaluated the impact of treatments composed of two soil series (Miles loamy fine sand and Tipton loam), two guar varieties (Kinman and Lewis), and two seed inoculants (Micronoc and USDA 3385) on guar nodulation (Thapa et al., 2018). Inoculants were compared to a third treatment of non-inoculation. This study was replicated twice with four replicates per treatment. Average nodules per plant was significantly higher in the clay soil compared to the sandy loam soil, 24.3 and 8.6, respectively. Guar plants in clayey soil produced more nodules. Guar plants in a sandy soil produced larger nodules per plant. Guar plants in a clayey soil averaged nodule weight was 497 mg per plant, and the sandy soil averaged nodule weight was 583 mg per plant. Guar varieties Lewis and Kinman did not impact nodule amount (17.5 and 15.5 per plant) or nodule weight (516 and 564 mg per plant). Significant differences were not found between inoculant treatments (no inoculant, Micronoc, and USDA 3385) on nodule counts per plant (16.5, 16.0 and 16.9) or weight per plant (536, 558, and 526 mg). From this study it can be assumed soil type plays a larger role in guar nodule production than initially realized. Secondarily, if soil initially contains specie specific *Rhizobium*, inoculants may not benefit nodule production.

A similar greenhouse study conducted in Vernon, TX from 2018-2019 compared three soils (Abilene clay loam, Tipton loam, and Miles loamy fine sand) and different N fertilizer rates (0, 10, 30, and 90 mg N kg^{-1}) impact on guar nodule production (Hinson & Adams, 2020). Four replications were conducted, and guar seed was not inoculated prior to planting. The clay loam with varying N rates produced the least number of nodules and had the lowest nodule weight than all other soils. The 0, 10, 30, and 90 mg N kg^{-1} treatments, nodule weight was 0, 0.32, 0, and 0 mg per plant and nodule amount averaged 0, 0.75, 0, 0, and 0.19 per plant. The loam soil with 0 N applied produced the largest number of nodules and average weight compared to other N rates. The 0, 10, 30, and 90 mg N kg^{-1} treatments, nodule weight was 740.8, 624.8, 454, and 116 mg per plant and nodule amount averaged 24.5, 19, 19, and 14.3 mg per plant. This trend is also seen in the loamy sand with 0 N application producing significantly larger average nodule weight, and while not significant, producing the most nodules averaged per plant. In the loamy sand 0, 10, 30, and 90 mg N kg^{-1} treatments, nodule weight was 507, 305, 274, and 70.5 mg per plant and nodule amount averaged 12.5, 12.2, 11.5, and 9.50 mg per plant. This study reflects the varying results of Thapa et al., (2018) findings that a clayey soil produced more nodules, but a sandy soil produced larger nodules. From this study we can conclude guar produces nodules in area of lower N concentration. However, it is best to base all N application off soil samples for optimal guar nodule production.

Guar production obstacles in the U.S.

Guar is grown for the derivatives of guar seed. Galactomannan gum is a main derivative of guar seed and used in multiple industries. Acreage has declined over time within the U.S., due to the price of imported guar gum to the U.S. (~$2/kg) has been well below historical values ($4-6/kg) (Trostle, 2020b). Unlike major crops in the SHP, guar currently does not have federal program crop insurance in place. However, USDA’s Risk Management Agency is consulting with outside sources to conduct a study (2021-2023) whether insurance programs on guar are feasible in Texas and Oklahoma (Trostle, 2020a). The only U.S processor of guar grain in the U.S. is in Brownfield, TX has resumed operation in 2023 (Guar Resources, 2023) after a two-year hiatus. While guar has the potential to enhance soil chemical properties, requires less inputs, and is widely used in a multitude of industries, planted acreage has not increased (Imel, 2015). The drought-tolerant legume with nitrogen-fixing capabilities, is considered an alternative crop that must overcome numerous challenges before being used across the SHP and RP.

Research Objectives

The overall objective of this research is to evaluate the effect of alternative crop rotations on cotton lint yield and soil chemical parameters on the SHP and RP.

Specific objectives include:

1.Evaluate the effect on cotton lint yields of a two-year rotation of guar and grain sorghum rotated with cotton, in comparison to a cotton monoculture, in the semi-arid Texas SHP and RP.

2. Evaluate the effect of different alternative crop rotations on soil pH, electrical conductivity, nitrate-N (NO_3^--N), P, K, Ca, Mg, S, and Na.

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CHAPTER II

EFFECTS OF ALTERNATIVE CROP ROTATION ON COTTON LINT YIELD AND SOIL CHEMICAL PARAMETERS

Introduction

Upland cotton (*Gossypium hirsutum* L.) is the dominant global natural fiber used in textiles and accounts for 97% of the United States (U.S.) cotton production. Texas is the largest producer of cotton within the U.S. producing 40% of U.S. cotton (USDA-ERS, 2022). The Texas High Plains (THP) region produced half of the 7.7 million bales of cotton produced in Texas in 2021 and is credited with 56% of the nation's cotton acreage (Agriculture, 2021; Plains Cotton Growers, 2021; Plains Cotton Growers, 2022).

The Ogallala Aquifer (OA) is the primary irrigation source for the THP, and the Seymour aquifer is the primary irrigation source for the Rolling Plains (RP). However, decreases in water levels have led cotton producers to revert to non-irrigated agriculture. The Southern High Plains (SHP) and RP are characterized as semi-arid regions with relatively low annual precipitation (466 and 720 mm, NWS, 2021; USA-Facts). In addition, producers have adopted other tolerant crops such as grain sorghum (*Sorghum bicolor* L.) and guar (*Cyamopsis tetragonoloba* L.). These alternative crops typically require less inputs and some produce more residue than a cotton crop. Guar, a legume, also has the potential to biologically fix N (BNF), which could reduce the amount of nitrogen (N) growers might apply (Tripp et al., 1982).

Cropping systems and management practices that use limited precipitation are highly desirable in regions of more predominant semi-arid rainfed acreage. Multiple crop rotation studies conducted have produced inconsistent results. A rainfed study conducted in Halfway, TX reported crop rotations in conjunction with conservation tillage yielded more than conventional cotton (Keeling et al., 1988). A rainfed experiment conducted in New Deal, TX, reported long term (5 years) non-legume crop rotations in conjunction with no till practices did not impact cotton lint yield (Acosta-Martínez et al., 2011). Similar results of no impacts on cotton lint yield were reported by DeLaune et al. (2020) when investigating various cover crop cropping systems and tillage practices study in the rainfed RP.

