The Effect of Irrigation Scheduling and

Manure Application on a

Sweet Corn/Guar Intercrop

by

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Abstract

Maximizing resource utilization in the semi-arid region of the Texas High Plains is a critical goal. When an input like drip irrigation is supplementing precipitation, intercropping is a cultural practice that can increase resource capture. A greenhouse study and a two year field study were conducted in 2013 and 2014 to determine the suitability of intercropping sweet corn (*Zea mays* var. *saccharata*) with guar (*Cyamopsis tetragonoloba*). The factorial design of the greenhouse experiment had three replications, three cropping treatments of sole sweet corn, sole guar and the intercrop of those two, and two watering treatments. The sole sweet corn produced 21% more green ear yield (GEY, unhusked ears) than the intercropped sweet corn. The lower watering treatment (LOW) produced twice as many ears than the higher watering treatment (HI), but the HI treatment produced 52% more sweet corn GEY than the LOW treatment. At the WTAMU Nance Ranch near Canyon, TX, the factorial design of the field experiment had four replications, three cropping treatments of sole sweet corn, sole guar and the intercrop of those two, two drip irrigation levels and two manure application rates of 22 Mg ha^{-1} yr^{-1} and 67 Mg ha^{-1} 2 yr^{-1}. In 2014, sweet corn fresh ear yield (FEY, husked ears) was higher in the sole sweet corn (0.67 Mg ha^{-1}) compared to the intercropped sweet corn (0.27 Mg ha^{-1}). In 2013, the higher manure rate produced 62% higher total FEY than the lower manure rate, but no differences were observed between the manure application rates in the second year. In 2013, the highest weed dry matter (DM), 5.72 Mg ha^{-1}, was measured in the sole guar treatment with 4.41 and 3.13 Mg ha^{-1} of weed DM measured from the intercrop and sole corn, respectively. As a result of this study, intercropping sweet corn and guar to maximize resource utilization, improve productivity and control weeds in the Texas High Plains is not recommended.

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CHAPTER 1: INTRODUCTION

1.1 Sweet Corn Use and Regions of Production

Sweet corn (*Zea mays* var. *saccarata*) is a vegetable crop grown for human consumption throughout the world. Globally, 9.8 million metric tons (Mg) of sweet corn were produced on 1.13 million hectares (ha) in 2012 (FAO, 2013). The U.S., Mexico, Nigeria, Indonesia, Hungary, South Africa, Peru, Guinea, France and Thailand were the top ten sweet corn producing countries by metric tons produced in 2012 (FAO, 2013). The U.S. was the highest sweet corn producer by mass produced, 4.09 million Mg, and by area harvested, 243,790 ha (FAO, 2013). At harvest, sweet corn can either be sold at a fresh market or be processed to make products like canned or frozen corn (Williams, 2006). Temperate, subtropical and tropical regions all around the world produce sweet corn intended for fresh consumption (Khazaei et al., 2010). Additionally, many developed countries like Australia, Brazil, Canada, China, New Zealand, South Africa and the U.S. grow sweet corn for processing (Williams, 2012).

According to the National Agricultural Statistics Service (NASS) (2013), sweet corn grown in the U.S. in 2013 had a total production value of 1.2 billion dollars. In the U.S., the fresh sweet corn market accounted for 40% of production and 70% of the production value of sweet corn (NASS, 2013). Conversely, sweet corn destined for processing only accounted for 30% of total sweet corn production value although it was grown on more land and had a greater harvest mass than fresh market sweet corn (NASS, 2013). California, Florida, and Georgia produced just over 50% of the fresh market sweet corn and Minnesota, Washington, and Wisconsin produced 79% of the processed sweet corn in the U.S (NASS, 2013). When growing fresh market sweet corn, agronomists measure performance based on number of marketable ears per unit area and are primarily concerned about the quality of whole cobs (Williams, 2012). The U.S. Department of Agriculture standards for sweet corn dictate that marketable U.S. no. 2 grade sweet corn ears destined for the fresh market must be fairly developed, free from smut, decay, and damage caused by birds, insects, or disease, and must be a minimum of 10.2 cm long (USDA, 1992). When managing sweet corn intended for processing, growers measure performance based on mass of ears produced per unit area and the percentage of ear mass accounted by fresh kernel mass (Williams, 2012). The fresh kernel mass is calculated as the difference between the fresh ear yield (FEY), which represents husked ears, and the cob mass (Williams, 2012).

1.2 Guar Use and Regions of Production

Guar (*Cyamopsis tetragonoloba*), also known as the cluster bean, is grown as a vegetable crop, forage crop, grain crop, green manure crop and intercrop (Badran et al., 2013; Gendy et al., 2013; Undersander, 1991). In India and Pakistan, people eat toasted guar seeds, use the plant for medicinal purposes and feed guar to their livestock (Gendy et al., 2013; Undersander et al., 1991). When exported to countries like the USA, Germany, the Netherlands, the U.K., Japan and Italy, guar seed is valued for containing a viscous galactomannan gum, which has uses in the oil mining, textile, cosmetics, pharmaceutical and food industries (Elsheikh and Ibrahim, 1999; Stafford and Seiler, 1986; UP Industrial Consultants Limited, 2003). In 2012, the world demand for guar gum skyrocketed, resulting in a 230% increase in the price of guar and a 75% jump in exports from India (Gresta et al., 2013). Annually, 1.0 to 1.6 million Mg of guar grain is produced from select regions around the world (Gresta et al., 2013). Claiming approximately 80% of production, India leads global guar production, Pakistan follows with 15% of production, and the US, Australia and South Africa contribute the remaining 5% (Gresta et al., 2014).

This crop has also been evaluated as a suitable crop for Mediterranean areas, which cultivate few summer crops due to limited water availability in that season (Gresta et al., 2014). Grown mainly in sub-tropical regions, guar is an attractive alternative crop because it is well adapted to arid and semi-arid climates (Badran et al., 2013; Gresta et al., 2013; Undersander et al., 1991). In the US, guar production is concentrated in North Texas and Southwest Oklahoma (Undersander et al., 1991). However, there is no meaningful crop insurance available for growing guar in the US except from the Noninsured Crop Disaster Assistance Program, which may not be an economical option for producers (Trostle, 2012).

In regions with high rainfall and high humidity, guar is useful as a green manure because grain production is limited (Undersander et al., 1991). In Australia, guar added 218 kg of nitrogen (N) ha^{-1} to the soil-plant system over the course of three years (Undersander et al., 1991). Since it is a short spring-summer crop, guar fits well in a crop rotation with sorghum, small grains or vegetables (Undersander et al., 1991). In India, guar is grown as an intercrop with pearl millet and rotated with pearl millet and other various crops like sesame, mung bean and soybean (National Agrometeorological Advisory Service Centre, 2012; Reddy et al., 2013). However, guar grain production is better when it is the primary crop rather than a catch crop (Trostle, 2012).

1.3 Intercropping

Widespread and cross-cultural use of intercrops demonstrates the numerous and varied benefits associated with intercropping, which is the cultivation of two or more crop species simultaneously in the same field (Echarte et al., 2011). Most producers design intercrops to maximize resource utilization by selecting crops that may fill different leaf canopy layers, occupy different soil layers, demand different concentrations of soil nutrients and have only partially overlapping growing seasons (Fukai and Trenbath, 1993; Trenbath, 1975). With appropriate crop pairings, intercropping can outperform sole cropping of the component crops (Fukai, 1993).

1.4 Irrigation in the Texas High Plains

Since the Texas High Plains region has a high evaporative demand and sweet corn is a high water-use crop, irrigation is essential for allowing sweet corn to reach its full potential in this region (Colaizzi et al., 2008; Garcia y Garcia et al., 2009). In the Northern Texas High Plains, nearly 100% of the land on which dent corn is grown is irrigated (Colaizzi et al., 2008). For that same region in 2000, sprinklers, usually in the form of center pivots, irrigate 72% of irrigated land (Colaizzi et al., 2008). However, subsurface drip irrigation (SDI), which has a water use efficiency equal to or greater than 95%, has been adopted by producers due to intensifying drought, rising energy costs, declining water resources, and government cost-share incentives (Colaizzi et al., 2008; Stewart, 2013). For this study, an above-ground drip irrigation system accommodated the needs of the experimental field and increased water use efficiency 5-35% above a sprinkler or center pivot irrigation system (Fipps and Dainello, 2009).

1.5 Feedlot Cattle Manure Application to Crops in the Texas High Plains

During the years 2005-2008, the Texas High Plains region annually marketed just under 5 million head of cattle, which account for 73.6% of Texas' total fed cattle production value (Amosson et al., 2009). According to the NASS (2014), the number of fed cattle in Texas was 2.73 million head on 1 January 2013. Despite the high variability encountered when measuring cattle feedlot waste, a feedlot steer produces an average of 5.3 kg of harvested manure (dry-basis) each day (Koelsch et al., 2007). Consequently, Texas fed cattle produced approximately 14,469 Mg of harvestable manure on 1 January 2013 (Koelsch et al., 2007; NASS, 2014). A year's worth of feedlot manure from the previous number of Texas fed cattle contains 66,500 Mg of organic N and 64 Mg of nitrate-N (NO_3-N) (Koelsch et al., 2007). Although it would be a feat to use all the manure produced by Texas feedlots, the application of cattle feedlot manure to cropland in Texas represents a valuable source of plant nutrients as well as a means of disposing of feedlot waste.

1.6 Objectives

Exploring agronomic sustainability in vegetable crop production, the objective of this study was to determine the effect of irrigation level and manure application on an organically managed sweet corn/guar intercrop grown in the semi-arid Texas High Plains.

The primary objective was to measure sweet corn yield and guar dry matter (DM) to determine if the combined yield of the sweet corn/guar intercrop outperformed the yield of the sole components. Sweet corn was evaluated primarily as a vegetable crop and guar was evaluated at as a forage crop.

The second objective was to observe how different levels of irrigation and manure application altered the growth of the sole crops and the competitive relationship between guar and sweet corn in the intercrop.

The final objective was to measure weed DM to compare the relative weed suppression in the sole sweet corn, sole guar and intercrop treatments. Originally, no weed control measures were planned, with the expectation that the intercrop would sufficiently compete with the weeds for resources.

CHAPTER 2: REVIEW OF LITERATURE

2.1 Sweet Corn Physiology

Sweet corn is a warm-season vegetable crop that has higher sugar and lower starch content than common dent corn (Lizaso et al., 2007; Wolford and Banks, 2014). These changes in endosperm content result from a genetic mutation at the sugary (*su*) locus (Schultheis, 1998). The three primary types of sweet corn are determined by three different mutations, standard (*su*), sugary enhancer (*se*) and supersweet (*sh2*), that occur at this locus (Wolford and Banks, 2014). Standard sugary varieties accumulate about two times more sugar than dent corn (Schultheis, 1998). Sugary enhancer hybrids accumulate even more sugar than standard sugary types without losing their tenderness and creamy texture (Wolford and Banks, 2014). Supersweet hybrids contain the highest amount of sugars of the three sweet corn types, but have kernels that are less tender and less creamy than the other two varieties (Wolford and Banks, 2014). Around 600 commercial hybrids of sweet corn are available in the U.S. to meet specific crop production and niche produce market needs (Pataky et al., 1998; Williams et al., 2009).

Unlike dent corn, which is harvested at physiological maturity, sweet corn is optimally harvested when the kernels are in milk stage, which is a narrow time period between the blister and dough stages (Lerner and Dana, 2001). Although sweet corn has a small harvest to consumption window, an increase in sugar content widens the allowable time period between the field and dinner table (Schultheis, 1998). Out of the three sweet corn varieties, the sugary enhancer hybrids are the most preferred for fresh consumption because of their high quality and ability to stay fresh for two to four days if refrigerated (Schultheis, 1998; Wolford and Banks, 2014). Since they can remain sweet up to ten days after harvest if cooled properly, supersweet hybrids are most suited for distant markets and have higher flexibility in timing of harvest and handling (Schultheis, 1998; Stall et al., 1989). Due to the differences in endosperm composition, sweet corn has lower rates of germination, emergence and seedling vigor than dent corn, resulting in uneven stands of sweet corn (Lizaso et al., 2007). Additionally, sweet corn differs from dent corn in canopy height and development (Williams and Masiunas, 2006). Due to its unique morphology, sweet corn tends towards prolific ear initiation at the cost of producing marketable ears (Andrew and Weis, 1974). As a result, dissimilar cultural practices like planting density, planting date and harvest timing of sweet corn and dent corn cause agronomists to manage them like completely different crops (Williams and Masiunas, 2006). Although they belong to the same species, sweet corn and dent corn exhibit significant genetic and phenotypic differences.

2.2 Sweet Corn Agronomic Practices

Due to the wide genetic variation among sweet corn hybrids and the global range of regions that grow sweet corn, agronomic practices for sweet corn production do not conform to a universal pattern. Destination market, relative maturity and expected growing season temperatures direct a grower’s choice of an appropriate planting date for sweet corn. Planting density and row spacing are highly dependent on the region, the hybrid of sweet corn being grown and field-specific conditions (Williams and Boydston, 2013). Early and effective weed management is critical for allowing sweet corn to reach its maximum growth potential (Wolford and Banks, 2014). Avoidance of water stress and is essential to optimizing sweet corn yields (Wolford and Banks, 2014). Although they are present in highly variable amounts, organic N and NO_3-N are found in feedlot manure, which can be applied as a fertilizer in dent corn and sweet corn (Tarkalson et al., 2006). As a creative scientist, a producer must understand the environmental and economic factors that influence proper management choices for growing sweet corn.

Unique market demand, flexibility of harvest date and variability of environmental conditions interact to prescribe a planting date and possibly multiple planting dates for sweet corn. As the first supply to meet consumer demand, an early summer harvest of fresh market sweet corn can be highly desirable to growers (Schultheis, 1998). Well-timed subsequent harvests are also important goals for farmers meeting the fresh market demand for sweet corn (Wolford and Banks, 2014). Planting over a range of dates also accommodates the sweet corn processing industry which ideally requires a continuous flow of sweet corn cobs (Williams, 2009). Unless a producer uses a soil warming mulch, sweet corn should not be planted more than 7 to 10 days before the regional average frost free date (Schultheis, 1998; Wolford and Banks, 2014). In the U.S., sweet corn is typically planted from mid-April to early-July (Williams, 2009). However, this wide planting window subjects sweet corn to a host of different biotic and abiotic stresses throughout the five month growing season and results in non-uniform growth and development across planting dates (Garcia y Garcia et al., 2009; Williams, 2008; Williams, 2009).

Relative maturities of sweet corn hybrids stretch from 58 days to 100 days (Wolford and Banks, 2014). Most varieties fall between 70 and 90 days with the earliest maturing varieties having lower quality than the mid-season and late maturing varieties (Schultheis, 1998). In a study analyzing data from 174 fields in the north central region (NCR) of the US, the portion of the production region south of 44°N produced 22.5% higher yields in sweet corn planted before May 3 compared to sweet corn planted after May 3 (Williams et al., 2009). Williams et al. (2009) attributed this to an increase in populations of several serious insect and disease pests of sweet corn that move into fields from the south as the growing season progresses (Williams et al., 2009). On the other hand, warmer soil and air temperatures play an important part in accelerating and optimizing sweet corn development. Growing an 82-day sweet corn hybrid in Illinois, Williams and Lindquist (2007) reported that sweet corn grew 22 cm taller, accumulated 18% more total shoot biomass and produced 43% less leaf area index (LAI) when planted in late June compared to early May. Also, supersweet varieties of sweet corn require a soil temperature at or above 18°C which is 5°C warmer than the standard soil temperature required to germinate dent corn and the other two sweet corn types (Wolford and Banks, 2014). Another caveat to planting date decisions is the level of weed competition in a field. In latitudes higher than 41.9°N in the NCR, Williams et al. (2009) reported 63.2% higher yields in weedy fields when sweet corn accumulated less than 1,044 growing degree days (GDD) than when it accumulated more than 1,044 GDD. The strategic planting of sweet corn varieties with different relative maturities to meet production goals quickly becomes a complex art.

