AN INTERCROP TRIAL OF OKRA-MELON-LIMA BEAN

by

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TABLE OF CONTENTS

Page

LIST OF FIGURES

LIST OF TABLES

ABSTRACT

Small-hold farmers practice various styles of intercropping around the world; their management of biodiversity has been linked to higher ecological resilience and productivity in comparison with monoculture systems. Agroecologists have studied on-farm biodiversity and intercropping systems to understand the myriad of ecosystem services they provide; properly designed intercrop systems have been shown to increase resource use efficiency, rehabilitate agricultural ecosystems, and increase overall production. The right combination and arrangement of cultivars or species can offer complementary and facilitative interactions between plants creating an environment where they are able to exceed the performance of their monoculture counterparts. Varying vegetative and root architectures allow plants to make more efficient use of radiation, water, and nutrients; as well as functioning as pest management systems. This project was a summer intercrop system of okra, melon, and lima beans. The land equivalence ratio (LER) of the system was calculated by block and an LER was calculated for the entire field using means of treatment plot yields. The null-hypothesis that there is no significant difference between the intercrop and monocrop yields of okra pods and biomass was tested using ANOVA.

I. BACKGROUND

Introduction

The "Green Revolution" brought mechanization, higher yielding varieties, and petroleum-based inputs to agricultural systems all over the world; these solutions have offered yield increases at the cost of ecosystem health causing soil erosion and degradation, chemical contamination, and loss of biodiversity (Giller et al., 1997; Tilman et al., 2002). The expense of machinery and chemicals is typically cost prohibitive to small-hold farmers and has led to insurmountable debt for many poor farmers; as well as an inability to compete with transnational corporation's dumping of artificially low or inflated food prices on local markets (Rosset, 2008). Instead of imposing destructive, expensive, and synthetic solutions on farmers around the world, studying and sharing ecologically focused practices appears to be the healthiest solution for all life.

Ecologically based agriculture, known as Agroecology, focuses on the management of biodiverse systems to attain more naturalized on-farm ecosystems. The management of multiple crop species or genotypes in the same field is known as intercropping, it is also called companion planting, poly-cropping, or multiple cropping. Multitudinous combinations and arrangements are used all over the world, especially in low-input, unmechanized, and subsistence agricultural systems (Brooker et al., 2014). Biodiversity is the standard in traditional farming systems, these systems offer a diverse diet, spread income throughout the year, more stable production, minimize ecological risk, reduce insect and disease incidence, intensify production with limited resources, and maximize returns with lower levels of technology (Altieri, 1999).

Traditional intercrop systems are estimated to provide 15-20 percent of the world's food supply, with Latin American farmers intercropping 70-90 percent of their beans with maize, potatoes, and other crops (Altieri, 1999). Intercropping systems in tropical Africa were surveyed by Okigbo and Greenland (1976), and the compound farm system is the most widespread permanent agricultural system. The compound farms systems contain the largest number of crop species compared to other agricultural systems in tropical Africa. These farms produce food, oils, spices, drugs, fiber, structural materials, animal feed, and other various uses. The farm-village is often located in the center of a network of fields with paths that lead to other field systems. This compound farming system helps to protect against the ever-encroaching destruction of 'wild' spaces, preventing the loss of plant resources through management of a biodiverse agricultural system. In Tlaxcala, Mexico there are savannahs of rotational corn and alfalfa broken by apple, apricot, plum, and walnut hedges. Some farmers plant pole bean in the same hole as corn, and some farmers tend chenopods and other beneficial volunteer plants around their fields (Altieri and Trujillo, 1987). Indigenous peoples from Central and North America have been growing corn, squash, and beans (commonly referred to as the "three sisters"), as well as chilis and other crops, together for millennia. In fact, their intercrop cultivation and domestication occurred simultaneously in the milpa agroecosystem practice of Mesoamerican cultures (Zizumbo-Villareal et al., 2012). The milpa is typically a 2-season corn and vegetable field which is transitioned into perennial plants until the farmer deems it appropriate to return for a slash-and-burn to prepare the field to be planted once again in for corn and vegetables. In the Tehuacan Valley of Mexico, recognized as the most biodiverse arid region in North America, Blancas et al. (2010)

identified 610 species of plants managed through agroforestry and milpa field systems.

These management practices include tolerating, encouraging, and protecting 'wild' plant

species, as well as sowing seed, propagating, and transplanting these 'wild' cultivars

from natural areas into managed areas such as agricultural systems and home gardens.