Guar, a drought tolerant legume is best suited in well drained soils and requires less inputs than a typical productive cotton crop. Galactomannan gum is derived from guar seed, and is the main purpose of production, because it is used in multiple industries including paper, oil, gas, and nutrition. The U.S. is the largest importer of guar, as a result, research within the U.S. has been limited (Abidi et al., 2015; Adams et al., 2020). Tripp et al. (1982) reported a guar-cotton crop rotation increased cotton lint yields up to 15%. Yield benefits were attributed to the guar crop improving soil fertility parameters, specifically adding plant available inorganic N into the soil. This study did not determine if soil chemical properties were impacted by the crop rotation. A recent economic analysis by Acharya (2020) reported a guar-cotton crop rotation increased net return compared to a cotton monoculture or grain sorghum-cotton rotation. While several publications highlight agronomic management and environmental impact from guar, minimal research has been conducted on the THP regarding guar's impact on soil chemical properties and cotton lint yield. (Hinson & Adams, 2020; Pabuayon et al., 2022; Shrestha et al., 2022)

Crop rotation benefits potentially include improving water dynamics, disrupting weed pressure, lowering pathological pressure, and improving soil chemical, physical, and biological properties within a management system. Introducing a crop that produces greater amounts of biomass can potentially decrease erosion and increase soil health (Acharya et al., 2019). Introducing legumes in rotation with cotton can decrease grower dependency on synthetic fertilizers. An experiment conducted in the Southeast of the U.S. reports a legume-cotton crop rotation increased soil nitrate-N (NO_3^--N) compared to a cotton monoculture (Bauer et al., 2009). A long-term experiment (25 years) conducted by Peoples et al. (2017) compared several legumes (field pea (*Piscum sativum*), chickpea (*Cicer arietinum*), lupin (*Lupinus angustifolius*), faba bean (*Vicia faba*), lentil (*Lens culinaris*), and vetch (*Vicia sativia*)) to wheat (*Triticum aaestivum*), barley (*Hordeum vulgare*), or canola (*Brassica napus*) cropping systems from 1989 to 2016 on growers' field across eastern Australia. Results reported greater amounts of soil N in rotations including a brown manure legume (60 ±16 kg N ha^{-1}) compared to non-legume cropping systems (35 ± 20 kg ha^{-1}). Hubbard et al. (2013) concluded in Tifton, GA on a Tifton loamy sand, a greater increase of total N (104%) can be achieved by the addition of sunn hemp (*Crotalaria juncea* L.) in a no-till three-year cropping system.

This study will evaluate the impact of three alternative crop rotations on soil chemical properties and cotton lint yield compared to a cotton monoculture. Adding drought tolerant crops into crop rotations could potentially increase SHP and RP growers' management options. The hypothesis of this project is a alternative crop rotation in rainfed conditions increases cotton lint yield due to improved soil chemical characteristic compared to a cotton monoculture. Objectives include determining whether implementing a guar rotation increases cotton lint yield, and determining whether there are measurable differences in soil chemical parameters or chemistry in a guar rotation compared to a cotton monoculture.

Materials and Methods

This study was conducted over a three-year period (2020-2022) at two rainfed sites of Texas A&M AgriLife Research & Extension Station. The first site was the Texas A&M AgriLife Research & Extension Center in Lubbock, Lubbock County, TX (33.692, -101.824). The soil is an Acuff loam (fine-loamy, mixed, super active, thermic Aridic Paleustolls; USDA-NRCS, 2014b). The previous crop before rotations were established was continuous cotton (2015-2020). The second site was at the Texas A&M AgriLife Agricultural Research Station in Chillicothe, Hardeman County, TX (34.193, -99.528). The soil is an Abilene clay loam (fine, mixed, super active, thermic Pachic Argiustolls; USDA-NRCS, 2014a). The previous crop was grass cover which was cultivated prior to planting in Chillicothe (33.692, -101.824). The soil type is an Acuff loam (fine-loamy, mixed, super active, thermic Aridic Paleustolls) (USDA-NRCS, 2014b).

The four tested crop rotations were: cotton-cotton (C-C), grain sorghum-cotton (GS-C), guar- cotton (GR-C), and guar- grain sorghum (GR-GS). The cotton variety selected for both sites from 2020-2022 was PhytoGen 490 W3FE (Corteva

ArgriScience, Indianapolis, IN), a mid-maturing variety, which is tolerant to 2,4-D choline, glyphosate, and glufosinate (Corteva Agriscience, n.d.). The guar variety was Lewis, a mid to late maturing variety, and the sorghum hybrid selected was Advanta AG 1203 with a mid-maturity.

Blocks were established within a single agronomic field at each site over multiple years to represent multiple short-term rotations at each site (Table 3.1). All treatments were replicated four times within each block. In the first year of each experiment, guar, cotton, and grain sorghum were planted in a randomized complete block design. In the second year of each experiment, cotton and sorghum were planted over the blocks established in the previous season. Two years of data were collected from Chillicothe, and one year of data was collected from Lubbock.

Soil sampling and planting dates varied each year at each site due to the ability to collect data or enter the field (Table 3.2). Seeding density varied each year due to the environmental factors such as moisture availability. Guar seeding density was increased due to decreasing germination percentage in 2021 (same seed lot). Cotton was planted in Lubbock on May 15, 2020, and May 21, 2021. Due to excessive rainfall and cool temperatures emergence was perceived as poor visually, so cotton was replanted June 10, 2020. Guar and grain sorghum were planted June 10, 2020, and 2021. Cotton was planted in Chillicothe on May 21, 2020, and June 8, 2021. Guar and grain sorghum were planted in Chillicothe on May 29, 2020, and June 9, 2021. Cotton, guar, and grain sorghum were planted June 9, 2022.

Plot dimensions at the Lubbock site in 2020-2021 were 15 m long, 12 rows in width, and row spacing was 1 m. Plot dimensions at the Chillicothe site in 2020-2021 were 14 m long, 12 rows in width, and row spacing was 1 m. Plots size was adjusted in Chillicothe to 12 m in length, 12 rows in width, and row spacing was 1 m in 2022.

Seeding densities differed due to environmental differences and germination percentages. Seeding densities for guar were 161,000 seeds ha^{-1} in 2020, 208,000 seeds ha^{-1} in 2021, and 158,000 seeds ha^{-1} in 2022. Seeding rates for cotton were 87,000 seeds ha^{-1} in 2020 and, in 2021, and 111,000 seeds ha^{-1} in 2022. Seeding rates for grain sorghum were 80,000 seeds ha^{-1} in 2020 and 2021, and 79,000 seeds ha^{-1} in 2022.

The annual thirty-year average precipitation for the SHP and RP is 466 and 720 mm, respectively (NWS, 2021; USA-Facts). The Lubbock site received 160 mm in 2020 of rainfall from June through October and 280 mm in 2021 of rainfall from May through October. The Chillicothe site received 342 mm in 2020 from May through October, 304 mm in 2021, and 342 mm in 2022 of rainfall during the growing season from June through October.

Fertilizer application was managed by Texas A&M AgriLife Research and Extension and differed due to available materials each year. The Lubbock site received 90 kg N ha^{-1} (as 32-0-0) on April 9, 2020, and 67 kg N ha^{-1} and 22 kg P_2O_5 ha^{-1} (as 32-0-0) on April 20, 2021. The Chillicothe site received 56 kg N ha^{-1} and 20 kg SO_4^{2-} ha^{-1} (as 33.5-0-0-12) on July 13, 2020, 45 kg N ha^{-1} and 22 kg P_2O_5 ha^{-1} (as 18-46-0) on

April 27th, 2021, and 39 kg N ha^{-1}, 29 kg P_2O_5 ha^{-1}, and 17 kg SO_4^{2-} ha^{-1} (as 27-20-0-12) on March 16, 2022.

Weed pressure was managed by recommendations from Texas A&M AgriLife Research and Extension, and plots were managed by manual weed control when weed pressure was high.