Since they depend on plant available resources like yearly precipitation and soil fertility, planting density and row spacing vary between tropical and temperate, arid and humid locations. Similar to common dent corn, modern sweet corn hybrids are planted at higher densities than past varieties (Williams and Boydston, 2013). In the Midwest, sweet corn population densities range from 40,800 to 64,400 plants ha^{-1} with an average of 56,000 plants ha^{-1} (Williams and Boydston, 2013). Because of poor stand establishment, reported seeding rates in the US are 13-19% higher than target population densities (Williams, 2009; Williams, 2012). Crop seeding levels in the Pacific Northwest usually exceed those of the Midwest by 30-40% (Williams and Boydston, 2013). Studies conducted in countries nearer the equator like Iran and India investigate much higher plant population densities ranging from 60,000 to 148,000 plants ha^{-1} (Abu-Awwad, 1994b; Bhatt et al., 2012; Haghighat et al., 2011; Khazaei et al., 2010; Shanti et al., 2012) Row spacing of sweet corn can fall between 60 and 100 cm with intra row spacing varying based on location and desired plant population density (Mallikarjunaswamy et al., 1999; Oktem et al., 2003; Schultheis, 1998; Stone et al., 2001; Williams, 2012; Wolford and Banks, 2014). Optimal planting depth is 2.5 cm in loamy, silty or clay loam soils and 3.8 cm in light sandy soils (Schultheis, 1998). Thorough seedbed preparation, including disking and harrowing multiple times, is critical to obtaining a full stand of uniform plants (Schultheis, 1998). As a high resource demanding crop, sweet corn must be planted at a density and spacing specifically tailored to a location's ability to meet crop requirements.

2.3 Sweet Corn Response to Irrigation

Occurring in throughout the world, drought induces periods of stress on sweet corn, resulting in less than optimum yields. Supplemental irrigation reduces the severity of water stress experienced by sweet corn grown in both arid and semi-arid climates. To determine the economical use of irrigation water, it is important to understand and quantify sweet corn water-yield relationships as influenced by the method of irrigation, severity of the water deficit, and timing of the water deficit. Since the water involved in crop usage flows through several mediums including the plant, soil, and air, a variety of different methods are employed to indirectly measure crop evapotranspiration. One way to estimate crop water requirements is by measuring Class A pan evaporation (E_{pan}). This equation takes a measurement of daily evaporation from a Class A pan and multiplies it by a coefficient determined by the location of the pan (Allen et al., 1998). Alternately, crop water requirements may be estimated by measuring available soil moisture. In the case of the maximum potential soil moisture deficit (Dp_{max}) equation, researchers actually measure the severity of soil water unavailability (Stone et al., 2001).

In a nine year-long study investigating sweet corn yield responses to surface irrigation in a humid continental climate in Wisconsin, Andrew and Weis (1974) applied supplemental irrigation to sweet corn based on occurrence of rainfall or symptoms of water stress during critical periods of sweet corn development in July and August. This study reported that a high or "optimum" irrigation level averaging 20 cm applied per growing season produced a FEY of 20.5 Mg ha^{-1}, which is a 34% increase over the 15.3 Mg ha^{-1} FEY produced by a low or "maintenance" irrigation level averaging 10 cm applied per growing season (Andrew and Weis, 1974). In seven out of the nine years, the optimum irrigation level resulted in significantly higher yields (Andrew and Weis, 1974). However, yearly weather variation resulted in a wide range of differences between the irrigation treatments from 12.86 Mg ha^{-1} (125% increase) in 1964 to 0.9 Mg ha^{-1} (4% increase) in 1965 and 1971, which are the two years where yields were similar between irrigation treatments (Andrew and Weis, 1974). If supplemental irrigation provides benefit to a study conducted in a humid continental climate, supplemental irrigation certainly has the potential to increase yields in drier climates.

In arid and semi-arid regions, it is important to maximize the efficiency of irrigation, which is affected by the method of irrigation delivery. In a one year study comparing methods of deficit irrigation in an arid region in India, three drip irrigation treatments had higher water use efficiencies (WUE) than a surface irrigation treatment applying water at 80% E_{pan} (WUE of 27.2 kg ha^{-1} mm^{-1}) (Viswanatha et al., 2002). Within the three drip irrigation treatments, the 80% E_{pan} and 60% E_{pan} drip treatments had similar water use efficiencies (32.7 and 33.3 kg ha^{-1} mm^{-1}, respectively) (Viswanatha et al., 2002). In addition, the 40% E_{pan} drip treatment had the highest WUE of 40.0 kg ha^{-1} mm^{-1} (Viswanatha et al., 2002). On the other hand, the 40% E_{pan} drip irrigation treatment produced the lowest FEY (13.2 Mg ha^{-1}), the 80% E_{pan} drip irrigation treatment produced the highest FEY (16.9 Mg ha^{-1}) and FEY was similar between the 80% E_{pan} surface irrigation treatment (14.1 Mg ha^{-1}) and the 60% E_{pan} drip irrigation treatment (14.2 Mg ha^{-1})(Viswanatha et al., 2002).

Experimenting with a wide range of irrigation levels for two years in the Jordan Valley, Abu-Awwad (1994) reported a FEY increase as sweet corn water use (WU) under drip irrigation increased from 25% E_{pan} (2.9 Mg ha^{-1}) to 50% E_{pan} (6.2 Mg ha^{-1}), 100% E_{pan} (14.1 Mg ha^{-1}) and 150% E_{pan} (17.7 Mg ha^{-1}). Narrowing the gap between irrigation levels, Ertek and Kara (2013) reported FEY increase as sweet corn WU under drip irrigation increased from 40% E_{pan} (11.2 Mg ha^{-1}) to 55% E_{pan} (12.6 Mg ha^{-1}), 70% E_{pan} (14.2 Mg ha^{-1}), and 85% E_{pan} (14.7 Mg ha^{-1}). However, there was no difference in FEY between the 85% E_{pan} drip irrigation level and 100% E_{pan} drip irrigation level (14.7 Mg ha^{-1}) (Ertek and Kara, 2013). A two-year study investigating four drip irrigation treatments applied at different frequencies reported a FEY increase between all treatments as percent E_{pan} increased from 70% (7.9 Mg ha^{-1}) to 80% (11.8 Mg ha^{-1}), 90% (12.3 Mg ha^{-1}), and 100% (13.4 Mg ha^{-1}) (Oktem et al., 2003).

Approaching the sweet corn water-yield relationship from a maximum potential soil moisture deficit (Dp_{max}) perspective, Stone et al. (2001) induced and measured soil moisture deficits at different periods of sweet corn development resulting in the following irrigation treatments: fully irrigated control, full deficit control, moderate early deficit, severe early deficit, moderate late deficit and severe late deficit. In a linear regression, Stone et al. (2001) reported a 34 kg ha^{-1} per mm Dp_{max} decrease in FEY ($r^2 = 0.90$; $P < 0.0001$), but did not find an effect of timing of water stress on overall yield response. Although the magnitude of sweet corn FEY response varies throughout these studies, increasing water deficit increases yield loss. However, Oktem et al. (2003) had FEY differences between a 10% change in higher E_{pan} irrigation treatment levels, while Ertek and Kara (2013) had similar FEY responses between the 85% and 100% E_{pan} irrigation treatment levels. Based on the findings of Stone et al. (2001), the frequency of irrigations used in the Oktem et al. (2003) study altered the level of maximum potential soil moisture deficit in each treatment and interacted with the amount of water applied to amplify the differences between treatments. On the other hand, Ertek and Kara (2013) applied their drip irrigation treatments at the same frequency, which caused the sweet corn FEY to respond in a natural growth curve-like fashion.

2.4 Sweet Corn and Dent Corn Response to Manure Fertilization

As an alternative fertilizer to commercial fertilizers, cattle feedlot manure is commonly used to fertilize field crops both domestically and globally (Haghighat et al., 2011; Khoshgoftarmanesh and Eshghizadeh, 2011). Typical application rates range from 5 to 62 Mg ha^{-1} (Amoah et al., 2012; Haghighat et al., 2011; Tarkalson et al., 2006). Containing 0.88-1.87% total N on a DM basis, feedlot manure holds around 77-84% of its total N in organic form, which can be mineralized to plant available forms at rate of 25-56% within the first year (Amoah et al., 2012; Mathers and Stewart, 1974; Tarkalson et al., 2006; Tester, 1990; Zhang et al., 1998; Zhang and Hamilton, n.d.). Along with providing N to field crops, feedlot manure supplies organic matter and macronutrients like phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca) (Amoah et al., 2012; Tarkalson et al., 2006; Tester, 1990). Naturally, carbon content of cattle manure ranges from 22-26%, while P, K, Mg and Ca range from 0.06-0.79%, 0.42-1.94%, 0.29-

0.55%, and 1.33-1.78%, respectively (Mathers and Stewart, 1974; Tarkalson et al., 2006; Tester, 1990; Zhang et al., 1998; Zhang and Hamilton, n.d.). However, manure can contain undesirable components like high levels of sodium (Na) and a high carbon to nitrogen ratio (C:N) that can result in N immobilization (Mathers and Stewart, 1974; Khoshgoftarmanesh and Eshghizadeh, 2011; Tarkalson et al., 2006). As with commercial fertilizers, over-application of feedlot manure resulted in unacceptable levels of NO_3-N leaching at manure application rates as low as 60 Mg ha^{-1} under irrigation (Chang and Entz, 1996). Additionally, Abbott and Tucker (1973) reported the presence of 6.9 and 10.4 ppm of extractable P in a clay loam in Phoenix, Arizona for 22 and 58 Mg ha^{-1} manure treatments, respectively. These two amounts of extractable P were higher than the non-manured control and lower than the highest manure application of 93 Mg ha^{-1} (Abbott and Tucker, 1973). However, Abbott and Tucker (1973) hesitated to attribute cotton lint yield gains strictly to the P content of manure.

Both dent corn and sweet corn respond to increasing levels of manure fertilization. With a yield range of 7.06 Mg ha^{-1} to 11.70 Mg ha^{-1} for different levels of manure treatments, a study conducted in western Iran during 2001 and 2002 reported consistent dent corn dry yield gains of 9%, 33%, 53%, 47% and 73% over the control in plots manured at 6, 12, 18, 24 and 30 Mg ha^{-1}, respectively (Khoshgoftarmanesh and Eshghizadeh, 2011). With respect to yield components, Khoshgoftarmanesh and Eshghizadeh (2011) reported that dent corn responded to lower manure fertilization rates by producing 8-13% more kernels per ear over the control, but the 1,000-seed weight was 3-4% less than the unfertilized control in the lowest manure treatment. On the other hand, the 30 Mg manure ha^{-1} resulted in a 67% higher 1,000-seed weight than the control (Khoshgoftarmanesh and Eshghizadeh, 2011).

For another study in Iran during 2009, Haghighat et al. (2011) reported different sweet corn green ear yields of 10.24, 16.02, and 22.13 Mg ha^{-1} for 0, 25, and 50 Mg ha^{-1} manure treatments, respectively. Investigating the response of dent corn to commercial fertilizer, manure fertilizer and the combination of the two, Amoah et al., (2012) reported no differences in dent corn yield, number of grains per ear, and 1,000-seed weight between the 20 Mg ha^{-1} manure treatment and the unfertilized control. In an irrigated study performed in a semi-arid region of southern Greece in 2005 and 2006, during which 2005 was a favorably wet year and 2006 was an unfavorably dry year, sweet corn yields were lower, ranging from 2.51 to 6.10 Mg ha^{-1}, than the dent corn yields in the previous study (Efthimiadou et al., 2009). Furthermore, sweet corn yield gains due to manure fluctuated more as evidenced by the 57-91%, 82-123%, and 133-190% higher yields than the control in the plots manured at 5, 10, and 20 Mg ha^{-1}, respectively (Efthimiadou et al., 2009). In addition, the 1,000-seed weights for the 5, 10 and 20 Mg ha^{-1} manure treatments were 12-18%, 10-22%, and 16-24% higher than the control (Efthimiadou et al., 2009). Sweet corn DM varied in a similar fashion (Efthimiadou et al., 2009).

In an extension of the study conducted in southern Greece in the years 2005 and 2006, Efthimiadou et al. (2012) reported a 138-175%, 270-272%, and 251-336% increase in weed DM from 37 days after planting (DAP) to 67 DAP for the 5, 10, and 20 Mg ha^{-1} manure treatments, respectively. At 37 DAP, there was an average 7% increase in weed

DM in the 10 Mg ha^{-1} manure treatment over the 5 Mg ha^{-1} manure treatment and there was an average 36% increase in weed DM in the 20 Mg ha^{-1} manure treatment over the 10 Mg ha^{-1} manure treatment (Efthimiadou et al., 2012). At 67 DAP, there was an average 51% increase in weed DM in the 10 Mg ha^{-1} manure treatment over the 5 Mg ha^{-1} manure treatment and there was an average 43% increase in weed DM in the 20 Mg ha^{-1} manure treatment over the 10 Mg ha^{-1} manure treatment (Efthimiadou et al., 2012). Comparatively, final harvest sweet corn DM increased 8% from the 5 Mg ha^{-1} manure treatment to the 10 Mg ha^{-1} manure treatment and 15% from the 10 Mg ha^{-1} manure treatment to the 20 Mg ha^{-1} manure treatment (Efthimiadou et al., 2012). Influenced by variables beyond the control of the researcher, corn yields have varied responses to low and moderate rates of manure fertilization.

In a 2002 to 2003 study irrigating dent corn at 75% of the recommended rate for optimum yields at North Platte, Nebraska, Tarkalson et al. (2006) reported no differences of corn grain yields, which ranged from 10.5 Mg ha^{-1} to 12.5 Mg ha^{-1}, between the recommended rate of manure fertilization (62 Mg ha^{-1}) and double the recommended rate of manure (124 Mg ha^{-1}). Similarly, Zhang et al. (1998) reported no difference between the 56 Mg ha^{-1} and 112 Mg ha^{-1} manure treatments in 1992, the year the 224 Mg ha^{-1} manure treatment was excluded, and no difference between the 112 Mg ha^{-1} and 224 Mg ha^{-1} manure treatments in 1993, the year the 56 Mg ha^{-1} treatment was excluded. Moreover, Mathers and Stewart (1974) reported drastically reduced corn DM for silage in the second year of applying 224, 448 and 896 Mg ha^{-1} of feedlot manure as well as high levels of nitrate in the forage. As manure fertilization rates increase, the marginal response of corn yields decrease.

2.5 Sweet Corn Response to Weed Pressure and Management

Especially in areas where insect pests are not a prominent management issue, weed management in sweet corn is crucial to crop success. Weed interference decreases sweet corn yields in over one-half of sweet corn fields in the Midwest (Williams, 2010). In a study investigating the effect of ragweed (*Ambrosia trifida*) on sweet corn yield traits in Illinois, Williams and Masiunas (2006) reported a maximum predicted loss of sweet corn FEY and marketable ears of 100% at a ragweed density of around 1.3 plants m^{-2}. Using a non-linear regression to compare percent loss of two different yield measurements with increasing ragweed density, Williams and Masiunas (2006) reported a similar yield reduction in boxes of marketable ears and FEY with predicted losses as high as 20% between 0.2 and 0.4 ragweed plants m^{-2}. In a complex analysis of how a ragweed plant's area of influence affect sweet corn yields, Williams (2010) reported that less than 50% of sweet corn plants produced marketable ears within 42 cm of a single giant ragweed plant and an isolated giant ragweed plant resulted in the loss of 35 marketable ears. While plant height, length and ear width decreased as proximity to giant ragweed increased, growing degree days and kernel moisture increased in sweet corn plants closes to giant ragweed (Williams, 2010). For sweet corn plants in closest proximity to giant ragweed (~8 cm), average thermal time to silking was delayed 17%, ear mass was reduced 64% and marketable ear number was reduced 86% compared to weed-competition free plants (Williams, 2010).

In a two year, two location study of sweet corn seeding level suppression of wild proso-millet, Williams and Boydston (2013) used a path analysis model to report a path coefficient of 0.492 for sweet corn crop seeding level and sweet corn LAI and a path coefficient of -0.571 for sweet corn LAI and weed biomass of wild proso-millet. However, Williams and Boydston (2013) reported a path coefficient of 0.628 for sweet corn seeding level and crop height and a path coefficient of -0.312 for corn height and wild proso-millet seed production. Despite the negative correlation of wild proso-millet biomass and seed production to sweet corn seeding levels, the highest sweet corn seeding levels in two locations over two years still resulted in the production of 0.142 kg to 0.497 kg m^{-2} of wild proso-millet DM and 5,800 to 22,400 wild proso-millet seed m^{-2} (Williams and Boydston, 2013). As a result, Williams and Boydston (2013) concluded that while a higher sweet corn seeding level reduces wild-proso millet DM, from a weed management perspective, the magnitude of weed suppression appeared relatively small. With regards to the interaction between maize dwarf mosaic virus and weed interference on sweet corn traits, sweet corn's ability to tolerate multiple stresses was additive during the vegetative phase, but became interactive during the reproductive phase (Williams and Pataky, 2012).