The farmers of the Tabasco region demonstrate a complex set of practices in their

management of non-crop plants for soil improvement, food, fodder, medicine, and

condiments; Chacon and Gliessman (1982) interviewed farmers in the Tabasco region of

Mexico about their non-crop management practices. In this region the farmers classify

non-crop plants as buen monte and mal monte ("good" plants and "bad" plants). These

plants range in size from 5cm – 4m and in 76 percent of the cases a plant could be

classified as both good and bad depending on the context. The most abundant mal monte

are found in corn fields where farmers claim that the plants compact, heat, or even dry the

soil damaging their crop and making the soil difficult to work. Buen monte are believed

to loosen the soil, provide soil nutrients, cool the soil, and maintain soil moisture; the

buen monte is easily cut and usually does not over-grow the crop.

Intercrop Concepts

Although every system is unique, field arrangements in intercrop research have

been classified by a few common terms: "mixed" where the component crops are not

arranged, as would be seen in a pasture or cover-crop mixture; "row" or "within-row"

where the component crops are alternated within the same row; "strip" where the

component crops are planted in alternating rows or strips of multiple rows; and "relay"

where the component crops are spaced in time (Brooker et al., 2014). The spacing can be

"additive" containing 100 percent recommended density of all components, "substitutive"

with 50 percent recommended density of each crop, or "intermediate" containing some

other proportion of density (Malézieux et al., 2009). Intercrop studies test the

effectiveness of a combination with the use of the LER (Mead and Riley, 1981). The

LER is the sum of the ratios of each species yield in intercrop divided by the species

yield grown in monoculture (Fig. 1).

$$LER = \frac{I_1}{M_1} + \frac{I_2}{M_2} + \frac{I_x}{M_x} + \bullet\bullet\bullet$$

Fig. 1. The Land Equivalence Ratio Formula. Where 'I_x' represents the yield of a species in the intercrop mixture and 'M_x' represents the yield of that same species in monoculture.

Therefore, an LER over 1 is referred to as "overyielding" and it indicates that overall

more yield can be produced by growing crops together than growing them individually,

although an increase in production does not necessarily hold for all crops in the mixture.

(Willey and Osiru, 1972).

<center>Biodiversity</center>

In plant biodiversity experiments it has been shown that increasing the number of

species in a system can increase the total biomass, though most studies have focused on

natural prairie and natural forest ecosystems (Altieri, 1999; Malézieux et al., 2009). It is

believed these results are due to the sampling effect hypothesis or the complementarity

effect hypothesis; the sampling effect hypothesis says, as you increase the number of

species in a system the chances of including a dominant species which disproportionately

contributes to overall biomass increases (Loreau, 1998; Gastine et al., 2003). The

complementarity effect hypothesis theorizes that due to their differing needs and habits

<center>4</center>

different species will occupy different niches in the environment reducing the effects of competition (Vandermeer, 2011). Complementarity is often associated with facilitation; however, in facilitation plants do not just exist harmoniously but have a positive effect on each other especially when experiencing abiotic stress (Chu et al, 2008). In 11 long-term grassland experiments, with a mean length of 13 years and >7,000 productivity measurements, Tilman et al. (2012) show that plant diversity has at least the same effect on biomass production as nitrogen (N), water, carbon dioxide, herbivores, drought, or fire; and over time plant biodiversity became the dominant factor contributing to overall ecosystem biodiversity compared with other treatments.

Arrangement

In intercropping systems, the arrangement of the component crops in time and space has significant influence on their relative success. Yu et al. (2016) analyzed 552 cereal-legume studies and determined sowing time and density to be key components in the competitiveness of an intercrop component, with cereals having a higher RYT. Although maize-bean mixtures have shown to be more productive than planting in monoculture, there is reduced yield, pod production, and leaf area in the beans due to reduced light interception compared to the monoculture (Wiley and Osiru 1972; Gardiner and Craker, 1981). Franco et al. (2015) conducted an experiment which demonstrated overyielding in a combination of peanut, watermelon, okra, and cowpea. Their research emphasized the necessity of optimum sowing dates as watermelon outperformed all other components in the first year of the study. Comparisons of above and below ground interactions in a maize-soybean relay intercrop, where treatments altered spacing between components with partitioned or non-partitioned root zones, found above ground

interactions to have higher contribution to intercrop advantage (Yang et al., 2017). In a wheat and field bean study, where the sole crops were planted at 25, 50, 75, 100, and 150 percent recommended density (RD) and all combinations of the intercrop at 25, 50, 75, and 100 percent, the highest LER of 1.29 was achieved when both crops were planted at 75 percent RD; the PLER of bean being 0.56 and the PLER of wheat 0.73 (Bulson et al., 1996).