Soil measurements

Soil samples were collected at 0-15, 15-30, and 30-60 cm depths, at the beginning of each growing season before crop rotations were implemented to determine soil chemical properties. The Lubbock site was sampled May 14, 2020, and April 9, 2021. The Chillicothe site was sampled May 20, 2020, April 27, 2021, and April 15, 2022. Samples were collected prior to fertilizer application with a Giddings HDGSRTS hydraulic probe (5.3 cm inner diameter) (Giddings Machine Company, Windsor, CO). Three cores were collected from each plot and mixed into a composite sample for each depth. Soil samples from both sites were then air dried (60 °C), ground, and passed through a <2 mm sieve. Samples were then sent to the Texas A&M University Soil, Forage, and Water testing lab in College Station, TX. for routine analysis.

Samples were analyzed for pH, electrical conductivity (EC), nitrate-N (NO_3^--N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), sodium (Na), iron (Fe), Zinc (Zn), manganese (Mn), copper (Cu), and organic carbon %. Soil pH and EC were analyzed by a mix of one to two ratio of soil and deionized water, a hydrogen selective electrode, and a conductivity probe (Rhoades, 1983; Schofield & Taylor, 1955). Mehlich III extractants were determined by inductively coupled plasma

(ICP) extraction to analyze P, K, Ca, Mg, Na, and S (Mehlich, 1978). Extractable NO_3^--N was determined by a cadmium column with a 1 N KCI solution, followed by a spectrophotometric measurement (Keeney et al., 1982). Soil micronutrients (Fe, Zn, Mn, and Cu) were extracted by a solution of 0.005 M DTPA, 0.01 M CaCl2 and 0.10 M triethanolamine determined by ICP (Lindsay & Norvell, 1978). Organic carbon % was determined by a combustion procedure (McGeehan & Naylor, 1988).

Agronomic measurements

Cotton was mechanically harvested at the Chillicothe site with a John Deere 482 two-row stripper without a burr extractor (Deere & Company, Moline, IL). Seeded lint cotton weights were weighed with an Intercomp CS750 medium capacity hanging scale (Intercomp, Medina, MN) after harvest. Plots were harvested in Chillicothe November 18, 2020, October 26, 2021, and December 19, 2022, respectively. Cotton was mechanically harvested at the Lubbock site with a two-row John Deere 7445 stripper with a burr extractor (Deere & Company, Moline, IL), lint cotton was weighed in the field. Plots were harvested in Lubbock November 12, 2020, and November 18, 2021. Plant population was recorded prior to harvest on the middle four rows harvested from each plot each year. Grab samples of 800 g of cotton lint were collected at harvest and ginned at the Texas A&M AgriLife Research and Extension Center gin in Lubbock, TX, in 2020. Samples were ginned at the USDA-ARS Cotton Gin Laboratory in Lubbock, TX, in 2021 and 2022. Ginned samples were then sent to the Texas Tech University Fiber and Biopolymer Research Institute (FBRI) in Lubbock, TX. Samples were analyzed with a high-volume instrument

(HVI). Analysis included micronaire (MIC), length, uniformity, strength, elongation, reflectance (Rd), yellowness (+b), color grade, and leaf.

Statistical analysis

JMP Pro 16.0 (SAS Institute, Cary, NC) software was used for statistical analysis. Analysis of variance for all parameters was used for four crop rotation treatments in a randomized complete block design with four replications. Cotton lint yield and soil elemental concentrations were compared among treatments within each block using Fisher's protected least significance difference with a critical alpha value of 0.05. Analysis was conducted on the impact of crop rotation on soil chemical parameters and cotton lint yield. The fixed variable was the treatment, and the random variable was the replication. Due to significance, year and locations were separated for analysis for agronomic data and soil parameters.

Results and Discussion

Precipitation and growing degree days

The Southern High Plains and Rolling Plains of Texas are semi-arid regions with dry and hot summers. The Lubbock site had 160 mm of precipitation in 2020 and 280 mm in 2021. Precipitation each year of the study was conducted was less than the 30-year average for the SHP (345 mm/May-September) (Figure 3.2). Growing degree days ($GDD_{15.6}$) accumulation for the Lubbock site was 1,150 in 2020, and 1,141 in 2021 (Figure 3.3). Unpredictable intense weather events early and late in the season were observed at each site during the studies. The extreme periods of precipitation and drought led to inconsistent stands at each site in each year. Intense period of droughts in the region in 2020 and 2022 led to low emergence. Cool and moist conditions at planting in 2021 led to low emergence. This is a common occurrence in rainfed research conducted in similar areas (Acosta-Martínez et al., 2011). The Lubbock site accumulated less $GDD_{15.6}$ in 2020 and 2021 than the suggested amount (1444 °C) for a productive cotton crop.

The Chillicothe site had more precipitation from 2020-2022 than the Lubbock site. Total seasonal precipitation was 342 mm in 2020, 304 mm in 2021, and 304 mm in 2022 compared to a thirty-year average of 460 mm from May through September (Figure 3.1). The GDD 15.6 accumulation for the Chillicothe site was 1,568 in 2020, 1,482 in 2021, and 1,644 in 2022 (Figure 3.3).

Soil characteristics

Soil collected at the Chillicothe site before the implementation of the rotation had an average pH of 7.5, electrical conductivity (EC) of 145 µmhos cm^{-1}, and nitrate-N (NO_3^--N) concentration of 2.8 mg kg^{-1} at a 0-60 cm depth in block one of 2020 (Table 3.3). The second block had an average pH of 7.7, EC of 297 µmhos cm^{-1}, and NO_3^--N of 6.7 mg kg^{-1} at a 0-60 cm depth in 2021 (Table 3.4). In 2020 and 2021, at the 0-15 cm depth P (35 and 33 mg kg^{-1}, respectively), S (9 and 10 mg kg^{-1}, respectively), and Mg (207 and 261 mg kg^{-1}, respectively) was rated moderate according to the Texas A&M AgriLife Extension Soil, Forage, and Water Testing Laboratory (College Station, TX). Potassium (289 and 315 mg kg^{-1} in 2020 and 2021, respectively) and Ca (2840 and 3619 mg kg^{-1} in 2020 and 2021, respectively) were rated very high, and Na (18 and 17 mg kg^{-1} in 2020 and 2021, respectively) was rated as very low.

Soil collected at the Lubbock site before the implementation of the rotation had an average pH of 8.0, EC of 229 µmhos cm^{-1}, and NO_3^--N of 12 mg kg $^{-1}$ at the 0-60 cm depth in block one of 2020 (Table 3.5). In 2020, at a 0-15 cm depth K (392 mg kg $^{-1}$), Ca (4589 mg kg $^{-1}$), and S (21 mg kg $^{-1}$) was rated very high according to the Texas A&M AgriLife Extension Soil, Forage, and Water Testing Laboratory (College Station, TX). Phosphorus (35 mg kg $^{-1}$) was rated moderate, Mg (687 mg kg $^{-1}$) was rated high, and Na (44 mg kg $^{-1}$) was rated very low in 2020, respectively.