In a study evaluating the effect of two planting dates and the duration of weed interference on sweet corn, Williams (2006) reported that sweet corn tolerance to weed interference is not uniform across the long planting season, with an early May planting suffering a maximum yield loss of 85% compared to a mid-June planting maximum yield loss of 15% due to weeds. In a study investigating the effect of the residual weed community over five different planting dates on sweet corn in Illinois, Williams (2009) reported similar crop stand counts early in the season and at harvest indicating that the residual weed community did not inhibit sweet corn emergence or induce crop mortality. Furthermore, in fields with unmanaged residual weed communities, late May plantings resulted in a 96% loss in green ear yield (GEY) and FEY as compared to early July plantings that resulted in a 23% and 22% loss in GEY and FEY, respectively (Williams, 2009). Using a classification and regression tree model to analyze survey data from over 170 sweet corn growers in the Midwest, Williams et al. (2009) reported the use of interrow cultivation as the primary factor determining higher yields in sweet corn. In addition, if a grower managed weeds with interrow cultivation, sweet corn hybrid maturity became more important than regional latitude in the regression tree (Williams et al., 2009).

2.6 Guar Physiology

Growing 46-102 cm tall, guar is a drought tolerant legume and is characterized by coarse, upright, and bushy growth, with most improved varieties having glabrous stems, leaves and pods (Gendy et al., 2013; Undersander et al., 1991). Researching the DM accumulation of 12 different guar genotypes under irrigated and dryland conditions in Chillicothe, Texas, Stafford (1987) observed higher leaf dry weights and leaf area maintenance during the growing season in day-length sensitive guar genotypes than in day-neutral genotypes. Relative maturities of guar range from 60-90 days for determinate types to 120-150 days for indeterminate types (Undersander et al., 1991). Pod clusters can be found on the main stem or lateral branches and 4-10 cm long pods contain 5-12 seeds, which vary in color from tan to pink to light gray or black (Undersander et al., 1991). Investigating the effect on branching and planting density on guar yield components in southeast Queensland, Beech et al. (1989) report an average individual pod growth rate of 65-75% of the critical rate of supply of carbon assimilate, supporting the results of Menon et al. (1971) which suggested a source limitation to yield, instead of a sink limitation. In a path coefficient analysis of guar yield components for 12 guar cultivars in three different locations, Stafford and Seiler (1986) reported that pods per plant and 100-seed weight positively affected guar grain yield, but were negatively correlated to each other. Requiring mechanical splitting to extract its valuable gum, guar seeds contain about 34% protein, 23% gum and 40% fixed oil (Badran et al., 2013). Considerable variability exists between different guar accessions for traits like days to maturity, plant height, pods per plant and pod length and guar breeding focuses on the development of high-yielding cultivars (Stafford and Seiler, 1986; Sultan et al., 2012;). The most common varieties grown in the US are the Kinman, Lewis, Matador and Santa Cruz varieties (Trostle, 2012). The Kinman variety has less branching, more pods on the main stem, and medium maturity (Trostle, 2012). To improve soil fertility, guar must be nodulated with N-fixing bacteria from the genus *Bradyrhizobium* (Badran et al., 2013; Elsheikh and Ibrahim, 1999; Trostle, 2012).

2.7 Guar Agronomic Practices

Depending on location and many different agronomic practices, guar grain yields vary from 100 to 2,480 kg ha^{-1} (Badran et al., 2013; Elsheikh and Ibrahim, 1999; Gresta et al., 2013; Kalyani, 2012; Rao and Shahid, 2011; Sajid et al., 2009; Stafford, 1987). Agronomic practices influencing this wide yield range include planting method, planting density, planting date, irrigation, rate of fertilizer, *Rhizobium* inoculation of guar seed, and weed management. On the other hand, environmental factors like soil type and seasonal precipitation can also affect guar growth and development.

The proper soil moisture and temperature are crucial for guar stand establishment (Trostle, 2012; Undersander et al., 1991). Guar germinates optimally at 30°C (Undersander et al., 1991). Guar thrives on medium-textured sandy loam to clay loam soils, but clayey soils are not recommended for this crop (Trostle, 2012; Undersander et al., 1991; Whistler and Hymowitz, 1979). In addition, guar tolerates saline soils well (Gresta et al., 2013). Depending on the end use of the crop, guar seed can be broadcast, drilled, and planted with a row planter (Undersander et al., 1991; Whistler and Hymowitz, 1979). At a rate of 20-40 kg ha^{-1}, forage guar is broadcast in irrigated fields but drilled in rows 30-45 cm apart in dryland fields in the Punjab and Rajesthan regions of India (Whistler and Hymowitz, 1979). Effectively utilizing light, available moisture and nutrients, the row sowing method resulted in 20% higher guar forage yields than the broadcast method in Agra, Uttar Pradesh, India (Whistler and Hymowitz, 1979). In the U.S., producers plant guar at a rate of 4.5-6.7 kg ha^{-1} in 90-102 cm rows with a row crop planter (Undersander et al., 1991; Whistler and Hymowitz, 1979). Alternatively, U.S. producers broadcast or drill guar seed at a rate of 13.5 kg ha^{-1} if soil moisture and anticipated precipitation are adequate for a higher plant population (Undersander et al., 1991).

Across all the locations of guar cultivation, planting date ranges from mid-May to August (Gresta et al., 2013; Kalyani, 2012; Kalyani and Sunitha, 2011). Reviewing the results of nine studies primarily conducted in India and Central Asia, Kalyani and Sunitha (2011) found that the planting date that optimizes guar grain yield and yield components falls between July 5 and July 15. Furthermore, Kalyani (2012) reported guar grain yields of 951, 553, 247 and 171 kg ha^{-1} as planting date progressed at two week intervals from the 1^{st} fortnight of July to the 2^{nd} fortnight of August. In the Texas High Plains, the target planting date falls between mid-May and early July (Trostle, 2012). In 2000, early planted guar took advantage of early rains, achieved yields of 1,347 kg ha^{-1}, and out-yielded the later planting dates (Trostle, 2001). Similarly, researchers in Southern Italy reported 10.5% higher yields for four US guar cultivars planted in early May than for guar planted in late June (Gresta et al., 2013). Based on the information given by of Gresta et al. (2013) and Trostle (2012), there are conflicting conclusions for the optimum planting date for guar in arid and semi-arid regions. If planted at the optimum date for a given location, acceptable yields can be achieved in areas with only 254-1016 mm of annual rainfall (Kalyani, 2012; Undersander et al., 1991).

2.8 Guar Response to Irrigation

From Italy to India to the rolling plains of Texas, typical grain yields fall between 500-1,700 kg ha^{-1} for dryland guar and 836-2,500 kg ha^{-1} for irrigated guar (Elsheikh and Ibrahim, 1999; Gresta et al., 2013; Rao and Shahid, 2011; Sajid et al., 2009; Stafford, 1987). Referencing work performed in India, Whistler and Hymowitz (1979) reported green forage yields of 8,000 -12,000 kg ha^{-1} under dryland conditions and 16,000-20,000 kg ha^{-1} under irrigated conditions. In a study of ten irrigated guar accessions under drip irrigation in Dubai, the average dry biomass yield was reported to be 9,500 kg ha^{-1}, with the highest dry biomass yield at 12,800 kg ha^{-1} (Rao and Shahid, 2011). A variety of irrigation amounts and frequencies appear throughout the literature. Rao and Shahid (2011) achieved an average grain yield of 2,170 kg ha^{-1} when irrigating with 1.33 liters (L) plant^{-1} or 10 mm every day until about 35 DAP after which the irrigation rate was doubled until harvest. Elsheikh and Ibrahim (1999) reported grain yields of 906 kg ha^{-1} when irrigating at 7 day intervals. However, a control treatment of guar in a N fertilizer study in Pakistan resulted in a 1,252 kg ha^{-1} grain yield under non-irrigated conditions (Sajid et al., 2009). When timing drip irrigation application via evapotranspiration calculations, Gresta et al. (2013) observed guar grain yields of 1,940-2,480 kg ha^{-1} when irrigating an average of 10 times during the growing season with each irrigation event falling 8 days apart and resulting in an average total irrigation depth of 268 mm. A five year study of guar grown during the 1940s in Arizona revealed that 3-4 irrigations optimized guar performance when using a pre-irrigated seedbed (Whistler and Hymowitz, 1979). Similarly, Trostle (2012) recommended using between 76-152 mm of irrigation which resulted in a guar grain yield range of 898-1,572 kg ha^{-1}. Each additional 25 mm of irrigation adds 112-168 kg ha^{-1} to guar grain yields (Trostle, 2012). With only 2-3 irrigation events totaling 134-138 mm of water, Stafford (1987) obtained an average guar grain yield of 918 kg ha^{-1}, which was a 32% increase over the dryland treatment in Chillicothe, TX. Frequent overhead sprinkler irrigation as used in peanuts grown on the Texas High Plains may even interfere with crucial stages in flower and pod development and resulted in a guar grain yield of 785 kg ha^{-1} (Trostle, 2012). Although guar responds positively to irrigation, dryland conditions may produce adequate yields and excessive irrigation may reduce guar yields.

2.9 Guar Response to Fertilizer and Inoculation

Like all plants, guar responds to fertilization, but guar can also benefit from inoculation. Optimizing the symbiotic relationship between guar and N-fixing bacteria, inoculation of guar seed with a species from the genus *Bradyrhizobium* is a means of increasing the N available to guar plants (Undersander et al., 1991). The *Bradyrhizobium* bacteria benefit from the protection and energy supplied by the guar roots and the guar benefits from the bacteria's biological fixation of atmospheric N to plant available N (Sajid et al., 2009). Studying the effect of four different *Bradyrhizobium* strains on five guar cultivar grain yields, Elsheikh and Ibrahim (1999) reported an average 10% increase over the control in grain yield associated with the use of bacterial inoculation.

In a study on the effects of both inoculation and fertilization in Egypt, Badran et al., (2013) observed that guar grain yield doubled when inoculated with *B. japonicum* and had a seven to eight-fold increase over the control when fertilized with N, P and K to meet 100% of its nutrient requirements. On the other hand, guar biomass per plant increased 180% when inoculated with *B. japonicum,* but it increased 220% when fertilized to meet 100% of its nutrient requirements (Badran et al., 2013). Interestingly, none of the intermediate combinations of fertilization and inoculation of guar outperformed the full fertilization treatment of guar (Badran et al., 2013). In a study applying N in the form of ammonium sulfate, guar grain yields were 1,252 kg ha^{-1}, 1,350 kg ha^{-1}, 1,461 kg ha^{-1}, 1,548 kg ha^{-1} and 1,755 kg ha^{-1} and increased significantly as N application increased from 0, 18, 22, 26 and 30 kg N ha^{-1}, respectively (Sajid et al., 2009). Unlike soils and environments in Asia, the rolling plains of Texas have poor nodulation of guar, even when seed has been inoculated (Trostle, 2012).

2.10 Guar Response to Weed Pressure and Management

Since they grow slowly, young guar plants are particularly susceptible to weed problems (Undersander et al., 1991). Both Trostle (2012) and Undersander et al., (1991) strongly discouraged planting guar in weedy fields, especially fields with perennial weeds. In addition, mechanical cultivation to keep weed pressure at bay during the growing season is recommended (Undersander et al., 1991). Alternately, both Trifluralin and Clethodim are herbicides approved for use in guar (Trostle, 2012). However, both Trifluralin and Clethodim primarily target grasses, which can be a problem in a grass/legume intercrop (Greenbook, n.d.).

2.11 Intercropping

In intercropping studies, researchers use the land equivalent ratio (LER) to assess the productivity of an intercrop relative to the productivity of the corresponding sole crops (Fukai, 1993). According to Addo-Quaye et al. (2011) the equation for LER is:

$$LER = (Y_{ij}/Y_{ii}) + (Y_{ji}/Y_{jj})$$

where Y is the yield per unit area, Y_{ii} and Y_{jj} are sole crop yields of the component crops i and j and Y_{ij} and Y_{ji} are the intercrop yield. However, the accurate computation of LER is heavily dependent on achieving maximum yields of the sole crops at optimum densities (Fukai, 1993). Less than optimum yields of the sole crops can result in an over-estimation of intercrop efficacy (Fukai, 1993). Intercrop mixtures are tailored to best utilize photosynthetically active radiation (PAR), soil nutrients, soil moisture and the competitive and complementary effects of the component crops.

The selection of two or more species or cultivars for an intercrop hinges upon the fine balance of how the species interact competitively and complementarily (Midmore, 1993). Where competition amplifies the two crop's demand for the same resource, complementarity attempts to minimize competition (Midmore, 1993). Farmers using an intercropping system aim to delay the crossover point between complementarity and competition to maximize the performance of each component crop (Midmore, 1993). The competitive ability of each component crop is determined by inherent qualities of the species (like plant height), relative freedom from pests or disease, and agronomic manipulation (like plant density) performed by the producer (Fukai and Trenbath, 1993). This principle can be problematic if the dominant species out-competes the other component crop, which is then suppressed completely or cannot produce a viable crop yield (Fukai and Trenbath, 1993).

There are two general types of intercropping: replacement and additive. Usually favoring a higher level of complementarity, replacement intercropping occurs when plants of a component crop in sole cropping are replaced by those of another component. Strip cropping by alternating three rows of dent corn with three identically spaced rows of soybean is an example of a replacement intercrop. Promoting a higher level of competition, additive intercropping increases plant density by adding a component crop to another component that is in the same arrangement and plant density as when sole cropped (Fukai and Trenbath, 1993).

Alley cropping of groundnuts between rubber trees demonstrates additive intercropping (Trenbath, 1975). In addition to modifying the spatial arrangement of the intercrop, producers can customize the temporal use of resources (Fukai and Trenbath, 1993). Fukai and Trenbath (1993) review the benefits of pairing crops with different growth durations and not that crops having similar growth durations derive less benefit from being intercropped. Additive intercropping and intercropping of species with similar growth durations may increase the possibility of resource ‘over-capture’ (Fukai and Trenbath, 1993). Since the management of each intercrop combination depends on the individual needs of the component crops, there is no universally correct way to intercrop. Instead, there are general crop physiologic and agronomic principles which guide the practice of intercropping. While it holds the potential to increase sustainability, intercropping systems have increased complexity which requires a higher level of management knowledge and labor with a less immediate and guaranteed return as compared to intensive sole cropping (Trenbath, 1999).

2.12 Intercropping to Control Pests and Diseases

By altering the host plant quality, directly affecting the attacking organism and indirectly affecting the attacking organism through predators and parasites, intercropping has variable effects on the incidence and spread of pests and diseases (Trenbath, 1993). Through intercrop competition, host plants may become less attractive to pests. In 1990, Gold et al. observed fewer cassava whiteflies on suppressed cassava plants in a cassava and cowpea intercrop possibly because the smaller plants were less effective interceptors of the weakly-flying insects (Trenbath, 1993). On the other hand, the level of competition may cross a threshold where suppressed plants become more susceptible to attack (Trenbath, 1993). Thinner cuticles and a lower carbohydrate metabolism undermine natural plant defense and recovery mechanisms (Trenbath, 1993). Even a perceived benefit like increased N content in a grain crop from a cereal and legume intercrop may boost population growth of pests like aphids (Trenbath, 1993). Intercrops may directly affect attacking organisms by interfering with visual and olfactory search cues for host plants, reducing the time spent on host plants due to the presence of non-host plants, and lowering the survival and fecundity of the pests (Trenbath, 1993). For example, the odor of shallots prevents carrot root flies from finding carrot plants interspersed with the shallots (Trenbath, 1975). Pest population dispersion and colonization is frustrated by regular encounters with non-host plants and this effect is amplified for pathogens, nematodes and weakly flying insects that disperse in a more random fashion (Trenbath, 1993). Unfortunately, intercrops are not invulnerable to generalist insect herbivores (Trenbath, 1993).

Similar to host quality modification by intercropping, indirect effects of intercropping on attacking organisms through predators and parasites yields varied responses (Trenbath, 1993). Perennial crops or plants with nectar are more likely to attract and harbor pest predator and parasite populations which can keep crop pests in check (Trenbath, 1993). In the Philippines, the peanuts in a peanut and maize intercrop provided an adequate habitat for lycosid spiders, which were more numerous in the intercrop than the sole crop and preyed on stalk borer larvae (Trenbath, 1993). On the other hand, a sole maize crop contained a greater abundance of predacious coccinellid beetles than the intercrop (Trenbath, 1993). Not only preying on corn borer eggs, the coccinellid beetles also had access to higher densities of evenly dispersed pollen and aphids in the sole maize crop (Trenbath, 1993). Since a high level of variability is observed in how intercrops affect crop pests and diseases, each interaction between attacking organisms and cropping systems should be evaluated on a case by case basis (Trenbath, 1993).