Rhizosphere

Probably the best-known form of facilitation in plant communities involves a symbiosis with nitrogen-fixing *Rhizobium spp.* that colonize roots of leguminous plants. In addition, there are numerous other microbial species associated with plants that also offer this function. In the tropics and sub-tropics there are over 200 species of plants nodulated by actinomycetes, the most promising of which are *Casuarina spp.* (Peoples and Craswell, 1992). Aside from legumes, the aquatic ferns of *Azolla spp.* are commonly used as a green manure intercropped with rice for their association with nitrogen-fixing cyanobacterium *Anabaena azollae*, as well as the ability to thrive in flooded fields and suppress weeds (Watanabe and Liu, 1992). Gramineous species, such as maize and wheat, have also been shown to facilitate nutrients in the rhizosphere. Phosphorus (P) mobilizing grasses exude acid phosphates, protons, and/or carboxylates into the rhizosphere which increases the concentration of soluble inorganic P in soil (Li et al. 2014). In a study of maize/faba bean intercrop, maize was shown to mobilize otherwise inaccessible P, resulting in grain yield increases of 49 percent for maize and 22 percent for faba bean over sole cropping (Li et al, 2007). Maize and sorghum were also shown to exude phytosiderophores, solubilizing and chelating otherwise insoluble organic and

inorganic forms of iron (Fe) and zinc (Zn), increasing their availability to the intercropped guava (Kamal et al., 2000). The observance of plants' ability to make efficient use of certain nutrients, alter the chemical makeup of the soil through root exudates, and have associations with N-harvesting microbial life offers much promise for the ecologically minded agriculturalist.

<div align="center">Pest Management</div>

Another way in which one crop can facilitate the growth of another is by controlling crop pests (i.e. insects and disease). For example, plant components can act as bait for insects, interfere with dispersal, or promote pest predators (Trenbath, 1993). Plants which function as bait to attract pests are referred to as "trap crops". Shelton and Badenes-Perez (2006) outline several modalities of trap cropping: conventional, dead-end, genetically engineered, perimeter, sequential, multiple, semiochemically assisted, push-pull, and biological control-assisted. Conventional trap cropping places a lower value crop, which is more attractive to pests, next to the higher value crop like the alfalfa-cotton strip intercrop where alfalfa functions as a reservoir for *Lygus spp.*; and the regular mowing of the alfalfa crop further reduces Lygus bug populations (Godfrey and Leigh; 1994). Dead-end trap cropping refers to plants which are highly attractive to insects, but their offspring are unable to survive. Sunn Hemp (*Crotalaria juncea*) has shown promise as a dead-end trap crop for the cowpea pod borer (*Maruca testulalis*) causing 50-100 percent larval mortality in laboratory conditions (Jackai and Singh, 1983). Genetically engineered trap cropping is the practice of relay cropping with early plantings of genetically modified crops, like those with the *Bacillus thuringiensis* (Bt) trait (Shelton and Badenes-Perez, 2006). Perimeter trap cropping arranges the trap crop around the

field of the main crop. In a study on control of pepper maggot (*Zonosemata electa)* in bell pepper fields planted with hot cherry pepper on the perimeter, maggots infested 15.4 percent of the main crop in control plots and only 1.7 percent of plots with the perimeter crop (Boucher et al., 2003). Sequential trap cropping is relay cropping with a trap crop, as in the study by Vernon et al. (2000) where dusky wireworms (*Agriotes obscurus)* caused 43 percent mortality of strawberries sole cropped, 29.6 percent mortality of strawberries planted 14 days before intercropped wheat, and 5.3 percent mortality of strawberries planted 8 days after intercropped wheat. Multiple trap cropping is the combination of crops for pest attraction throughout the season or for multiple species of pests (Shelton and Badenes-Perez, 2006). Mizell et al. (2008) recommend a combination of buckwheat, field pea, millet, sorghum, sunflower, and triticale to protect cash crops as all served as host plants for stinkbug and leaffooted bug species, as well as some attracting pollinating bees, specialist parisitoids of stinkbugs (adult Trissolcus spp.) and other generalist predators (i.e. ladybeetle species, lacewings, etc.). Semiochemically assisted trap cropping refers to use of crops that naturally produce semiochemicals or have semiochemicals applied to make them more attractive or repulsive to pests (Shelton and Badenes-Perez, 2006). Push-pull trap cropping is a combination of intercrop components that repel pests (through odors, pheromones, and other semiochemicals) and trap crops. The combination legume *Desmodium spp.,* maize, and napier grass is an effective push-pull system which has been adopted by nearly 60,000 farmers in western Kenya (Khan et al., 2014). Biological control-assisted trap cropping is using plants to enhance natural enemies of crop pests; Crookston (1976) found cotton untreated with insecticide but interplanted with sorghum achieved a yield 24 percent higher than treated

monoculture due to the sorghum functioning as a microhabitat for cotton bollworm

(*Helicoverpa armigera)* predators. Also, some weeds (specifically those from the

families Asteraceae, Apiaceae, and Fabaceae) can host and support populations of

beneficial arthropods that can suppress pest populations (Altieri and Letourneau, 1984).