Soil characteristics after the first year of crop rotation

Potential benefits of adding alternative crops to a system include reducing erosion, increasing soil organic matter (SOM), and suppressing weeds and pests. Including a legume could potentially increase inorganic N by biological N fixation (BNF), (Rose et al., 2022). The impact of drought tolerant summer legumes on soil chemical and cotton lint yield is limited. Multiple studies evaluated the impact of winter legume cover crops on soil chemical parameters and cotton lint yield. However, in a semiarid environment a winter cover crop has the potential to reduce soil moisture for the summer cash crop, and without timely rainfall or irrigation, the cash crop could experience moisture stress (Burke et al., 2022; DeLaune et al., 2020).

Another concern of incorporating a winter cover crop into a cropping system includes the availability of inorganic N to the next crop (Lewis et al., 2018). Nitrogen cycling is highly impacted by climate and soil biological, chemical, and physical parameters, the concern is the next crop’s demand will not coincide with the release of inorganic N. An insufficient amount of nutrients at pivotal growth stages can hinder plant growth and production, therefore reducing potential return (Grzyb et al., 2021).

Mineralization is impacted by decomposition rates, and environmental factors such as moisture impact decomposition rates, increased moisture can increase the rate of decomposition (Canessa et al., 2021). Another factor that impacts mineralization and decomposition rates is carbon to nitrogen ratios (C: N). Legumes typically have a narrower C:N ratio, therefore residual legume biomass should mineralize more quickly than cereals that may have a wider C:N ratio (Aiosa et al., 2020; Pissinati et al., 2018). We could theorize the rate of mineralization was more rapid in plots that contained guar and could increase nutrient availability. Legume mineralization rates differ across many biotic and abiotic variables within a system, little information is available on the mineralization rate of guar.

While literature of guar-cotton rotations in semiarid environments is limited, a recent study evaluates the impact of guar on soil N in a winter-wheat cropping systems in the Texas Rolling plains. Shrestha et al. (2023) reported greater amounts of NO_3^--N following a guar crop compared to a winter wheat crop found in Chillicothe, TX on a rainfed Tipton loam from 2018-2021 soil samples from a depth of a 0-60 cm depth. However, wheat yields did not significantly increase from a summer guar-winter wheat cropping system in any year. The Chillicothe site averaged pH of 7.3 and EC of 157 µmhos cm^{-1} in 2021. After the first year of the crop rotation significant differences were only found in NO_3^--N at lower depths from 15-60 cm (Table 3.6). Cropping systems containing guar, (GR-C and GR-GS) had increased available NO_3^--N compared to all other cropping systems. At the 15-30 cm depth rotations including guar accumulated greater NO_3^--N (P=0.032), compared to the GS-C rotation, (GR-C (7 mg kg^{-1}), GR-GS (7 mg kg^{-1}), GS-C (3 mg kg^{-1}), and C-C (5 mg kg^{-1}), respectively). A similar response was determined at the lower depth of 30-60 cm, however, systems containing guar had increased NO_3^--N compared to all other crop rotations (P=0.033), (GR-C (6 mg kg $^{-1}$), GR-GS (5 mg kg $^{-1}$), GS-C (3 mg kg $^{-1}$), and C-C (3 mg kg $^{-1}$), respectively). Differences were not found at any depth between crop rotations for pH, EC, P, K, Ca, Mg, S, and Na.

The second block at the Chillicothe site averaged pH of 7.7 and EC of 146 µmhos cm^{-1} in 2022. The second block did not have differences among systems for soil chemical properties at any depth (Table 3.7). Nitrate-N ranged from 6-8 mg kg $^{-1}$ in the 0-15 cm depth, 5-6 mg kg $^{-1}$ in the 15-30 cm depth, and 3-4 mg kg $^{-1}$ in the 30-60 cm depth. Differences were not found at any depth between crop rotations for pH, EC, P, K, Ca, Mg, S, and Na.

The first block at the Lubbock site had an average pH of 8.0 and EC of 227 µmhos cm^{-1} in 2021. Differences were determined for NO_3^--N from a total depth of 0-60 cm, with systems containing guar had a significantly greater NO_3^--N compared to the GS-C rotation (Table 3.8). However, systems containing guar were not significantly greater than the cotton monoculture; GR-C (15 mg kg $^{-1}$), GR-GS (13 mg kg $^{-1}$), GS-C (8 mg kg $^{-1}$), and C-C (12 mg kg $^{-1}$). While not significant (P=0.087) systems containing guar had greater NO_3^--N compared to all other crop rotations in 0-15 cm GR-C (14 mg kg $^{-1}$), GR-GS (12 mg kg $^{-1}$), GS-C (7 mg kg $^{-1}$), and C-C (9 mg kg $^{-1}$). A similar numerical trend is seen within lower depths of 15-30 and 30-60 cm depth: GR-C (16 and 16 mg kg $^{-1}$), GR-GS (14 and 13 mg kg $^{-1}$), GS-C (9 and 9 mg kg $^{-1}$), and C-C (15 and 11 mg kg $^{-1}$).

Incorporating guar within a cropping system can increase inorganic N within a rainfed system, due to N fixation (Abidi et al., 2015). However, environmental conditions are not always conducive to N fixation. The differences in environment may have impacted N fixation, the Chillicothe location was previously in a grass cover and did not receive applications of fertilizer in years prior, and inherently had lower NO_3^--N. Management practices such as fertilizer programs and the ability to inoculant guar can inhibit the capability of guar to biologically fix N within a system. Inherent species-specific rhizobia can improve guar nodule production. Reduced N fixation could be due to the absence or smaller quantity of indigenous soil rhizobia or their ineffectiveness in either site. Other possible explanations may be the difference in soil types between the two sites. Previous experiments report guar produces more nodules in sandy soils (Thapa et al., 2018). The tighter soils in Chillicothe may have hindered nodule production, however, the greater residual inorganic N within the Lubbock site may have reduced nodule production and limited the benefit of guar within the rotation. Quantitative data was not collected on guar nodule production within this study. Historic data reports guar does not nodulate effectively without an inoculant. Due to the availability of inoculum, guar plant may have poor nodule production or none.

Precipitation increases the mobility of NO_3^--N within a profile. Via precipitation throughout the year, NO_3^--N potentially leached to lower depths in the profile (Bronson, 2008). This could be a possible explanation why the lower depths had increased concentrations of NO_3^--N in systems containing guar at the Chillicothe site in block 1. Neely et al. (2018), reported 14 % increase of soil total N at the 0-15 cm depth of a loamy fine sand with a grain sorghum and cowpea (*Vigna unguiculata* L.) intercrop compared to a sorghum monoculture from 2010 to 2011.

Most soil chemical parameters evaluated were not impacted due to the short-term duration of the implemented cropping systems. Research conducted in semi-arid environments has demonstrated the importance of long-term crops rotations to understand the impact upon soil chemical parameters (Acosta-Martínez et al., 2011; Lewis et al., 2018). Due to seasonal weather variability, the impacts of the crop rotation may be delayed compared to more humid regions (Burke, 2018; Thapa et al., 2021). However, with the declining water levels of the Ogallala Aquifer, it is imperative different management strategies are tested in a dryland setting.