2.13 Intercropping Advantages

The primary benefit of intercropping is derived from a higher resource use efficiency which typically results in higher aggregate yields and a higher LER. However, there are other potential benefits to intercropping besides yield improvements (Trenbath, 1975). First of all, cultivating two crops instead of one is one step towards field diversity, which contributes to a lower risk of crop failure (Trenbath, 1999). This is mainly due to the well-documented compensatory effects of intercropping, whether in response to biotic stresses like pest attack or abiotic stresses like varied nutrient distribution throughout a field (Trenbath, 1975; Trenbath, 1993). This principle is most effective when the stress occurs before the unharmed component crop nears maturity (Trenbath, 1993). Especially in additive intercrops with a short understory component, additional soil cover can reduce erosion (Midmore, 1993). Repeatedly, experiments aiming to raise productivity under conditions of sustainability report the greater complementarity of intercrops in utilizing natural resources at low input levels (Midmore, 1993). Certain crops like squash are particularly desirable as in intercrop component because of their ability to effectively suppress weeds (Fujiyoshi, 2007). Indicating its allelopathic effects, the squash and corn intercrop had 90% and 70% less total weed biomass than the corn monocrop alone and the corn monocrop shaded by artificial leaves created to simulate the shading caused by the squash leaves, respectively (Fujiyoshi, 2007). Additionally, the corn yield of the intercropped corn was on par with the monocropped corn (Fujiyoshi, 2007). Taking advantage of the N produced by rhizobium nodulation on leguminous plants, a popular intercrop combination is the pairing of a legume with a non-legume (Midmore, 1993). Since legumes can create their own N supply, the non-legume component responds more competitively to N additions to the intercrop (Midmore, 1993). As a result, multiple studies examining the response of cereal and legume intercrops to N fertilization suggest that the intercropping efficiency of a cereal and legume intercrop is greater under low fertility than high fertility conditions (Midmore, 1993). Despite the higher level of management required to maintain them, intercrops can increase crop system diversity, improve soil stability, increase productivity of low input systems, suppress weeds, and reduce N fertilizer inputs through the use of legumes.

2.14 Intercropping Corn with Legumes

Although instances of an intercrop of sweet corn and guar are absent from the literature, dent corn and sweet corn have been intercropped with other various legumes like alfalfa, mungbean, soybean, and southernpea. In a three-year study of intercropping perennial alfalfa with dent corn, Zhang et al. (2011) report alfalfa and sweet corn biomass LERs of 0.98, 0.88, 0.96 and 1.12 in 2007, 1.04, 1.06, 1.07 and 1.05 in 2008, and 1.08, 1.19, 1.26 and 1.24 in 2009 for the alfalfa to dent corn mixing ratios of 33:67, 43:57, 50:50, and 55:45, respectively. The three lower mixing ratios increased with each successive year ($P < 0.05$), but only the highest alfalfa to dent corn mixing ratio had an LER > 1.0 in all three years (Zhang et al., 2011). In a mungbean and sweet corn intercrop grown in Iran, Sarlak et al. (2008) report mungbean and sweet corn biomass LERs of 1.03, 0.94, and 0.97 for the mungbean to sweet corn mixing ratios of 25:75, 50:50, and 75:25, respectively. Unlike Zhang et al.(2011) and Sarlak et al., (2008), Addo-Quaye et al. (2011), Echarte et al. (2011), and Francis and Decoteau (1993) calculate LER from the grain yield of both the legume and maize. While holding the dent corn population constant over two different soybean densities in Ghana, Addo-Quaye et al. (2011) report the three highest LERs, which ranged from 1.37 to 1.42 in the major season and 1.31 to 1.56 in the minor season, from the doubled soybean density treatments out of ten soybean density by planting date combinations. However, the major season favored LERs from the doubled soybean density in the treatments where soybean was planted either before or simultaneously with the dent corn (Addo-Quaye et al., 2011). But the minor season, during which the experiment was irrigated once a week, favored LERs from the doubled soybean density in the treatments where dent corn was planted before or simultaneously with the soybean (Addo-Quaye et al., 2011). For both seasons, the dent corn component of the intercrop had a numerically larger contribution to LER, but in the doubled soybean density during major season, the soybean component influenced the LER more than the dent corn (Addo-Quaye et al., 2011).

While keeping the soybean population constant over two different maize densities, Echarte et al. (2011) reported that the LER of the soybean and maize intercrop increased 5% or remained constant as the ratio of soybean plants to maize plants increased. Intercropping sweet corn in South Carolina at about half the plant population used in the previous dent corn studies, Francis and Decoteau (1993) report an LER for southernpea and sweet corn yield of 1.26, 1.32 and 1.24 for the high, medium and low sweet corn populations, respectively. Out of these five studies, the only leguminous crop to demonstrate competitive dominance over corn was alfalfa, according to three different competition indices (Zhang et al., 2011). While corn is the stronger competitor in corn-legume intercrops, the relative success of the leguminous component usually has a stronger influence on the LER than the corn component, which is consistent with Fukai and Trenbath's (1993) discussion of intercrop productivity, dominance and suppression.

CHAPTER 3: MATERIALS AND METHODS

3.1 Greenhouse Experiment

A greenhouse study was conducted at the WTAMU Greenhouse in Canyon, Texas in the late summer of 2014. Eighteen buckets were filled to the top with 49,554 cubic centimeters (cm) of potting mix (Miracle-Gro® Moisture Control® Potting Mix, formulated from sphagnum peat moss, processed forest products, compost, coir, perlite, a wetting agent, and fertilizer in the following amounts: 0.21% N, 0.11% P_2O_5, 0.16% K_2O). Each bucket (experimental unit, EU) had a surface area of 0.31 m^2. There were three blocks of six buckets and each block contained combinations of three different crop treatments and two watering levels.

Planting of both sweet corn and guar occurred on 25 July 2014. In the sole sweet corn and intercropped treatments, the sweet corn variety ‘Bodacious’ (Pioneer Seed) was planted at six seeds per EU. On 5 and 8 August 2014, sweet corn plants were thinned at the V1-V2 stage to two sweet corn plants spaced 20 cm apart. In the sole guar and intercropped treatments, the ‘Kinman’ variety of guar was planted at twelve plants per EU. On 5 and 8 August 2014, guar plants were thinned to four plants per EU spaced evenly around the corn plants or across the bucket surface. At the sweet corn V6 stage on 19 August 2014, wooden dowels were tied to the young corn plants for support.

Before planting, all buckets were watered and brought to field capacity by adding 8.83 L to each bucket. After planting, irrigation amounts were measured and applied manually in two equal doses per week. The high watering level (HI) treatment received 4.2 L per week, the equivalent of 25 mm of irrigation per week, until the corn plants reached the V6 stage on 19 August 2014. After that, the HI treatment received 8.4 L per week, the equivalent of 51 mm of irrigation per week, until harvest. This resulted in the equivalent of 483 mm of water added to the HI treatment, except in the sole guar buckets, which received only 203 mm (Table 3-1).

Table 3-1. Greenhouse watering level treatments.

	Depth Equivalent of Total Water Applied
	mm
HI Treatment	
Corn	483
Intercrop	483
Guar	203
LOW Treatment	
Corn	279
Intercrop	279
Guar	191

When the soil in the buckets became partially saturated with water, the sole guar treatments were not watered for a three week period between 6 and 25 September 2014 and then only the low watering level (LOW) of guar was resumed for two weeks until harvest. The LOW treatments received the equivalent of 25 mm of irrigation per week during the entire growing season. This resulted in the equivalent of 279 mm of water added to the corn and intercrop treatments in the LOW treatment and 191 mm of water added to the sole guar treatment in the LOW treatment (Table 3-1).

All plants from each EU were harvested on 14 October 2014, 81 DAP. At harvest, corn plants were cut at the soil surface and measured for plant height. Corn ears were weighed with husks (green ear yield) and evaluated for marketability. Only marketable ears were husked, re-weighed (fresh ear yield) and separated from the biomass samples for drying and additional yield measurements. All plant samples were dried at 70° C to constant weight.

The greenhouse data were analyzed with SAS 9.3 software using PROC ANOVA ($\alpha = 0.10$) (SAS Institute Inc., 2011). Where applicable, greenhouse data means were separated using Tukey's HSD ($\alpha = 0.10$). Sweet corn yield data from marketable ears only in the HI treatment were analyzed using PROC TTEST ($\alpha = 0.10$).

3.2 Field Experiment

3.2.1 Experimental Design

A field experiment was conducted in 2013 and 2014 at the WTAMU Nance Ranch, located 11.3 km east of Canyon, Texas. The site had an Olton clay loam soil type. The experimental field was composed of 48 3.05 m x 6.10 m plots (experimental unit) blocked by irrigation with the cropping system and manure fertilizer levels randomized by strips within irrigation block (Figure 3-1). The east block had the conventional irrigation treatment and the west block had the phase irrigation treatment. Cropping strips ran east to west and manure fertilization strips ran north to south. Cropping system treatments were sweet corn alone, guar alone and the intercrop of sweet corn and guar. Manure application treatments were either 22 Mg ha^{-1} yr^{-1} or 67 Mg ha^{-1} 2 yr^{-1}.

Figure 3-1. Experimental plot design showing irrigation blocks, randomized strip treatments of cropping system and manure fertilization, and assigned plot numbers for the field experiment in 2013 and 2014.

North

W: Crop Assignment	Manure Fertilization				Manure Fertilization				E: Crop Assignment
	67 Mg ha^{-1} 2 yr^{-1}	22 Mg ha^{-1} yr^{-1}	22 Mg ha^{-1} yr^{-1}	67 Mg ha^{-1} 2 yr^{-1}	67 Mg ha^{-1} 2 yr^{-1}	22 Mg ha^{-1} yr^{-1}	67 Mg ha^{-1} 2 yr^{-1}	22 Mg ha^{-1} yr^{-1}	
Guar	8	7	6	5	4	3	2	1	Corn
Corn	16	15	14	13	12	11	10	9	Intercrop
Guar	24	23	22	21	20	19	18	17	Guar
Intercrop	32	31	30	29	28	27	26	25	Corn
Corn	40	39	38	37	36	35	34	33	Guar
Intercrop	48	47	46	45	44	43	42	41	Intercrop
	↑ Phase Irrigation Block ↑				↑ Conventional Irrigation Block ↑				

South

Due to the dry conditions of the seedbed during both years, the field received 32 mm and 122 mm of pre-irrigation between 1 and 3 June 2013 and between 15 and 16 May 2014, respectively. For seedbed preparation in 2013, all plots were tilled twice with a single tooth sub-soiler (King Kutter Sub-Soiler Sub-Y, King Kutter Inc., Winfield, AL) and disked with a disk harrow (King Kutter Box Frame Disc Harrow, Model# 18-20-CBF, King Kutter Inc., Winfield, AL). Due to problems with the seed drill (Great Plains Solid Stand 3P500, Great Plains Manufacturing, Salina, KS), the sweet corn seed planted on 7 June 2013 had an insufficient stand. Before the second planting, the experimental plot was sprayed on 26 June 2013 with a small field tank sprayer (#64 Tank Band 2x70 T Bolt 100 L&G, Wylie Manufacturing Company, Petersburg, TX) containing recommended rates of 2, 4-D and dicamba (Ortho® Weed-B-Gon Weed Killer for Lawns Plus Crabgrass Control Concentrate, Scotts Company LLC, Marysville, OH) as well as glyphosate and diquat dibromide (Roundup® Weed and Grass Killer Concentrate Plus, Monsanto Company, Marysville, OH). Following chemical application, the field was disked and replanted on 1 July 2013. For seedbed preparation in 2014, plots were manually sprayed on 16 May 2014 with a small hand-held tank sprayer containing 2, 4-D and dicamba (Weed-B-Gone™ Crabgrass Control) at recommended rates.

Manure application rates were 22 Mg ha^{-1} per year and 67 Mg ha^{-1} per two years. In the first year, both manure treatments were applied to the field on 5 June 2013. In the second year, only the 22 Mg ha^{-1} treatment was applied 22 May 2014. Each manure application was applied with a manure spreader (H&S Model 80 Manure Spreader, H&S Manufacturing, Marshfield, WI) and was disked into the field afterward with a disk harrow. No analysis was run on the manure applied to the field. However, Mathers et al. (1972) measured manure from 23 feedlots and based on the averages of these, it can be estimated that harvested feedlot manure has a moisture content of 34.5%. Also based on the estimates found in Mathers et al. (1972), 295 kg of N, 117 kg of P, and 330 kg of K were applied with each application of the 22 Mg ha^{-1} manure treatment and 898 kg of N, 355 kg of P, and 1,005 kg of K were applied in the single application of the 67 Mg ha^{-1} manure treatment.

The sweet corn variety, ‘Bodacious’ (Pioneer Seed), which has a relative maturity of 75 days, was planted at a rate of 62,000 seeds ha^{-1} with 76 cm rows on 1 July 2013 and 22 May 2014 with a 4-row crop planter (12 cell plate and 14 tooth distance gear on a Cole 12MX Multiflex Planter/Fertilizer, Cole Planter Company, Albany, GA). Due to uneven stand establishment both years, manual planting on 10 and 12 July 2013 and 13 June 2014 was performed to fill in row gaps for a target rate of 124,000 seeds ha^{-1}. ‘Kinman’ guar seed was manually broadcast in the plots with a seed broadcaster (Scotts® HandyGreen® II Hand-Held Spreader, Scotts Company LLC, Marysville, OH) at a rate of 26,652 seeds ha^{-1} on 1 July 2013 and 23 May 2014.

3.2.2 Irrigation Design

The irrigation water source was the West Texas A&M University Nance Ranch well. Irrigation was delivered via a 5 cm mainline pipe that ran north to south between the two irrigation blocks and had 12 valves (6 to a side) attached to a total of 48 drip hoses that were 24 m in length. Forty emitters were spaced 61 cm apart on each drip hose and delivered 7.58 L hr^{-1} $emitter^{-1}$. Although all precipitation alters the rate of evaporation at the soil surface, the Texas High Plains has a high evaporative demand. Due to the high solar radiation, high vapor pressure deficit (VPD) and strong regional advection in this region, Holman et al. (2013) estimate that 2500 mm year^{-1} of Class A pan evaporation leaves the soil and is unavailable to plants. As a result, only rainfall events greater than 13 mm were accounted for in irrigation reductions.

3.2.3 Precipitation and Irrigation in 2013 and 2014

During the 2013 growing season, the experimental plot received a total of 120 mm of precipitation with 74 mm coming from rainfall events greater than 13 mm (Figure 3-2; Table 3-2).

Figure 3-2. Precipitation in 2013 and 2014 as compared to 30-year average precipitation in Canyon, Texas.

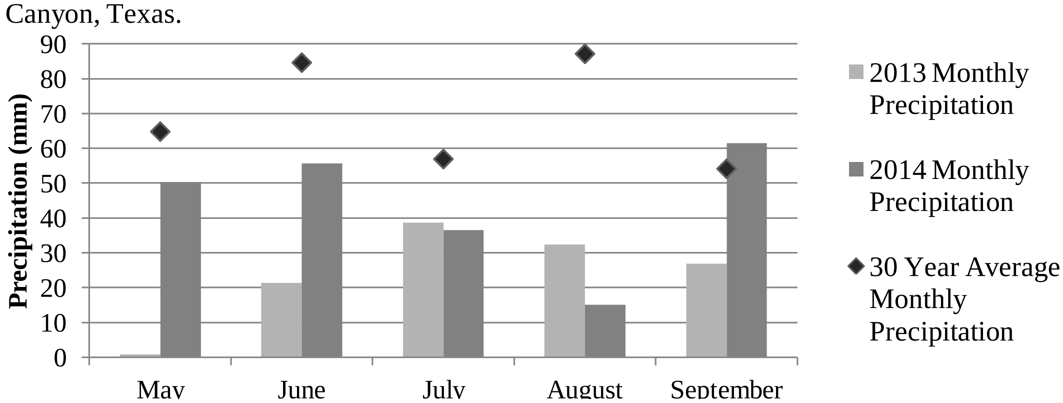


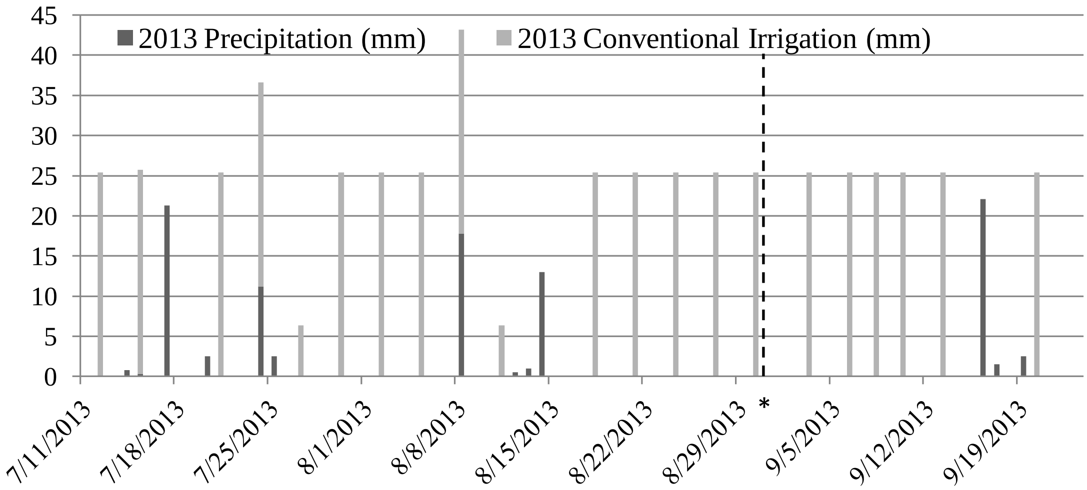
Table 3-2. Precipitation and irrigation measurements for the growing seasons (May-September) of 2013 and 2014 for the experimental site located at the West Texas A&M University Nance Ranch near Canyon, TX.