II. OBJECTIVES

The overall goal of this research was to assess the productivity of an intercrop arrangement of okra, melon, and lima bean in central Texas. The first objective was to determine the LER of the intercrop treatments in relation to the monoculture treatments using their produce yields. The second objective was to determine if the intercrop treatment caused any significant difference in the production of produce and biomass yields. The third objective was to determine if there was any significant difference in soil nutrients between the treatments that may have caused variation in yield.

III. JUSTIFICATION

Few crops can withstand the summer heat in Texas, but okra, lima beans, and melons thrive. Small producers tend to practice strip intercropping out of necessity due to the limited size of their property and need for diversity at their markets. Okra requires hand harvesting and is a cultural standard in the diet of the southern United States. Clemson Spineless 80 Okra was recommended by a farmer in San Marcos, Texas and was used in the low-input intercrop study done by Franco et al. (2014). Melons are one of the few annual summer fruits that can be grown in the study area and have the best flavor when picked at full-slip, the term for when they pluck off the vine without being forced. Edisto 47 Muskmelon was selected for being well adapted to heat and humidity, as well as being resistant to Alternaria leaf spot, powdery mildew, and downy mildew. Lima beans are another popular staple of the southern diet and are known for growing well during hot weather. Henderson Bush Lima Bean was chosen for its wide adaptability to different climates and soil types.

IV. STUDY AREA

The research field was located at the Student Sustainable Farm on the Freeman Ranch in San Marcos, Texas. The soil is of the Tarpley series consisting of shallow, well-drained clay soil, with an A-horizon at depths of 0 - 15 cm., a B-Horizon at depths of 15 – 43 cm., and an indurated layer of limestone at depths of 33 – 52 cm. This soil series is not recommended for vegetable production according to the Natural Resource Conservation Service (NRCS) web soil survey. The field was prepared with disc-harrow, chisel plow, and then raked into beds by hand. Rocks of fist size and larger were removed by hand. The vegetation along the perimeter of the field was managed via string trimmer once per month. The beds and pathways were weeded with the use of a scuffle hoe and by hand. One drip line per bed was run down the centers of each of the 12 beds. The irrigation schedule was ever 2-7 days as necessary in relation to rainfall events but averaged 15.5 hours per week. The season lasted from May 27, 2017-November 2, 2017; during this time the average rainfall was 337.31 mm. and irrigation totaled 223.52 mm. for a total of 560.83 mm.

Experimental Design

The experiment consisted of an additive within-row/strip intercrop arrangement of three crops with their respective monocultures, arranged in a randomized block design with three blocks. Three blocks were monocultures of okra, melon and bean respectively, and the fourth block was an intercrop of all three species. The monocultures were replicated three times and the intercrop was replicated nine times. In the field treatments were randomly assigned to each section (Section A, B, and C) by the roll of a single die. Sections were 41 m by 5 m and separated by 1m wide pathways (Fig. 2). Each section was subdivided into 6 m long plots separated by 1 m wide pathways. Within plots, there were four 1 m wide beds separated by 33 cm wide pathways. The null-hypothesis was that there would be no significant difference in total yields between intercrop and monoculture treatments. The alternative hypothesis was that there would be significant difference in total yields between the intercrop and monoculture treatments.