Cotton lint yield

Analysis was conducted by year and locations due to the varying environment between years and locations. The crop rotations did not significantly impact second-year cotton lint yields at any site or any year (Figure 3.4). Yield averages for the Chillicothe site in block 1 of 2021 for crop rotations follow as 642, 684, and 760 kg ha^{-1} for C-C, GR-C, and GS-C, respectively. Yield averages for the Chillicothe site in block 2 of 2022 for crop rotations follow as 199, 252, and 290 kg ha^{-1} for C-C, GR-C, and GS-C, respectively. Yield averages for the Lubbock site in block 1 of 2021 for crop rotations follow as 319, 279, and 334 kg ha^{-1} for C-C, GR-C, and GS-C, respectively.

The variability of precipitation in 2021 and 2022 is reflected in the Chillicothe cotton lint yields. Increased drought in 2022 limited cotton lint yield, in contrast to 2021 when adequate precipitations was received. Past research reported soils of high residual NO_3^--N would not be conducive for optimal guar nodule production. Relatively large rates of fertilizer application can inhibit nodule production. Past research suggests relatively low rates of 10 mg N kg $^{-1}$ are optimal to continue plant productivity while limiting the hinderance of nodule production (Hinson & Adams, 2020). The Lubbock site may not have benefited from the addition of legume due to high residual NO_3^--N (15-30 cm 9 mg kg $^{-1}$ and 30-60 cm 12 mg kg $^{-1}$) lower within the profile due to it being traditional cotton production prior years and receiving blanket applications of fertilizer every year. Pabuayon et al. (2021) found in site specific with substantial residual NO_3^--N that plant yield was not impacted by additional N. While not significant a numerical trend is visible at all three sites in all years with the GS-C crop rotation produced greater cotton lint yield than all other rotations. Even though lint yields were not significantly impacted in this research, summer legume crop rotations on loamy fine sand, had greater lint yield than when cotton followed a fallow period in Florence, SC (Bauer et al., 2009).

In recent years, many studies have highlighted guars resilience to heat and water stress, reporting that it could be a suitable crop within the SHP and RP (Pabuayon et al., 2022; Shrestha et al., 2022). Despite heavy use in numerous industries such as oil, gas, textiles, and nutrition, guar is considered a minor crop (Adams et al., 2020; MacMillan et al., 2021). Another factor limiting the adoption of large-scale guar production within the SHP and RP of TX, is the availability of commercial guar inoculum within the U.S. (MacMillan et al., 2021). Furthermore, the prices of guar grain have decreased in recent years, and currently federal crop insurance is not available (Trostle, 2020).

This research demonstrates that cotton lint yields were not impacted by a short-term guar-cotton crop rotation compared to a cotton monoculture. To truly understand the potential benefits, a long-term rotation in multiple sites is required to evaluate the economic sustainability of the system.

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Table 3.1 Crops planted from 2020-2022 at the Chillicothe and Lubbock, Texas sites to evaluate the effect of cropping rotation sequences from cotton, grain sorghum, and guar.

Location	Block	Crop Rotation	2020	2021	2022
Lubbock	1	C-C	Cotton	Cotton	
		GR-C	Guar	Cotton	
		GS-C	Grain Sorghum	Cotton	
		GR-GS	Guar	Grain Sorghum	
Chillicothe	1	C-C	Cotton	Cotton	
		GR-C	Guar	Cotton	
		GS-C	Grain Sorghum	Cotton	
		GR-GS	Guar	Grain Sorghum	
Chillicothe	2	C-C		Cotton	Cotton
		GR-C		Guar	Cotton
		GS-C		Grain Sorghum	Cotton
		GR-GS		Guar	Grain Sorghum

Table 3.2 Soil sampling dates, planting dates, and seeding densities from 2020-2022 at the Chillicothe and Lubbock, Texas site for cotton, grain sorghum, and guar.

Location	Soil Sampling Date	Planting Date	Crop	Seeding Density (seeds ha^{-1})
Chillicothe	5/20/2020	5/21/2020	Cotton	87,000
Chillicothe	5/20/2020	5/29/2020	Grain Sorghum	80,000
Chillicothe	5/20/2020	5/29/2020	Guar	161,000
Chillicothe	4/27/2021	6/8/2021	Cotton	87,000
Chillicothe	4/27/2021	6/9/2021	Grain Sorghum	80,000
Chillicothe	4/27/2021	6/9/2021	Guar	208,000
Chillicothe	4/15/2022	6/9/2022	Cotton	111,000
Chillicothe	4/15/2022	6/9/2022	Grain Sorghum	79,000
Chillicothe	4/15/2022	6/9/2022	Guar	158,000
Lubbock	5/14/2020	5/15/2020	Cotton	87,000
Lubbock	5/14/2020	6/10/2020*	Cotton	87,000
Lubbock	5/14/2020	6/10/2020	Grain Sorghum	80,000
Lubbock	5/14/2020	6/10/2020	Guar	161,000
Lubbock	4/9/2021	5/21/2021	Cotton	87,000
Lubbock	4/9/2023	6/10/2021	Grain Sorghum	80,000
Lubbock	4/9/2022	6/10/2021	Guar	208,000

Figure 3.1 Mean monthly temperature and total monthly precipitation at the Chillicothe, TX site from 2020-2022.

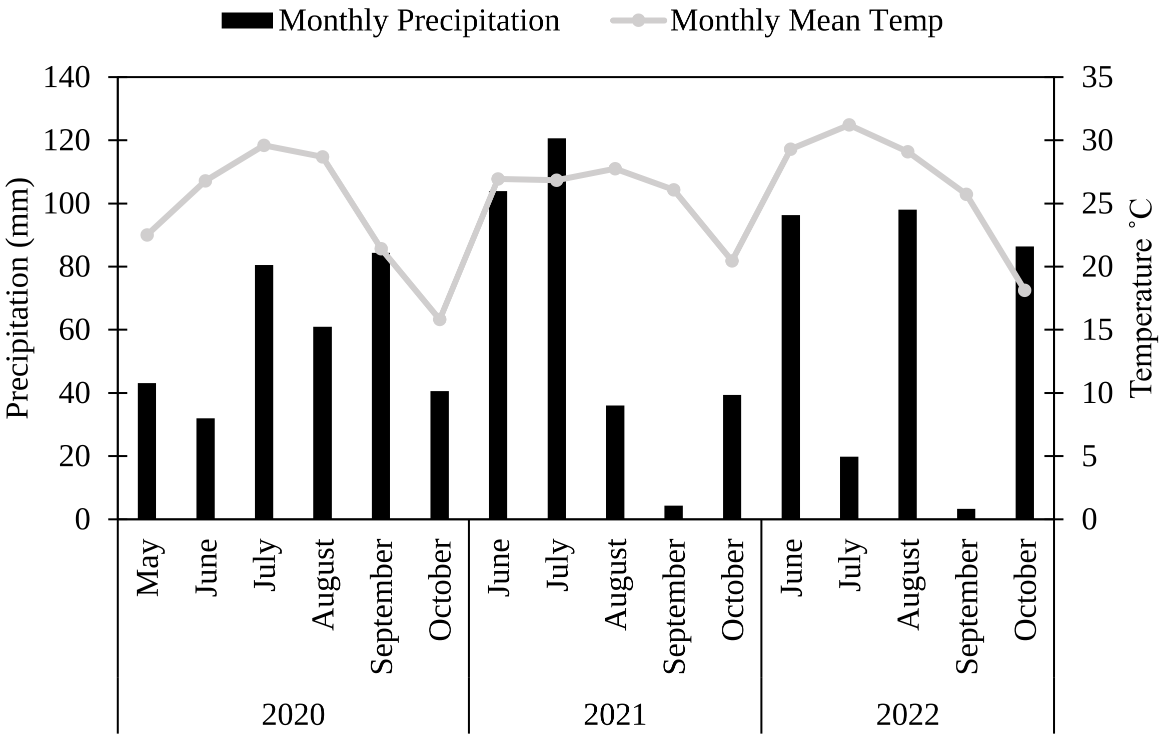

Figure 3.2 Mean monthly temperature and total monthly precipitation at the Lubbock TX site from 2020-2021.