	2013	2014
	------------- mm	-------------
Total Precipitation	120	219
Conventional Irrigation Application	495	330
Phase Irrigation Application	432	229
Total Water Received in Conventional Treatment	615	549
Total Water Received in Phase Treatment	552	448
Difference Between Irrigation Treatments	63	102

WT feedlot weather station at Lat: 34.97° N Lon: 101.80° W Elevation 1,100 m

In 2013, plots receiving the conventional irrigation (CONV) treatment had 25 mm of water applied every three days (Figure 3-3).

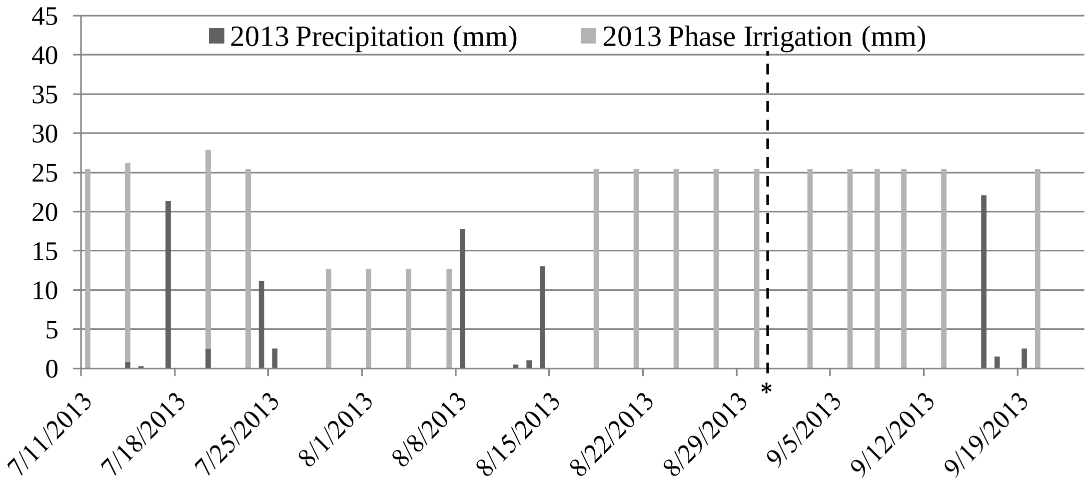
Figure 3-3. 2013 precipitation and irrigation of conventional irrigation plots.



*Silking occurred at 51 DAP on 31 August 2013.

Adjusting for precipitation events, the CONV treatment resulted in a total of 495 mm of irrigation water in 2013 (Table 3-2). The two instances of higher precipitation occurring on the same day as an irrigation event were unintentional and the precipitation occurred after the irrigation was applied (Figure 3-3). Plots receiving the phase irrigation (PHASE) treatment had 25 mm of water applied every three days except for a three week period leading up to the critical two-week period before sweet corn tasseling, from 26 July to 17 August 2013 (Figure 3-4). During these three weeks, only 13 mm of water was applied every three days to the PHASE treatment (Figure 3-4). Adjusting for precipitation events, the PHASE treatment received a total of 432 mm of irrigation water in 2013 (Table 3-2).

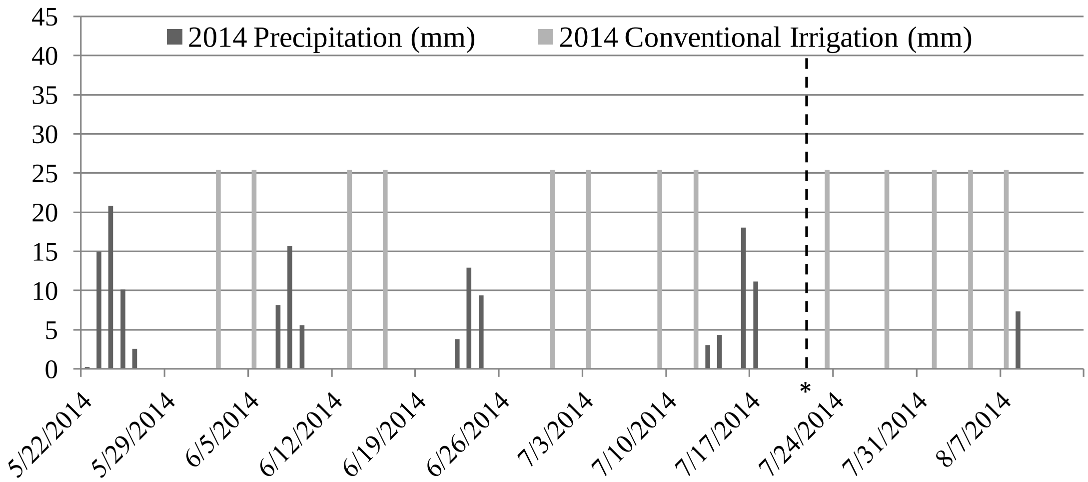
Figure 3-4. 2013 precipitation and irrigation of phase irrigation plots.



*Silking occurred at 51 DAP on 31 August 2013.

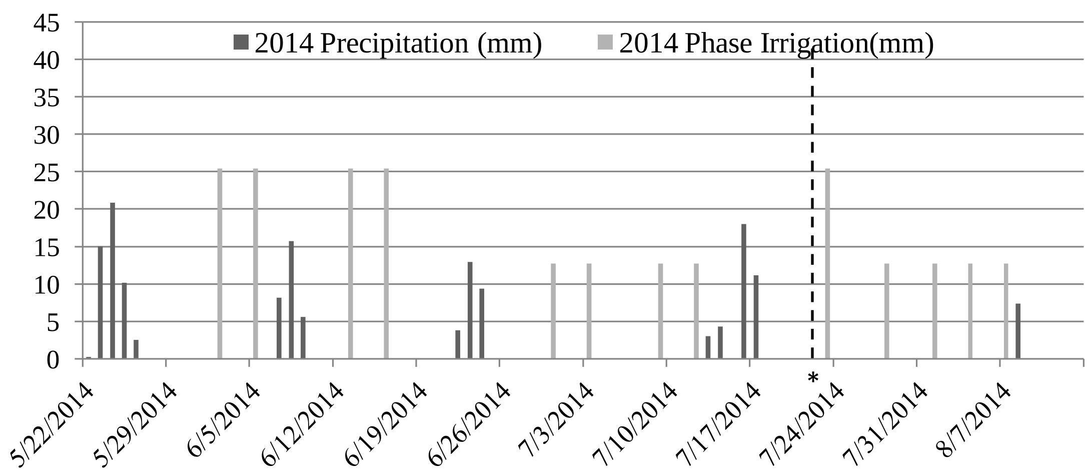
During the 2014 growing season, the experimental plot received a total of 219 mm of precipitation with 130 mm coming from rainfall events greater than 13 mm (Table 3-2). This rainfall amount is nearly twice as much as the plot received the previous year (Table 3-2; Figure 3-2). In 2014, plots receiving the CONV treatment had 25 mm of water applied twice a week for 11 weeks (Figure 3-5). Adjusting for precipitation events, the CONV treatment in 2014 received a total of 330 mm of irrigation water (Table 3-2). Plots receiving the PHASE treatment in 2014 (Figure 3-6) had 25 mm of water applied twice a week for five weeks then the amount was reduced to 13 mm twice a week for three weeks, raised again to 25 mm twice a week for one week and then reduced again to 13 mm twice a week for the final two weeks. Adjusting for precipitation events, the PHASE treatment in 2014 resulted in a total of 229 mm of irrigation water (Table 3-2).

Figure 3-5. 2014 precipitation and irrigation of conventional irrigation plots.



*Silking occured at 62 DAP on 23 July 2014.

Figure 3-6. 2014 precipitation and irrigation of phase irrigation plots.



*Silking occurred at 62 DAP on 23 July 2014.

3.2.4 Weed Control

No weed control was utilized during the 2013 summer growing season. Due to the prolific response of the weeds in 2013, chemical and physical control was employed in 2014. On 12 and 13 June 2014, a mixture of quinclorac (QuinStar® 4L GT), 2, 4-D and dicamba (Weed-B-Gone™ Crabgrass Control) was applied at recommended rates to the weeds in all plots using a manual sponging applicator. This herbicide application was ineffective against grass weeds and burned the tips of some corn plants. Afterwards, weeds were mechanically controlled twice by weed whacking the inter-row spaces of all plots on 26 through 30 June 2014 and again on 12 through 16 July 2014. Consequently, weed height measurements were only taken in 2013 shortly after harvest on 8 September 2013.

3.2.5 Harvesting Methods

Sweet corn harvest data were obtained from a 1.5 m sample in 2013 and a 1.8 m sample in 2014 from one of the inner two rows of each plot. The difference in sampling length was due to the difficulties with a thinner and more uneven sweet corn plant stand in 2014. In 2013, all sweet corn samples were harvested on 23 September 2013, 72 to 75 DAP. In 2014, all sweet corn samples were harvested on 13 August, 2014, which was 83 DAP. Number of sweet corn plants in each sample was counted and sweet corn plant height was measured. Sweet corn ear samples were counted, weighed with husks (green ear yield) and without husks (fresh ear yield), and dried at 70°C to constant weight. The grain was then threshed, cleaned, and weighed for dry grain weight and the number of grains was counted. In 2013, guar and weed samples were harvested from a 1.0 m^2 quadrat between 24 and 29 September. In 2014, weed samples were harvested from a 1.0 m^2 quadrat between 19 and 21 August. Weed and guar samples were dried at 70°C to constant weight and then weighed.

3.2.6 Calculation of LER

The equation for LER is:

$$LER = (Y_{ij}/Y_{ii}) + (Y_{ji}/Y_{jj})$$

where Y is the yield per unit area, Y_{ii} and Y_{jj} are sole crop yields of the component crops i and j and Y_{ij} and Y_{ji} are the intercrop yield. In this experiment, Y_{ij} and Y_{ii} represented sweet corn FEY from their respective cropping treatment and Y_{ji} and Y_{jj} represented guar biomass from their respective cropping treatment.

3.2.7 Soil Sampling

Soil samples were taken on 30 May 2013, 9 January 2014, and 15 October 2014. ServiTech (Amarillo, TX) analyzed all the soils samples using a row crop analysis which measured soil pH, percent organic matter (% OM) and parts per million (ppm) of NO_3-N, P, K, sulfur (S), Ca, Mg, Na and zinc (Zn).

3.3.8 Statistical Analysis

The field data were analyzed with SAS 9.3 software using PROC ANOVA (α = 0.10) (SAS Institute Inc., 2011). Where applicable, field data means were separated using Tukey’s HSD (α = 0.10).

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Greenhouse Experiment

Due to the unexpected variability of potting soil used in the experiment, four random EUs showed signs of P deficiency, purple-red streaks on the stalks and base of ears, on the sweet corn plants. The sole sweet corn treatment produced 10% more plant DM than the intercropped sweet corn (Table 4-1).

Table 4-1. Means ± standard error for sweet corn height, DM, yield and yield components by treatment main effects in the greenhouse experiment in 2014.

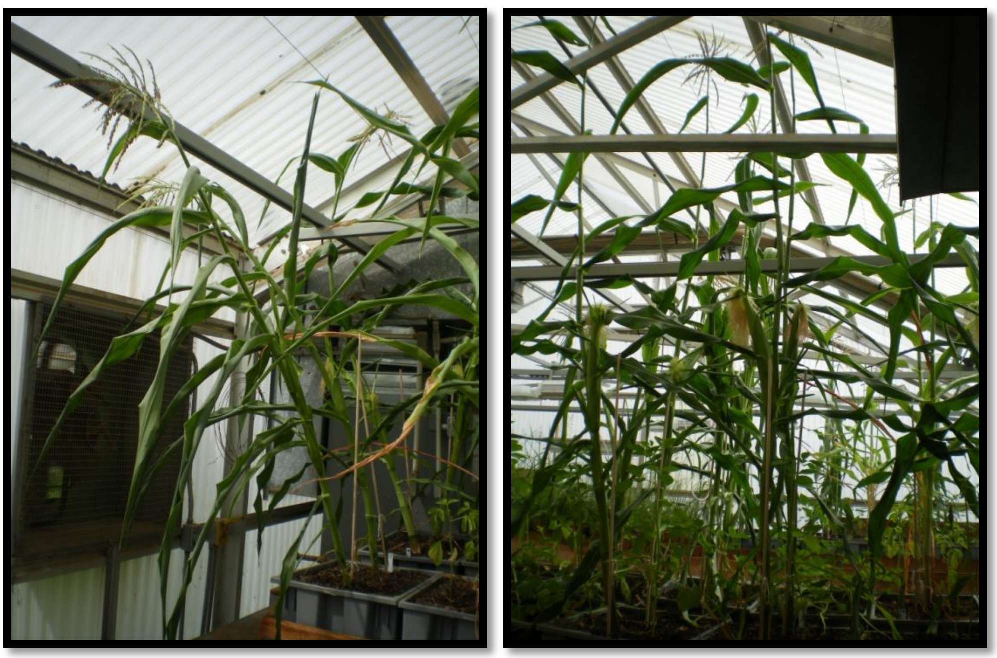
	Plant Ht	Plant DM	Total Green Ear† Yield	Green Ears	Green Ear Yield	Marketable Ears
Watering level‡	cm	----------- g	-----------	ear ct	g ear^{-1}	ear ct
HI	230 ± 9 a§	363 ± 11 a	686 ± 37 a	4 ± 0 b	189 ± 22 a	2 ± 0
LOW	184 ± 5 b	219 ± 15 b	326 ± 64 b	8 ± 1 a	43 ± 6 b	0 ± 0
Crop						
Corn	208 ± 12 a	307 ± 28 a	566 ± 71 a	6 ± 1 a	138 ± 42 a	1 ± 0
Intercrop	205 ± 13 a	275 ± 39 b	446 ± 109 a	5 ± 1 a	95 ± 27 b	1 ± 0

†Green ear yield represents sweet corn fresh ear weight including husks.
‡HI treatment = 483 mm and LOW treatment = 279 mm.
§Means by treatment column with the same letter are not different ($\alpha = 0.10$); N = 6.

Compared to a study in China where alfalfa was identified as the dominant component crop in an intercrop, this DM increase is much smaller than the reported average 44% increase of sole dent corn DM over dent corn DM in four sweet corn/alfalfa intercropping ratios over three years (Zhang et al., 2011). As a result of decreased DM, the intercropped sweet corn produced 21% less green ear yield (GEY) than the sole sweet corn (Table 4-1). Conducting an intercrop study with sweet corn and southernpea in raised beds using supplemental irrigation as needed, Francis and Decoteau (1993) reported a 22% decrease in sweet corn GEY in intercropped sweet corn grown at the same density as the sole sweet corn compared to the sole sweet corn GEY.

More leaf curling, which is a sign of water stress, was observed on the sweet corn plants in the LOW treatment than in the HI treatment (Figure 4-1).

Figure 4-1. Leaf curling in LOW treatment (pictured left) and absence of leaf curling in HI treatment (pictured right) on 16 September 2014.



As expected, the LOW treatment, which was 30% lower than the HI treatment, resulted in 20% less sweet corn plant height and 40% less sweet corn DM than the LOW treatment. (Table 4-1). In the semi-arid environment of Isparta, Turkey, Ertek and Kara (2013) reported sweet corn height reductions of 3-20% in the drip irrigation treatments that were reduced 15-60% E_{pan} compared to the 100% E_{pan} drip irrigation. Using drip irrigation in the Jordan Valley, Jordan, Abu-Awwad (1994) reported 29% less DM in the 50% E_{pan} irrigation treatment (274 mm of water applied) compared to the 100% E_{pan} irrigation treatment (373 mm of water applied).

Although the LOW treatment produced more ears, the HI treatment produced more GEY on both a total and per ear basis than the LOW treatment (Table 4-1). The water stress in the LOW treatment induced prolificacy of ears at the cost of producing marketable ears (Figure 4-2).

Figure 4-2. Prolific, yet undeveloped sweet corn ears on the same sweet corn plant in a low watering treatment.