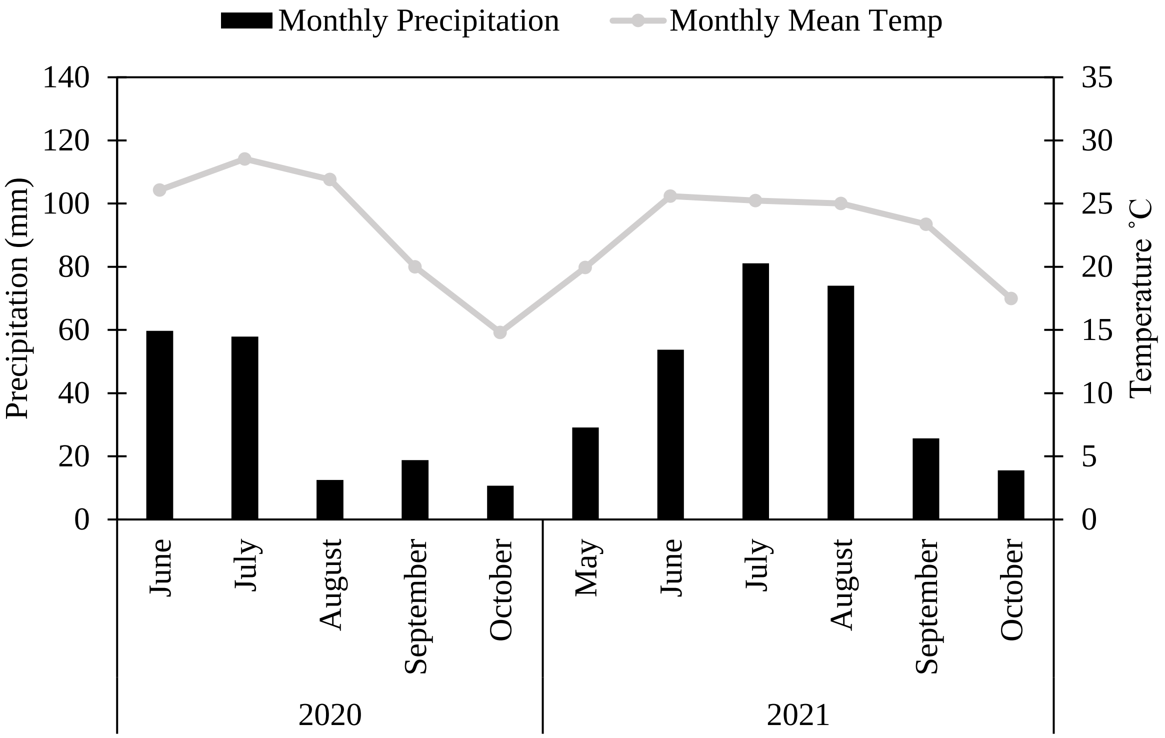

Figure 3.3 Total growing degree days ($GDD_{15.6}$) at the Chillicothe and Lubbock, TX sites from 2020-2022. An accumulation of 1444 $GDD_{15.6}$ is recommended for a productive cotton crop.

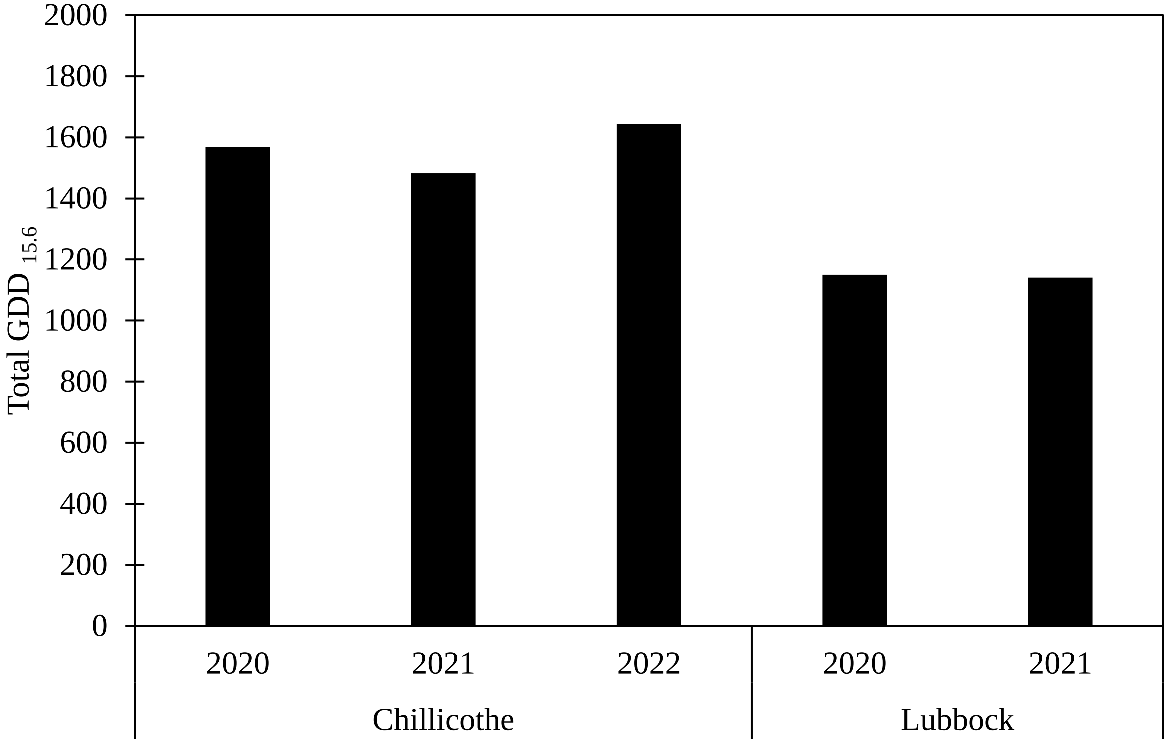

Figure 3.4 Mean cotton lint yield after the second year of the rotation for Chillicothe and Lubbock, TX rainfed sites from 2021-2022. Cotton to cotton, guar to cotton, and grain sorghum to cotton represented by C-C, Gr-C, and GS-C, respectively. Error bars represent standard error of the sample mean.