However, in Wisconsin, Andrew and Weis (1974) reported relatively more husks and non-usable ears in their 'optimum' irrigation treatment, compared to their 'maintenance' irrigation treatment over a nine year period. The 'optimum' treatment had an average of 201 mm of water applied each year and the 'maintenance' treatment had an average of 100 mm of water applied each year (Andrew and Weis, 1974). Since the LOW treatment in this study did not produce any marketable ears, fresh ear yield (FEY), dry grain weight and number of grains were measured only from the HI treatment, which showed no differences in those yield traits between the sole sweet corn and intercropped sweet corn treatment (Table 4-2). When supplied with more water, sweet corn can take advantage of this resource and more effectively compete with guar.

Table 4-2. Marketable sweet corn yield component means ± standard error from the HI treatment by crop main effect in the greenhouse experiment in 2014.

	Marketable Ears	Total Fresh Ear† Yield	Fresh Ear Yield	Dry Grain Wt	Grain Ct
	ear ct	g	g ear^{-1}	g ear^{-1}	grain ct ear^{-1}
Corn	2 ± 0 a‡	515 ± 21 a	257 ± 11 a	73 ± 4 a	453 ± 15 a
Intercrop	2 ± 0 a	485 ± 30 a	242 ± 15 a	67 ± 6 a	417 ± 33 a

†Fresh ear yield represents sweet corn fresh ear weight without husks.
‡Means by column with the same letter are not different (α = 0.10); N = 3.

Unlike sweet corn, guar DM was affected by the interaction of watering level and crop treatment (Table 4-3). The sole guar in the LOW treatment had 39% and 33% more DM than the intercropped guar in the LOW treatment and the sole guar under the HI treatment, respectively (Table 4-3). But in Chillicothe, TX, Stafford (1987) reported 18% more shoot DM $plant^{-1}$ for irrigated guar, which received 134-138 mm of irrigation, as compared to dryland guar.

Table 4-3. Irrigation and crop interaction means ± standard error for guar DM in the greenhouse experiment in 2014.

Watering Level†	Crop	Guar DM
		g
HI Treatment	Guar	22 ± 4 b‡
	Intercrop	24 ± 2 ab
LOW Treatment	Guar	33 ± 1 a
	Intercrop	20 ± 2 b

†HI treatment = 203 mm and LOW treatment = 191 mm.
‡Means by column with the same letter are not different (α = 0.10); N = 3.

The additional water applied at the beginning of the HI treatment in guar was not utilized by the guar at the same rate that it was being applied, which hindered the growth of the guar plants. These results are consistent with Undersander et al. (1991), who reported that guar prefers well-drained sub-soils.

Since the buckets were randomized and different treatments were placed directly adjacent to each other on the greenhouse benches, the sole guar tended to elongate horizontally and sprawl out to avoid shading by the adjacent sweet corn plants. However, intercropped guar plants tended to grow upright. As the taller component, sweet corn was observed to be the dominant component crop in the intercrop. However, in the greenhouse, both sweet corn and guar performed best when grown separately, sweet corn thriving under the HI treatment and guar thriving under the LOW treatment.

4.2 Field Experiment

4.2.1 Sweet Corn Biomass and Yields

Sweet corn plant height was affected by an interaction of irrigation and crop treatment in both 2013 and 2014. In 2013, the heights under the PHASE treatment differed between the intercropped sweet corn and sole sweet corn (Table 4-4). But in 2014, sweet corn plants were shorter.

Table 4-4. Irrigation and crop interaction means ± standard error for sweet corn plant height near Canyon, TX in 2013.

Irrigation†	Crop	Plant Ht
		cm
CONV Treatment	Corn	174 ± 4 ab‡
	Intercrop	172 ± 5 ab
PHASE Treatment	Corn	188 ± 3 a
	Intercrop	168 ± 6 b

†CONV treatment = 495 mm and PHASE treatment = 432 mm.
‡Means by column with the same letter are not different ($\alpha = 0.10$); N = 8.

Additionally, the heights under the CONV treatment differed between the intercropped sweet corn and sole sweet corn (Table 4-5). This 50-61% reduction in plant height in the second year of the experiment, when planting occurred over a month earlier than the previous year, is an extreme case compared to the results of Williams and Lindquist (2007), who reported only a 22 cm increase in sweet corn height in a late June planting compared to an early May planting. However, the results of Williams (2009) suggest that planting date becomes more critical in weedy fields, with later plantings performing more favorably.

Table 4-5. Irrigation and crop interaction means ± standard error for sweet corn plant height near Canyon, TX in 2014.

Irrigation†	Crop	Plant Ht
		cm
CONV Treatment	Corn	87 ± 3 a‡
	Intercrop	67 ± 5 b
PHASE Treatment	Corn	79 ± 3 ab
	Intercrop	76 ± 6 ab

†CONV treatment = 330 mm and PHASE treatment = 229 mm.
‡Means by column with the same letter are not different ($\alpha = 0.10$); N = 8.

A difference occurred in the 2013 sweet corn population between the irrigation treatments, the CONV treatment resulting in 62,985 plants ha^{-1} and the PHASE treatment resulting in 82,364 plants ha^{-1} (Table 4-6). However, the 2013 population effect happened unintentionally as a result of poor stand establishment and an additional manual replanting at the initiation of the study. Furthermore, this field-sized population difference originated in an average two plant difference in the number of plants in the sample area. In 2014, there were no differences between any treatments in the sweet corn plant population, which averaged 47,974 plants ha^{-1} (Table 4-6).

Table 4-6. Sweet corn population, DM, and yield means ± standard error by treatment main effects in the field experiment near Canyon, TX in 2013 and 2014.

	Total Plants	Total Plant DM	Total FEY†	Total Ears	FEY
	plant ct ha^{-1}	----------------- Mg ha^{-1} ------------------		ear ct ha^{-1}	g ear^{-1}
			2013		
Irrigation‡					
CONV	62984 ± 4829 b§	5.79 ± 0.52 a	5.56 ± 1.19 a	33915 ± 6012 a	137 ± 18 a
PHASE	82364 ± 5154 a	6.02 ± 0.63a	5.35 ± 1.00 a	35530 ± 5663 a	139 ± 11 a
Manure Fertilizer					
67 Mg ha^{-1} 2 yr^{-1}	74828 ± 6374 a	6.64 ± 0.58 a	6.75 ± 1.12 a	40375 ± 5922 a	166 ± 9 a
22 Mg ha^{-1} 1 yr^{-1}	70521 ± 4599 a	5.16 ± 0.52 b	4.16 ± 0.96 b	29070 ± 5383 a	110 ± 17 b
Crop					
Corn	76443 ± 5027 a	6.35 ± 0.49 a	6.22 ± 1.09 a	40375 ± 6076a	140 ± 15 a
Intercrop	68906 ± 5936 a	5.45 ± 0.64 a	4.69 ± 1.06 a	29070 ± 5208 a	135 ± 15 a
			2014		
Irrigation¶					
CONV	50664 ± 4416 a	0.91 ± 0.10 a	0.49 ± 0.16 a	17934 ± 4037 a	17 ± 4 a
PHASE	45283 ± 2678 a	0.93 ± 0.10 a	0.45 ± 0.13 a	18831 ± 3977 a	19 ± 4 a
Manure Fertilizer					
67 Mg ha^{-1} 2 yr^{-1}	48422 ± 4368 a	0.89 ± 0.10 a	0.46 ± 0.18 a	15244 ± 3697 a	20 ± 5 a
22 Mg ha^{-1} 1 yr^{-1}	47525 ± 2919 a	0.95 ± 0.09 a	0.48 ± 0.11 a	21521 ± 4142 a	15 ± 3 a
Crop					
Corn	46628 ± 3874 a	1.071± 0.11 a	0.67 ± 0.18 a	21969 ± 4698a	23 ± 5 a
Intercrop	49318 ± 3519 a	0.767 ± 0.07 b	0.27 ± 0.07 b	14796 ± 2889 a	13 ± 3 b

†Fresh ear weights represent husked ears.
‡CONV treatment = 495 mm and PHASE treatment = 432 mm in 2013.
§Means by treatment column with the same letter are not different (α = 0.10); N = 16.
¶CONV treatment = 330 mm and PHASE treatment = 229 mm in 2014.

Interestingly, the 2013 population difference was not reflected by a difference in sweet corn DM, number of ears and FEY by irrigation treatment for that year (Table 4-6). Since the irrigation treatments in 2013 only differed by 63 mm, the lack of differences between these treatments are in agreement with the results of Ertek and Kara (2013), who reported similar (*P* < 0.001) ear numbers and FEY between their 100% E_{pan} (64,559 ears ha^{-1} and 14.7 Mg ha^{-1}, respectively) and 85% E_{pan} (64,184 ears ha^{-1} and 14.7 Mg ha^{-1}, respectively) irrigation treatments, which were only 36 mm different.

Sweet corn DM for 2013 in the 67 Mg ha^{-1} 2 yr^{-1} manure fertilizer treatment was 6.64 Mg ha^{-1}, which was 29% higher than 5.16 Mg ha^{-1} for the 22 Mg ha^{-1} yr^{-1} treatment (Table 4-6). Similarly, sweet corn total FEY, FEY ear^{-1}, ear length, dry grain weight ear^{-1} and number of grains ear^{-1} were 62%, 51%, 34%, 55% and 53% higher, respectively, in the 67 Mg ha^{-1} 2 yr^{-1} treatment compared to the 22 Mg ha^{-1} yr^{-1} treatment (Table 4-6; Table 4-7). Although using relatively lower rates of manure fertilization on sweet corn in Iran, Khoshgoftarmanesh and Eshghizadeh (2011) reported 35% higher plant DM and 40% higher dry grain weight when manure fertilizer was tripled. No differences were measured for these yield traits between the irrigation treatments and crop treatments in 2013 (Table 4-6; Table 4-7).

Just like plant height and plant population, 2014 sweet corn DM was lower than the previous year. Despite the control measures taken during the growing season, the planting date caused the intensity of weed competition experienced in the early part of the season. No sweet corn biomass or yield traits were affected by irrigation or manure treatment in the second year (Table 4-6).

Table 4-7. Sweet corn yield component means ± standard error of the field experiment near Canyon, TX in 2013.

	Ear Length	Dry Grain Wt	# of Grains
	cm	g ear^{-1}	grain ct ear^{-1}
Irrigation†			
CONV	10 ± 1 a‡	25 ± 4 a	240 ± 33 a
PHASE	10 ± 1 a	24 ± 3 a	242 ± 23 a
Manure Fertilizer			
67 Mg ha^{-1} 2 yr^{-1}	12 ± 0 a	29 ± 2 a	291 ± 19 a
22 Mg ha^{-1} 1 yr^{-1}	9 ± 1 b	19 ± 4 b	190 ± 30 b
Crop			
Corn	11 ± 1 a	23 ± 3 a	252 ± 29 a
Intercrop	10 ± 1 a	25 ± 4 a	229 ± 27 a

†CONV treatment = 495 mm and PHASE treatment = 432 mm.
‡Means by treatment column with the same letter are not different ($\alpha = 0.10$); N = 16.

The weeds had the advantage in competing for both water and nutrients and masked any effect that these treatments might have had on the crops of interest. Instead, crop treatment was the only main effect in 2014. The sole sweet corn produced 1.07 Mg ha^{-1} of DM, which was higher than the intercropped sweet corn at 0.77 Mg ha^{-1} of DM.

Number of sweet corn ears ha^{-1} did not differ between any treatments in 2014 (Table 4-6). Although FEY ear^{-1} was higher in the sole sweet corn crop than the intercropped sweet corn, the 22 g ear^{-1} produced by the sole corn crop was still not sufficient in size or development to be consumed or marketed (Table 4-6). The intensity of weed pressure reduced ear growth and delayed ear development. None of the sweet corn ears harvested in 2014 were deemed marketable and the yield components of ear length, dry grain weight ear^{-1} and number of grains ear^{-1} were not measured. Similarly, Williams (2010) reported a 17% delay in thermal time to silking, a 64% loss in ear mass and an 86% loss of marketable ears when measuring the damage to sweet corn yields caused by close proximity to giant ragweed.

4.2.2 Guar Biomass

In 2013, guar DM differed between the sole guar, which was higher ($P < 0.10$) at 290 kg ha^{-1}, and the intercropped guar treatment, which produced 110 kg ha^{-1}. These values were drastically lower than dryland guar biomass yields in India, which range from 8,000-12,000 kg ha^{-1} (Whistler and Hymowitz, 1979). Due to weed pressure, no guar plants in 2014 made it past the second trifoliate leaf and were so small and few in number that no biomass sample was taken. The cooler temperatures of late May as compared to early July and the uncontrolled weeds in the field compounded to prevent good guar emergence and slow the development of the guar seedlings (Undersander et al., 1991).

4.2.3 Weed Biomass and Total Biomass

In 2013, weed DM was highest in the sole guar treatments, regardless of irrigation, and in the intercrop under the PHASE treatment (Table 4-8).

Table 4-8. Irrigation and crop interaction means ± standard error for weed DM near Canyon, TX in 2013.

Irrigation†	Crop	Weed DM
		Mg ha^{-1}
CONV Treatment	Corn	4.13 ± 0.55 ab‡
	Intercrop	3.50 ± 0.46 b
	Guar	5.69 ± 0.84 a
PHASE Treatment	Corn	2.13 ± 0.26 b
	Intercrop	5.31 ± 0.45 a
	Guar	5.75 ± 0.70 a

†CONV treatment = 495 mm and PHASE treatment = 432 mm.
‡Means by column with the same letter are not different ($\alpha = 0.10$); N = 8.

The lowest weed DM values for 2013 occurred in the intercrop with the CONV treatment and the monocropped sweet corn with the PHASE treatment (Table 4-8). Furthermore, the lowest weed DM values in 2013, when no weed control was applied, were not much lower than the weed DM measured in 2014, when multiple weed control strategies were used. Since the same weed control measures were applied to all plots in 2014, there were no differences ($P < 0.10$) between any treatments for weed DM, which still averaged 3.51 Mg ha^{-1}. In addition to the severe crop disadvantage caused by the early planting date in 2014, the limitations associated with managing a grain/legume intercrop increased the difficulty of effectively controlling the weed community in this experiment.

When comparing total crop DM and weed DM for each crop treatment in 2013, the intercrop produced the most total DM, but the sole corn produced the most crop DM and least weed DM. Furthermore, the intercrop did not demonstrate a weed suppressive effect (Figure 4-3; Table 4-9).

4.2.4 Intercrop Productivity and LER

For both years, sweet corn yield and guar biomass were lower than typical values because of the heavy weed pressure in the experimental location. Less than optimum yields in the sole crops resulted in an over estimated intercrop productivity compared to the sole crop when Y_{ij}/Y_{ii} and Y_{ji}/Y_{jj} were calculated. Since it is evident that maximum yields for either sweet corn or guar were not achieved in this study, a calculation and discussion of LER from the measured results would be unmerited and misinterpreted according to Fukai (1993). Unfortunately, the interaction of sweet corn and guar did not have a complementary effect on the two crops and did not increase individual crop productivity.

Figure 4-3. Total sweet corn, weed and guar DM in each crop treatment.

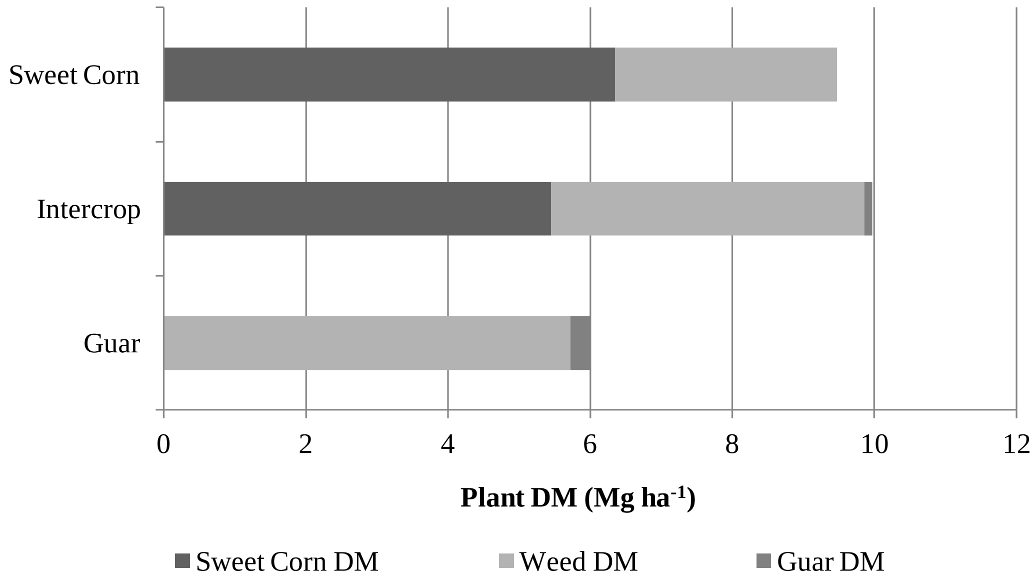


Table 4-9. Means ± standard error for sweet corn, guar and weed DM by crop treatment in the field experiment near Canyon, TX in 2013.