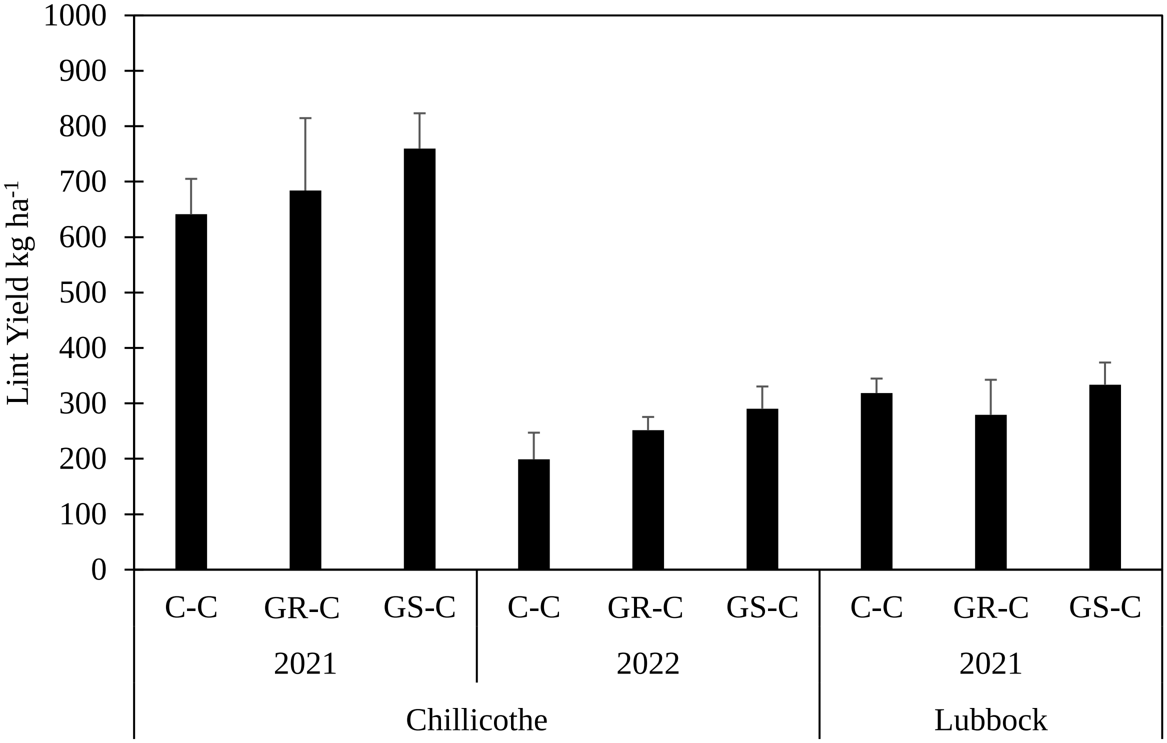

Table 3.3 Soil chemical properties comparison at the Chillicothe, TX rainfed site for block one in 2020. Preliminary soil samples were collected from depths 0-15, 15-30, 30-60 cm before crop rotations were implemented. Electrical conductivity and nitrate-N are denoted by EC and NO_3^--N.

Depth	pH	EC	NO_3^--N	P	K	Ca	Mg	S	Na
cm	-	µmhos cm^{-1}	mg kg^{-1}						
0-15	7.4	114	3	35	289	2840	207	9	18
15-30	7.5	131	3	19	241	3444	244	11	30
30-60	7.5	191	3	9	242	3828	313	12	93
	P-value								
0-15	0.994	0.966	0.421	0.485	0.925	0.943	0.286	0.323	0.278
15-30	0.721	0.229	0.782	0.447	0.785	0.705	0.633	0.480	0.278
30-60	0.737	0.195	0.410	0.613	0.542	0.880	0.395	0.074	0.648

Table 3.4 Soil chemical properties comparison at the Chillicothe, TX rainfed site for block two in 2021. Preliminary soil samples were collected from depths 0-15, 15-30, 30-60 cm before crop rotations were implemented. Electrical conductivity and nitrate-N are denoted by EC and NO_3^--N.

Depth	pH	EC	NO_3^--N	P	K	Ca	Mg	S	Na
cm	-	µmhos cm^{-1}				mg kg^{-1}			
0-15	7.6	173	15	33	315	3619	261	10	17
15-30	7.7	201	3	10	254	4480	315	45	26
30-60	7.6	492	2	2	250	5271	446	212	85
					P-value				
0-15	0.520	0.756	0.771	0.783	0.937	0.979	0.350	0.155	0.139
15-30	0.577	0.741	0.848	0.833	0.821	0.977	0.749	0.545	0.180
30-60	0.445	0.978	0.398	0.395	0.741	0.973	0.456	0.875	0.173

Table 3.5 Soil chemical properties comparison at the Lubbock, TX rainfed site for block one in 2020. Preliminary soil samples were collected from depths 0-15, 15-30, and 30-60 cm before crop rotations were implemented. Electrical conductivity and nitrate-N are denoted by EC and NO_3^--N.

Depth	pH	EC	NO_3^--N	P	K	Ca	Mg	S	Na
cm	-	µmhos cm^{-1}	mg kg $^{-1}$						
0-15	8.0	220	15	35	392	4589	687	21	44
15-30	8.0	187	9	13	321	4444	697	19	62
30-60	7.9	280	12	9	319	6861	685	34	96
	P-value								
0-15	0.907	0.513	0.516	0.315	0.664	0.706	0.286	0.930	0.894
15-30	0.501	0.386	0.646	0.438	0.863	0.439	0.350	0.672	0.697
30-60	0.347	0.552	0.177	0.691	0.923	0.620	0.710	0.050	0.876

Table 3.6 Soil chemical properties comparison at the Chillicothe, TX rainfed site for block one in 2021. Soil samples were collected after the first year of the rotation from depths 0-15, 15-30, 30-60, and 0-60 cm after crop rotations were implemented. Means within soil chemical property with the same letter are not different at $p < 0.05$. Electrical conductivity and nitrate-N are denoted by EC and NO_3^--N.

Depth	Crop	pH	EC	NO_3^--N†	P	K	Ca	Mg	S	Na
cm	Rotation	-	µmhos cm^{-1}				mg kg $^{-1}$			
0-15	C-C	7.3	157	19	36	357	2803	260	3	17
	GR-C	7.0	164	25	43	352	2237	243	3	19
	GS-C	7.1	187	20	46	373	2343	249	2	21
	GR-GS	7.1	169	23	49	390	2258	238	2	18
15-30	C-C	7.5	172	5ab	6	256	3871	342	9	23
	GR-C	7.4	147	7a	15	267	3682	320	8	44
	GS-C	7.4	108	3b	14	293	3696	318	5	33
	GR-GS	7.5	159	7a	9	271	3803	339	8	28
30-60	C-C	7.5	188	3b	1	224	4521	423	9	42
	GR-C	7.3	111	6a	5	226	3424	323	2	18
	GS-C	7.6	174	3b	2	238	4493	385	8	93
	GR-GS	7.5	128	5a	2	255	4143	417	5	36
0-60	C-C	7.4	172	9	15	279	3732	342	7	27
	GR-C	7.2	146	14	24	293	3052	290	5	29
	GS-C	7.4	156	9	21	301	3511	317	5	49
	GR-GS	7.3	152	12	20	305	3401	331	5	27
					P-value					
0-15		0.804	0.743	0.377	0.719	0.680	0.686	0.202	0.634	0.804
15-30		0.958	0.125	**0.032**	0.673	0.344	0.997	0.935	0.873	0.821
30-60		0.767	0.490	**0.033**	0.205	0.779	0.764	0.187	0.685	0.704
0-60		0.619	0.649	0.497	0.767	0.800	0.705	0.451	0.782	0.652

Table 3.7 Soil chemical properties comparison at the Chillicothe, TX rainfed site for block two in 2022. Soil samples were collected after the first year of the rotation from depths 0-15, 15-30, 30-60, and 0-60 cm after crop rotations were implemented. Means within soil chemical property with the same letter are not different at $p < 0.05$. Electrical conductivity and nitrate-N are denoted by EC and NO_3^--N.