	Corn DM	Weed DM	Guar DM
	----------------------------	Mg ha^{-1}	----------------------------
Corn	6.35 ± 0.49†	3.13 ± 0.39	-
Intercrop	5.45 ± 0.64	4.41 ± 0.39	0.11 ± 0.04
Guar	-	5.72 ± 0.53	0.29 ± 0.06

†N = 16.

4.2.5 Change in Soil Properties

Of the soil properties measured, only available NO_3-N, Ca, P, and the sodium adsorption ratio (SAR) changed over the experimental period. The interaction of irrigation and crop affected available NO_3-N and Ca (Figures 4-10 and 4-11). However, these differences were marginal, did not follow an easily interpretable pattern and may be attributed to the inherent seasonal variation in the soil.

Table 4-10. Irrigation and crop interaction means ± standard error for soil available NO_3-N from May 2013 to October 2014.

Irrigation†	Crop	May 2013	January 2014	October 2014	Overall Change in NO_3-N
		ppm			
CONV Treatment	Corn	3.7 ± 1.3	7.3 ± 1.5	3.0 ± 1.0	-0.7 ± 1.9 ab‡
	Intercrop	6.3 ± 2.0	5.9 ± 1.8	1.6 ± 0.3	-4.8 ± 2.0 ab
	Guar	3.9 ± 1.2	5.0 ± 1.5	2.1 ± 0.1	-1.8 ± 1.2 ab
PHASE Treatment	Corn	11.6 ± 4.9	5.9 ± 1.0	2.5 ± 0.4	-9.1 ± 4.6 b
	Intercrop	3.0 ± 0.6	8.1 ± 1.8	3.0 ± 0.7	0.0 ± 0.9 a
	Guar	3.8 ± 1.8	5.0 ± 1.5	2.1 ± 0.3	-1.7 ± 2.0 ab

† CONV treatment = 495 mm in 2013 and 330 mm in 2014; PHASE treatment = 432 mm in 2013 and 229 mm in 2014.
‡Means by column with the same letter are not different ($\alpha = 0.10$); N = 8.

Table 4-11. Irrigation and crop interaction means ± standard error for soil available Ca from May 2013 to October 2014.

Irrigation†	Crop	May 2013	January 2014	October 2014	Overall Change in Ca
		ppm			
CONV Treatment	Corn	1720 ± 111	1536 ± 24	1851 ± 74	+131 ± 162 a‡
	Intercrop	1806 ± 63	1556 ± 51	1753 ± 58	-53 ± 92 ab
	Guar	1883 ± 103	1560 ± 36	1788 ± 34	-96 ± 117ab
PHASE Treatment	Corn	2160 ± 146	1562 ± 54	1789 ± 37	-371 ± 119 b
	Intercrop	1848 ± 74	1621 ± 121	1811 ± 108	-37 ± 116 ab
	Guar	1898 ± 100	1574 ± 54	1706 ± 72	-192 ± 96 ab

†CONV treatment = 495 mm in 2013 and 330 mm in 2014; PHASE treatment = 432 mm in 2013 and 229 mm in 2014.
‡Means by column with the same letter are not different ($\alpha = 0.10$); N = 8.

The soil SAR was not affected by treatment interactions or main effects. However, soil SAR increased from the first sampling date to the second sampling date and then remained constant until the third sampling date (Table 4-12). The Ogallala aquifer, the source of irrigation water in this experiment, is typically regarded as fresh, which means that the water contains 0-1,000 mg liter^{-1} of total dissolved solids according to the Texas Groundwater Protection Committee (Ashworth and Hopkins, 1995). However, this does not mean that the Ogallala aquifer is devoid of any dissolved solids (Hopkins, 1993). In a water-quality evaluation of the Ogallala aquifer, Hopkins (1993) reported a detection limit of 1 mg liter^{-1} for Ca, Mg, and Na. The evaluation performed by Hopkins (1993) reflects the results of the present study as the initial addition of irrigation water increased the SAR, but the subsequent addition of irrigation did not alter the ratio of Na to Ca and Mg.

Table 4-12. Soil SAR means ± standard error by sampling date.

Date	SAR
	ppm
May 2013	0.0101 ± 0.0006 a†
January 2014	0.3020 ± 0.0153 b
October 2014	0.3178 ± 0.0097 b

†Means by column with the same letter are not different ($\alpha = 0.10$); N = 48.

The 67 Mg ha^{-1} 2 yr^{-1} manure treatment resulted in a greater increase in available soil P than the 22 Mg ha^{-1} 1 yr^{-1} manure treatment (Table 4-13). At the end of a four-year experiment studying the utilization and availability of P from feedlot manure in Mohave clay loam, Abbott and Tucker (1973) reported 6.9 and 10.4 ppm of sodium bicarbonate extractable P in soils that received 22 Mg ha^{-1} 4 yr^{-1} and 58 Mg ha^{-1} 4 yr^{-1} of manure fertilizer, respectively. Interestingly, the amount of available phosphorus in the 67 Mg ha^{-1} 2 yr^{-1} manure treatment did not decrease after the duration of the second growing season, even though it did not receive a second application of manure that spring (Table 4-13). The 22 Mg ha^{-1} 1 yr^{-1} manure treatment increased after each application and growing season (Table 4-13).

Table 4-13. Available soil phosphorus means ± standard error by manure fertilizer treatment in the experimental field plots from May 2013 to October 2014.

Manure Fertilizer	May 2013	January 2014	October 2014	Change in Phosphorus
	ppm			
67 Mg ha^{-1} 2 yr^{-1}†	29 ± 2	70 ± 6	71 ± 6	+42 ± 6 a‡
22 Mg ha^{-1} 1 yr^{-1}§	29 ± 3	43 ± 2	57 ± 4	+27 ± 5 b

†This amount of manure was applied on 5 June 2013.
‡Means with the same letter are not different (α = 0.10); N = 24.
§This amount of manure was applied 5 June 2013 and 22 May 2014.

CHAPTER 5: CONCLUSION

Despite numerous cases of beneficial intercropping systems, this experiment demonstrated that sweet corn and guar were not suitable components for an intercrop. Repeating this study in a non-weedy may more conclusively determine if a sweet corn/ guar intercrop is an appropriate pairing. No LER advantages were determined due to the inadequate performance of the sole crops.

Although the yield variability was wide, this study also detected no significant sweet corn yield differences between the two field irrigation treatments, despite the 13-30% irrigation water reduction in the PHASE irrigation treatment. Further study of scheduling reduced irrigation for sweet corn would contribute to the understanding of sweet corn water use efficiency and provide helpful recommendations for water use and conservation in sweet corn.

The lack of sweet corn yield differences in the manure treatments in the second year of this study suggests the feasibility of practicing biennial applications of manure fertilizer in sweet corn. Biennial instead of annual applications of manure fertilizer may reduce fuel costs, soil compaction, and field labor required to maintain soil productivity.

Growing monocropped guar for forage in crop rows and with different agronomic treatments on the northern Texas High Plains would be another valuable topic of future research.

Monocropped sweet corn suppressed weeds most effectively and was the most productive option for the location and conditions of this experiment. Further study of growing sweet corn, whether monocropped or intercropped, late in the growing season on the Texas High Plains would give a better understanding of sweet corn interactions with weed pressure.

As a result of this study, intercropping sweet corn and guar to improve productivity and control weeds is not recommended.

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APPENDIX

Table A-1. Average daily air temperature and average vapor pressure deficits for the experimental site located at the West Texas A&M University Nance Ranch near Canyon, TX for 2013 and 2014.

Average Daily Air Temperature

Month	2013	2014	30 Yr. Avg.
	------------------------------ °C	------------------------------	
May	19.1	19.2	19.1
June	25.0	23.2	23.8
July	24.4	23.7	25.8
August	24.7	24.7	25.1
September	21.8	19.8	21.1

Average Daily Vapor Pressure Deficit

Month	2013	2014
	---------------- kPa	----------------
May	1.404	1.443
June	1.679	1.167
July	1.510	1.212
August	1.444	1.499
September	1.260	0.713

WT feedlot weather station at Lat: 34.97° N Lon: 101.80° W Elevation 1,100 m
Thirty-year averages from http://www.ncdc.noaa.gov/cdo-web/datatools/normals.

Table A-2. Treatments applied to each plot in the field experiment in 2013 and 2014.

Plot	Irrigation Treatment	Fertilizer Treatment	Crop Treatment	Replication
1	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Sweet Corn	1
2	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Sweet Corn	1
3	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Sweet Corn	2
4	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Sweet Corn	2
5	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Guar	1
6	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Guar	1
7	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Guar	2
8	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Guar	2
9	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Intercropped Sweet Corn	1
10	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Intercropped Sweet Corn	1
11	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Intercropped Sweet Corn	2
12	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Intercropped Sweet Corn	2
13	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Sweet Corn	1
14	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Sweet Corn	1
15	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Sweet Corn	2
16	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Sweet Corn	2
17	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Guar	1
18	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Guar	1
19	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Guar	2
20	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Guar	2
21	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Guar	3
22	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Guar	3
23	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Guar	4
24	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Guar	4
25	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Sweet Corn	3
26	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Sweet Corn	3
27	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Sweet Corn	4
28	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Sweet Corn	4
29	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Intercropped Sweet Corn	1
30	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Intercropped Sweet Corn	1
31	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Intercropped Sweet Corn	2
32	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Intercropped Sweet Corn	2
33	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Intercropped Sweet Corn	3
34	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Intercropped Sweet Corn	3
35	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Intercropped Sweet Corn	4
36	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Intercropped Sweet Corn	4
37	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Sweet Corn	3
38	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Sweet Corn	3
39	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Sweet Corn	4
40	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Sweet Corn	4
41	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Guar	3
42	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Guar	3
43	Phase Irrigation	22 Mg ha^{-1} yr^{-1}	Sole Guar	4
44	Phase Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Sole Guar	4
45	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Intercropped Sweet Corn	3
46	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Intercropped Sweet Corn	3
47	Conventional Irrigation	22 Mg ha^{-1} yr^{-1}	Intercropped Sweet Corn	4
48	Conventional Irrigation	67 Mg ha^{-1} 2 yr^{-1}	Intercropped Sweet Corn	4

Table A-3. Raw sweet corn data per m^2 from the field experiment in 2013.

Plot	Plant Population	Plant Ht	Total Ears	Total Plant Wet Wt	Total Plant Dry Wt	Total Green Ear Yield	Total Fresh Ear Yield	Total Dry Ear Wt
	plant ct	cm	ear ct	---------------------- g -----------------------				
1	9	190	3	3694	603	536	325	106
2	9	195	6	4501	603	1322	911	263
3	9	179	3	2666	431	508	375	116
4	9	184	5	4427	603	950	665	204
9	6	177	3	1663	259	407	262	79
10	4	156	1	807	86	184	125	44
11	6	132	0	1076	216	0	0	0
12	6	163	5	2495	259	919	696	230
13	5	185	3	3669	345	1243	888	265
14	4	168	6	2984	302	1412	876	251
15	4	157	3	1884	259	680	383	122
16	5	173	6	3547	431	1200	1118	319
25	9	194	8	5969	560	1998	1400	421
26	7	193	3	2617	259	849	587	176
27	8	174	1	2055	302	227	153	57
28	8	193	7	4354	431	1701	1240	356
29	5	196	3	2422	388	590	387	117
30	8	169	3	2250	302	504	364	123
31	6	176	4	3131	388	1099	821	261
32	9	184	8	5406	603	2350	1736	535
33	9	192	3	3351	474	583	395	122
34	12	173	3	4281	690	790	559	174
35	8	174	4	3253	517	1032	735	251
36	11	180	1	3376	690	192	141	53
37	10	171	1	3082	647	168	141	54
38	7	162	0	1590	302	0	0	0
39	8	180	2	3327	603	109	63	33
40	9	193	7	4158	517	1298	845	234
45	5	177	4	3155	345	923	622	180
46	5	159	0	1027	259	0	0	0
47	5	154	3	2422	388	719	512	161
48	4	159	1	2275	474	215	149	61

Table A-4. Raw sweet corn data per m^2 from the field experiment in 2013.

Plot	Ear Length	Total Grain Wt	Total Grain
	cm	g	grain ct
1	12	31	453
2	12	143	1566
3	11	69	705
4	11	135	1355
9	9	29	416
10	10	16	266
11	0	0	0
12	10	143	1020
13	15	176	1697
14	12	149	1484
15	12	59	726
16	12	213	2109
25	12	274	2242
26	13	98	903
27	9	16	281
28	14	247	2448
29	11	60	651
30	11	63	595
31	13	186	1448
32	14	386	2941
33	9	54	702
34	10	103	702
35	13	185	1350
36	10	23	278
37	13	15	247
38	0	0	0
39	8	7	98
40	10	142	1633
45	11	95	882
46	0	0	0
47	12	98	904
48	13	27	250

Table A-5. Raw guar biomass data per m^2 from the field experiment in 2013.

Plot	Guar DM
	g
5	53
6	42
7	4
8	8
9	21
10	1
11	1
12	0
17	71
18	17
19	6
20	2
21	19
22	11
23	7
24	37
29	5
30	12
31	31
32	9
33	67
34	4
35	6
36	20
41	26
42	27
43	88
44	47
45	0
46	0
47	0
48	0

Table A-6.Raw sweet corn biomass and yield data per m^2 from the field experiment in 2014.

Plot	Population	Plant Ht	Total Ears	Total Plant Wet Wt	Total Plant Dry Wt	Total Green Ear Yield	Total Fresh Ear Yield	Total Dry Ear Wt
	# plants	cm	# ears	------------------------		g		------------------------
1	6	90	4	621	144	137	82	18
2	5	87	5	771	132	326	209	40
3	4	74	1	261	62	36	20	1
4	5	76	2	421	109	46	20	1
9	5	69	2	333	71	59	33	2
10	3	73	1	212	71	20	0	0
11	4	74	0	203	52	0	0	0
12	4	88	3	398	76	134	78	7
13	6	80	1	500	122	33	26	2
14	7	100	6	748	138	238	114	12
15	4	100	4	575	100	238	144	23
16	4	83	4	728	115	297	228	46
25	4	90	4	696	132	173	82	8
26	4	76	1	353	82	62	36	2
27	4	71	0	245	58	0	0	0
28	4	69	1	405	84	69	33	5
29	6	70	3	421	88	78	33	3
30	6	68	1	464	89	49	23	2
31	6	78	3	506	99	117	59	6
32	2	80	1	144	29	36	13	1
33	5	108	4	617	125	186	78	8
34	7	61	0	320	78	0	0	0
35	5	75	1	274	55	36	29	2
36	5	60	1	304	65	33	26	2
37	2	76	0	114	35	0	0	0
38	3	85	1	248	60	42	29	2
39	5	90	2	483	109	98	55	4
40	8	82	0	265	74	0	0	0
45	7	68	2	154	108	62	39	4
46	4	76	1	229	50	20	13	1
47	5	52	1	349	89	13	7	0
48	5	39	0	160	47	0	0	0

Table A-7. Raw weed data per m^2 for 2013 and 2014 from the field experiment.

Plot	2013 Max Weed Ht	2013 Weed DM	2014 Weed DM
	cm	------------------------------ g	------------------------------
1	185	150	330
2	201	150	257
3	198	200	189
4	189	200	219
5	193	450	341
6	130	450	407
7	168	400	330
8	201	400	242
9	221	550	231
10	201	800	378
11	146	350	357
12	176	550	346
13	157	550	270
14	178	400	467
15	170	250	270
16	217	600	285
17	199	750	261
18	191	750	333
19	160	700	294
20	192	750	402
21	191	650	325
22	155	450	427
23	156	650	292
24	201	1100	388
25	168	150	455
26	198	200	382
27	177	300	308
28	207	350	440
29	174	350	268
30	170	350	321
31	217	300	471
32	229	650	540
33	189	500	447
34	182	500	537
35	185	550	346
36	182	450	454
37	176	400	356
38	151	400	382
39	137	150	420
40	193	550	365
41	166	500	323
42	135	500	238
43	116	450	243
44	185	200	505
45	199	350	244
46	142	300	447
47	196	200	305
48	175	300	400

Table A-8. Raw soil data sampled in May 2013 from the field experiment.

Plot	pH	Sol. Salts	OM	SAR	NO_3-N	P	K	S	Ca	Mg	Na	Zn
		mmho/cm	------- % -------		---------------------------- ppm ----------------------------							
1	6.7	0.53	1.2	0.0150	35	46	337	17	1544	253	11	0.9
2	7.0	0.37	1.5	0.0110	11	24	318	9	2548	464	28	0.9
3	7.0	0.21	1.4	0.0108	2	20	260	8	2313	485	26	0.9
4	6.8	0.14	1.3	0.0118	3	31	310	8	2207	507	20	1.0
5	6.7	0.13	1.4	0.0140	1	36	312	11	1919	446	14	1.1
6	7.0	0.19	1.5	0.0059	1	18	306	9	2304	508	17	0.5
7	6.3	0.22	1.6	0.0140	9	41	342	11	1674	363	14	1.0
8	6.8	0.08	1.7	0.0109	1	25	298	7	2368	494	15	0.9
9	7.0	0.11	1.3	0.0065	2	13	238	8	2252	418	16	0.5
10	6.7	0.10	1.4	0.0072	3	20	256	6	1717	337	14	0.5
11	6.9	0.07	1.5	0.0091	3	21	273	9	1980	416	18	0.7
12	6.7	0.12	1.4	0.0170	1	33	317	9	1853	416	16	1.3
13	6.6	0.10	1.4	0.0130	7	31	311	9	1814	424	15	1.0
14	6.7	0.18	1.4	0.0120	3	25	298	11	1734	405	12	0.9
15	6.2	0.14	1.4	0.0225	11	54	396	9	1354	317	11	1.5
16	6.8	0.10	1.7	0.0064	<1	14	261	6	2196	441	14	0.5
17	6.6	0.11	1.3	0.0144	4	33	300	8	2012	407	19	1.1
18	6.9	0.09	1.3	0.0119	3	25	258	10	1957	393	24	0.9
19	7.0	0.09	1.3	0.0116	<1	21	278	8	2335	508	33	1.0
20	6.8	0.10	1.6	0.0184	3	38	330	9	2016	475	18	1.5
21	6.5	0.18	1.5	0.0135	2	29	324	13	1708	389	17	1.0
22	6.7	0.07	1.4	0.0098	7	23	267	8	1661	368	11	0.7
23	6.7	0.08	1.3	0.0097	2	18	248	9	1746	381	9	0.7
24	6.5	0.11	1.6	0.0166	8	47	371	10	1685	376	12	1.2
25	6.3	0.25	1.3	0.0177	31	38	354	12	1869	386	13	1.3
26	6.7	0.14	1.5	0.0103	8	25	281	10	2114	419	23	0.8
27	7.2	0.09	1.4	0.0046	<1	15	287	8	2834	504	35	0.4
28	6.7	0.14	1.4	0.0103	2	32	316	10	1854	421	20	0.8
29	6.8	0.11	1.5	0.0092	2	33	320	7	1742	408	17	0.7
30	6.4	0.19	1.3	0.0051	15	18	268	9	1802	431	18	0.4
31	6.3	0.13	1.5	0.0158	12	46	384	13	1799	415	13	1.2
32	6.7	0.08	1.3	0.0109	3	26	341	12	1734	391	11	0.8
33	6.8	0.08	1.4	0.0068	5	29	289	10	1856	380	15	0.5
34	7.0	0.06	1.2	0.0041	2	22	239	7	1884	372	22	0.3
35	6.8	0.15	1.4	0.0114	6	51	367	9	1650	344	17	0.8
36	6.5	0.10	1.6	0.0101	2	44	362	10	1592	343	11	0.7
37	6.7	0.08	1.4	0.0070	3	45	351	7	1607	371	12	0.5
38	6.7	0.11	1.5	0.0040	4	19	248	7	1736	394	15	0.3
39	6.8	0.11	1.5	0.0081	<1	25	217	8	1272	391	13	0.6
40	6.9	0.10	1.7	0.0048	<1	21	270	9	2050	481	20	0.4
41	7.0	0.08	1.4	0.0054	<1	17	246	8	1760	370	24	0.4
42	7.2	0.11	1.4	0.0026	<1	12	238	6	2069	403	23	0.2
43	6.5	0.18	1.2	0.0076	16	34	262	6	1560	305	13	0.5
44	6.8	0.13	1.3	0.0076	3	36	344	7	1474	309	11	0.5
45	6.7	0.14	1.2	0.0060	5	23	244	9	1586	319	10	0.4
46	6.8	0.13	1.6	0.0087	2	32	336	9	2015	453	25	0.7
47	6.4	0.17	1.4	0.0083	11	48	362	12	1654	370	14	0.6
48	6.9	0.10	1.5	0.0050	<1	26	322	9	2118	461	14	0.4

Table A-9. Raw soil data sampled in January 2014 from the field experiment.

Plot	pH	Sol. Salts	OM	SAR	NO_3-N	P	K	S	Ca	Mg	Na	Zn
		mmho/cm	------- % -------		---------------------------- ppm ----------------------------							
1	6.4	0.19	1.1	0.1906	8	34	297	13	1491	306	31	0.4
2	6.9	0.26	1.3	0.1802	9	83	339	15	1681	334	31	1.7
3	6.8	0.29	1.1	0.2585	3	31	330	25	1822	407	47	0.7
4	7.1	0.13	1.3	0.2700	6	69	320	13	1703	412	48	1.6
5	6.5	0.29	1.3	0.3824	4	47	326	33	1530	353	64	0.9
6	6.9	0.11	1.3	0.2507	4	43	324	10	1715	433	45	0.8
7	6.8	0.16	1.3	0.2696	2	41	283	13	1571	378	46	0.7
8	7.2	0.15	1.4	0.2897	5	55	344	12	1675	401	51	0.9
9	6.6	0.16	1.1	0.2578	5	35	245	19	1567	322	43	0.7
10	6.7	0.35	1.4	0.7713	17	97	665	46	1401	332	124	1.7
11	6.7	0.14	1.2	0.2528	3	39	326	13	1676	369	44	0.8
12	7.0	0.23	1.3	0.3261	8	85	392	19	1620	366	56	1.4
13	7.0	0.31	1.3	0.3365	10	83	440	19	1564	363	57	1.5
14	6.9	0.16	1.3	0.2338	3	66	377	13	1421	346	38	1.5
15	6.4	0.23	1.2	0.2135	6	36	294	26	1469	338	35	0.7
16	6.7	0.38	1.6	0.4959	14	78	393	32	1504	338	82	1.5
17	6.2	0.27	1.2	0.2113	13	39	254	32	1442	309	34	0.6
18	7.2	0.23	1.5	0.3056	10	187	342	16	1768	409	55	4.1
19	7.0	0.18	1.1	0.2713	4	47	322	16	1516	339	45	1.0
20	7.2	0.12	1.1	0.3118	3	43	314	9	1684	401	55	0.9
21	6.8	0.16	1.1	0.6293	5	93	544	42	1487	347	104	2.0
22	6.8	0.14	1.2	0.2474	2	36	311	14	1428	329	40	0.7
23	7.2	0.15	1.2	0.2623	3	42	337	10	1603	374	45	0.8
24	6.3	0.25	1.0	0.3299	15	60	390	29	1468	335	54	1.1
25	7.2	0.17	1.3	0.3356	4	56	326	14	1411	328	54	0.8
26	6.9	0.21	1.2	0.3557	6	72	387	19	1430	307	57	1.3
27	7.2	0.12	1.2	0.2353	2	33	329	9	1517	336	39	0.7
28	7.0	0.18	1.1	0.3029	9	58	347	13	1439	324	49	1.2
29	7.2	0.21	1.4	0.3559	6	51	394	15	1498	348	59	1.3
30	6.8	0.17	1.2	0.2630	2	46	271	22	1641	403	46	0.9
31	6.5	0.27	1.4	0.1567	18	43	264	28	1749	399	28	0.9
32	7.0	0.14	1.4	0.3390	7	62	385	18	1593	372	58	1.4
33	6.8	0.14	1.1	0.2600	4	46	314	16	1431	325	42	1.4
34	7.3	0.16	1.2	0.2913	11	89	285	9	1347	323	46	1.7
35	6.9	0.19	1.2	0.2339	4	63	307	22	1508	356	39	1.2
36	6.9	0.15	1.2	0.3641	13	64	506	28	2421	524	76	1.6
37	6.9	0.19	1.2	0.4576	7	40	398	25	1541	360	77	0.9
38	6.9	0.09	1.2	0.2638	3	30	307	12	1580	372	45	0.6
39	6.9	0.14	1.2	0.2915	3	36	308	17	1633	409	51	0.7
40	6.9	0.30	1.5	0.3030	12	83	442	19	1577	390	52	1.6
41	7.2	0.10	1.2	0.2861	1	35	300	15	1606	367	49	0.8
42	7.6	0.09	1.1	0.2098	2	27	255	7	1744	364	37	0.6
43	7.0	0.12	1.1	0.2516	4	70	314	11	1500	305	41	1.1
44	6.9	0.07	0.9	0.2836	3	52	285	10	1329	295	44	0.8
45	6.5	0.19	1.1	0.2104	3	44	303	20	1374	292	33	0.7
46	6.8	0.13	1.2	0.2899	4	49	320	18	1489	350	48	0.6
47	7.1	0.13	1.3	0.2829	3	43	332	13	1722	384	50	0.8
48	6.5	0.33	1.3	0.3263	4	52	417	25	1384	322	52	0.9

Table A-10. Raw soil data sampled in October 2014from the field experiment.

Plot	pH	Sol. Salts	OM	SAR	NO_3-N	P	K	S	Ca	Mg	Na	Zn
		mmho/cm	------- % -------		---------------------------- ppm ----------------------------							
1	7.5	0.33	1.2	0.6599	5	79	433	19	1635	373	114	1.4
2	7.3	0.24	1.1	0.3183	2	59	409	11	1912	412	59	1.2
3	7.4	0.25	1.1	0.3060	2	54	343	7	1824	425	56	1.3
4	7.2	0.32	1.1	0.3881	2	49	367	19	1697	416	69	1.2
5	7.6	0.20	1.1	0.3315	2	77	386	7	1869	466	62	1.6
6	7.4	0.24	1.2	0.3615	2	48	347	11	1630	400	63	1.3
7	7.5	0.19	1.0	0.3028	2	34	291	6	1840	448	56	0.9
8	7.1	0.25	1.2	0.2971	2	34	317	13	1811	412	54	0.7
9	7.5	0.23	1.2	0.2330	3	49	351	8	2098	434	45	1.1
10	7.4	0.22	1.5	0.3565	3	103	393	10	2010	445	68	2.8
11	7.4	0.29	1.2	0.3710	2	45	358	13	1937	453	70	1.2
12	7.8	0.24	1.3	0.2562	2	126	351	6	2031	510	50	2.4
13	7.6	0.23	1.3	0.2925	3	58	378	7	2018	512	57	1.5
14	7.6	0.27	1.6	0.3085	2	80	370	11	1882	474	58	2.2
15	7.5	0.21	1.2	0.3066	2	45	313	6	1791	439	56	1.0
16	7.0	0.31	1.2	0.3779	10	97	407	16	1651	393	66	2.4
17	7.1	0.22	1.0	0.2442	3	42	295	11	1717	376	43	1.1
18	7.6	0.23	1.1	0.3683	2	55	380	8	1958	418	69	1.4
19	7.6	0.24	1.1	0.3409	3	68	373	9	1740	409	61	1.3
20	7.7	0.34	1.4	0.3598	3	146	441	13	1983	479	69	3.2
21	7.3	0.23	1.2	0.2928	2	51	344	10	1827	447	54	1.3
22	7.3	0.29	1.4	0.2452	2	80	327	10	1731	422	44	2.2
23	7.3	0.33	1.4	0.3093	2	55	349	15	1912	448	58	1.4
24	6.9	0.45	1.3	0.3876	3	59	371	36	1681	388	68	1.6
25	7.1	0.42	1.2	0.3484	2	51	354	25	1808	399	63	1.5
26	7.5	0.28	1.2	0.3325	2	51	315	12	1865	408	61	1.3
27	7.5	0.29	1.3	0.2686	3	86	336	11	1892	437	50	2.0
28	7.5	0.28	1.2	0.3329	2	75	354	13	1679	418	59	1.6
29	7.4	0.32	1.1	0.3119	2	89	356	15	1862	452	58	2.1
30	7.2	0.32	1.2	0.3895	2	64	335	19	1609	377	67	1.5
31	6.9	0.27	1.3	0.2292	2	34	301	15	1919	446	43	0.7
32	7.5	0.22	1.5	0.2556	3	79	352	7	1978	481	49	2.1
33	7.2	0.24	1.1	0.2740	6	90	274	9	1689	379	48	1.0
34	7.2	0.26	1.1	0.2941	6	90	274	9	1149	326	44	2.0
35	7.3	0.22	1.1	0.2972	1	40	329	8	1854	441	55	0.8
36	7.5	0.19	1.2	0.2818	1	54	294	6	1718	397	50	1.0
37	7.7	0.20	1.1	0.2869	2	65	330	7	1618	407	50	1.4
38	7.3	0.27	1.3	0.3236	1	78	361	13	1785	437	59	1.6
39	7.5	0.31	1.6	0.2449	2	75	346	11	2269	530	50	2.3
40	7.4	0.22	1.3	0.3788	2	51	360	10	1797	427	69	1.4
41	7.6	0.16	1.2	0.3141	2	43	297	6	1546	364	53	1.1
42	7.4	0.18	1.1	0.2999	1	45	263	4	1550	331	50	1.0
43	7.4	0.19	1.0	0.3158	1	45	320	6	1766	367	56	0.8
44	7.2	0.23	1.0	0.2329	2	98	358	10	1391	310	37	1.5
45	7.5	0.21	1.0	0.3474	<1	56	323	10	1514	356	58	1.0
46	7.4	0.21	1.2	0.3014	<1	53	341	11	1670	401	53	1.5
47	7.5	0.21	1.1	0.3266	<1	25	309	10	1824	437	60	0.6
48	7.4	0.19	1.2	0.2511	2	38	296	7	1651	402	44	0.9

Table A-11. Treatments assigned to each bucket in the greenhouse experiment.

Bucket	Watering Level	Crop Treatment	Replication
1	High Watering Level	Sole Sweet Corn	1
2	High Watering Level	Sole Sweet Corn	2
3	High Watering Level	Sole Sweet Corn	3
4	High Watering Level	Sole Guar	1
5	High Watering Level	Sole Guar	2
6	High Watering Level	Sole Guar	3
7	High Watering Level	Intercropped Sweet Corn	1
8	High Watering Level	Intercropped Sweet Corn	2
9	High Watering Level	Intercropped Sweet Corn	3
10	Low Watering Level	Sole Sweet Corn	1
11	Low Watering Level	Sole Sweet Corn	2
12	Low Watering Level	Sole Sweet Corn	3
13	Low Watering Level	Sole Guar	1
14	Low Watering Level	Sole Guar	2
15	Low Watering Level	Sole Guar	3
16	Low Watering Level	Intercropped Sweet Corn	1
17	Low Watering Level	Intercropped Sweet Corn	2
18	Low Watering Level	Intercropped Sweet Corn	3

Table A-12. Raw corn biomass data from the greenhouse experiment in 2014.

Bucket†	Plant Ht	Total Plant Wet Wt‡	Total Plant Dry Wt
	cm	-------------------- g	--------------------
1	223.5	1914.9	395.4
2	248.9	1292.6	337.9
3	226.7	1626.6	370.5
7	190.5	1659.5	387.2
8	243.8	1391.0	360.0
9	245.1	1408.7	325.7
10	170.8	1301.5	251.2
11	203.2	1117.8	239.0
12	177.8	1271.0	250.6
16	195.6	575.4	167.7
17	171.5	1084.7	226.8
18	184.8	699.4	180.4

†Bucket area = 0.31 m^2.

‡Each bucket held two plants.

Table A-13. Raw guar biomass data from the greenhouse experiment in 2014.

Bucket†	Guar DM‡
	g
4	20.6
5	26.5
6	26.3
7	19.1
8	30.2
9	17.5
13	18.3
14	24.1
15	17.1
16	33.7
17	31.2
18	32.8

†Bucket area = 0.31 m^2.

‡Each bucket held four guar plants.

Table A-14. Raw sweet corn yield and yield component data from the greenhouse experiment in 2014.

Bucket†	Total Unhusked Wet Ear Wt	Total Ears	Marketable Ears	Marketable Unhusked Wet Ear Wt	Marketable Husked Wet Ear Wt	Marketable Dry Ear Wt	Marketable Grain Wt	Marketable Grains
	g	----- ear ct -----		------------------------- g -------------------------				grain ct
1	819.0	4	2	707.4	533.2	198.1	155.4	921
2	577.3	2	2	577.3	472.3	168.5	132.2	949
3	726.8	4	2	657.2	538.2	192.1	150.1	848
7	733.2	5	2	660.5	510.8	182.8	138.1	841
8	619.3	4	2	574.8	423.9	145.4	111.1	718
9	639.9	4	2	611.1	518.8	184.7	150.2	943
10	444.5	11	0	0	0	0	0	0
11	417.4	10	0	0	0	0	0	0
12	410.2	6	0	0	0	0	0	0
16	86.7	3	0	0	0	0	0	0
17	429.4	10	0	0	0	0	0	0
18	169.0	5	0	0	0	0	0	0

†Bucket area = 0.31 m^2.