Depth cm	Crop Rotation	pH -	EC µmhos cm^{-1}	NO_3^--N	P	K	Ca mg kg^{-1}	Mg	S	Na
0-15	C-C	7.6	91	8	36	544	2990	192	10	11
	GR-C	7.7	94	6	35	534	3275	197	10	11
	GS-C	7.7	97	9	26	461	3460	173	10	9
	GR-GS	7.8	92	6	29	479	3507	173	16	8
15-30	C-C	7.6	119	6	15	503	3431	228	14	22
	GR-C	7.8	123	6	14	493	3777	242	18	36
	GS-C	7.7	133	5	12	455	3645	225	25	13
	GR-GS	7.7	133	6	12	471	3397	194	15	9
30-60	C-C	7.6	194	4	6	455	4476	295	75	61
	GR-C	7.7	153	4	7	457	4100	332	23	123
	GS-C	7.5	289	3	5	449	4663	361	176	25
	GR-GS	7.5	235	3	6	479	4613	334	160	20
0-60	C-C	7.6	135	6	19	500	3632	238	33	32
	GR-C	7.7	123	5	19	495	3717	257	17	57
	GS-C	7.7	173	6	14	455	3923	253	71	16
	GR-GS	7.7	153	5	15	477	3839	234	63	13
		P-value								
0-15		0.728	0.969	0.447	0.502	0.118	0.871	0.519	0.476	0.749
15-30		0.867	0.895	0.911	0.859	0.263	0.974	0.823	0.636	0.308
30-60		0.803	0.856	0.090	0.843	0.967	0.944	0.784	0.743	0.248
0-60		0.804	0.818	0.763	0.773	0.305	0.946	0.909	0.713	0.131

Table 3.8 Soil chemical properties comparison at the Lubbock, TX rainfed site for block one in 2021. Soil samples were collected after the first year of the rotation from depths 0-15, 15-30, 30-60, and 0-60 cm after crop rotations were implemented. Means within soil chemical property with the same letter are not different at $p < 0.05$. Electrical conductivity and nitrate-N are denoted by EC and NO_3^--N

Depth cm	Crop Rotation	pH -	EC µmhos cm^{-1}	NO_3^--N†	P	K	Ca mg kg^{-1}	Mg	S	Na
0-15	C-C	8.0	172	9	25	425	4497	770	10	62
	GR-C	8.0	184	14	25	434	4571	798	12	63
	GS-C	8.0	200	7	19	446	5768	799	13	66
	GR-GS	8.0	215	12	16	421	6632	786	16	79
15-30	C-C	7.9	226	15	9	374	4908	770	13	77
	GR-C	8.0	224	16	14	382	4254	776	13	72
	GS-C	8.0	220	9	6	344	4967	743	13	71
	GR-GS	8.0	216	14	8	393	6017	770	18	83
30-60	C-C	8.0	264	11	5	384	8090	790	20	101
	GR-C	8.0	291	16	7	396	6655	802	28	108
	GS-C	8.0	240	9	6	407	8208	814	22	103
	GR-GS	8.0	270	13	4	367	7750	788	28	111
0-60	C-C	8.0	221	12ab	13	394	5832	777	15	80
	GR-C	8.0	233	15a	15	404	5160	792	17	81
	GS-C	8.0	220	8b	10	399	6314	785	16	80
	GR-GS	8.0	233	13a	9	394	6799	781	21	91
						P-value				
0-15		0.824	0.584	0.087	0.111	0.855	0.053	0.743	0.351	0.237
15-30		0.873	0.987	0.246	0.397	0.413	0.270	0.549	0.468	0.472
30-60		0.744	0.916	0.282	0.443	0.514	0.056	0.502	0.497	0.742
0-60		0.788	0.943	**0.003**	0.281	0.944	0.091	0.749	0.305	0.479

† Mean followed by letters are presented for NO_3^-- N for significant P-values.

CHAPTER III

CONCLUSIONS

The objective of this study was to evaluate and compare alternative crop rotations to a cotton monoculture and determine the effect on soil chemical parameters and cotton lint yield in semi-arid regions of the Southern High Plains (SHP) and Rolling Plains (RP). Including an alternative summer legume within a management system can potentially improve soil chemical and physical parameters, decrease pests, and weed pressure, and provide grazing material for livestock. Guar is a minor crop within the region even though it is considered well adapted for semi-arid environments and can potentially biologically fix nitrogen (N). In this three-year study we compared short term cotton-cotton monoculture to guar-cotton, sorghum-cotton, and guar-sorghum crop rotations at two sites (Lubbock and Chillicothe, TX). We hypothesized a guar-cotton crop rotation would improve soil chemical parameters as well as increase cotton lint yield compared to the monoculture.

The Chillicothe location in the RP had two blocks, one implemented from 2020-2021 and another 2021-2022 in close proximity within the same field. The first block in the second year (2021) of the rotation had greater nitrate-N (NO_3^--N) in guar crop rotations a the 15-30 cm depth compared to the sorghum-cotton crop rotation. At the lowest depth of 30-60 cm cropping systems including guar had significantly greater amounts of NO_3^--N vs. all other rotations. Other soil chemical parameters were not impacted by the short-term rotation in the first block. The second block at the Chillicothe location (2021-2022) did not demonstrate changes to soil chemical parameters. The Lubbock site in the SHP had one block implemented from 2020-

2021, and individual depths did not demonstrate changes to NO_3^-- N by the implementation of guar within a crop rotation. The total depth from 0-60 cm had significantly increased amounts of NO_3^-- N compared to the sorghum-cotton crop rotation. This data suggests guar has the potential to improve NO_3^--N within a management system and could potentially reduce synthetic fertilizer usage. This is in spite of an apparent lack of readily observed guar nodulation. These potential benefits of a guar-cotton rotation did not impact cotton lint yield, compared to the cotton monoculture.

While not increasing cotton lint yield this study suggests a potential benefit of adding a summer legume, by possibly increasing NO_3^--N availability, and therefore reducing reliance on synthetic fertilizers. Further research is needed to evaluate how Ammonium (NH_4^+) can be impacted by the addition of guar within a rotation. Further research is also needed to evaluate economically whether this option is sustainable. However multiple obstacles hinder guar growth in acreage in either region. Guar currently does not have a commercial inoculum available within the US and does not have federal crop insurance for growers. Despite its uses within numerous industries , guar has multiple hurdles to overcome to graduate from a minor crop within either region.