The intercrop arrangement was additive, containing 100 percent recommended density of all three species (Fig. 3). Okra was seeded on May 27, 2017 down the centers of the assigned beds and thinned to 1 plant every 60.96 cm. on June 20. Melon was seeded into ten 72-cell trays on June 2 and transplanted between the okra on June 21, with 1 melon every 60.96 cm. Due to poor germination of the melon, the two spaces on each end of the bed were skipped but spacing was kept uniform between the transplants as can be seen in Fig. 2. Lima Beans were sown on June 23, in two rows on either side of each bed 33cm. from the center of the bed with one seed every 10 - 15 cm. Lastly, no fertilizer was applied to the field and no soil test were conducted prior to planting.
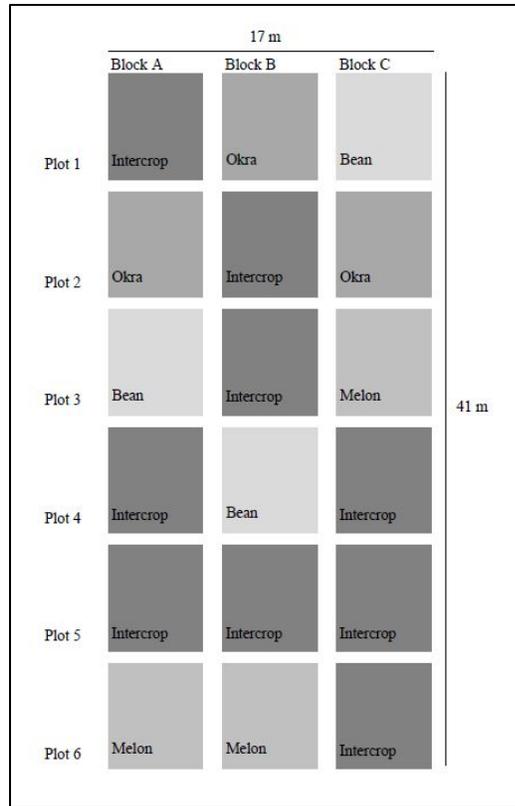
Fig. 2. Field Layout.
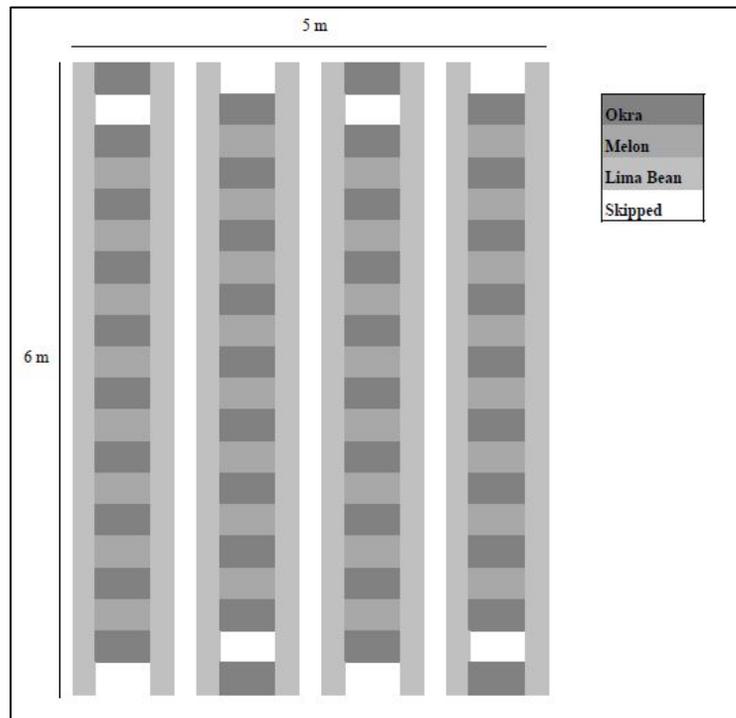
Fig. 3. Intercrop Treatment Plot Layout. The white cells signify spaces which were skipped due to a lack of melon transplants. The monoculture plots use the same spacing.

Harvest Procedure

Okra pods and melons were harvested at regular intervals of 2-5 days as the crops ripened throughout the season: July 25 to November 2 (100 days). There were 31 harvests of okra and 30 harvests of melon. Lima bean was harvested as dry bean at the end of the season. Yields were weighed by plot in aggregate. Once all plants ceased production, the okra plants were collected individually to be dried and weighed for comparing biomass production of monocrop versus intercrop. Twelve soil samples per plot were collected to form a composite sample for each plot. Soil tests were run for nitrate, phosphate, and potassium using the Palintest Photometer 7500.

VI. RESULTS

The LER was calculated for all three blocks using their respective monoculture yields and the mean yields of their intercrop plots (Fig 4). The LER was also calculated for the entire field using the mean yields of all the monocrop plots and the mean yields of all intercrop plots (Table 1).

$$\text{LER B} = \frac{61.34}{62.90} + \frac{0.06}{32.23} + \frac{.01}{1.21} = 0.98$$

Fig. 4. The LER Formula for Block B. The numerators are mean values of the intercrop yields in block B and the denominators are the monocrop yields of each crop from block B.

The vegetable yields in the intercrop were predominantly okra pods, means were calculated by treatment with each intercrop block having its own unique field (Table 2). Okra vegetative biomass was weighed by plant and means were calculated by treatment (Table 3). The intercrop yields of lima bean were greatly suppressed, and only a single melon was produced in the intercrop; means were calculated by treatment (Table 4 & 5).
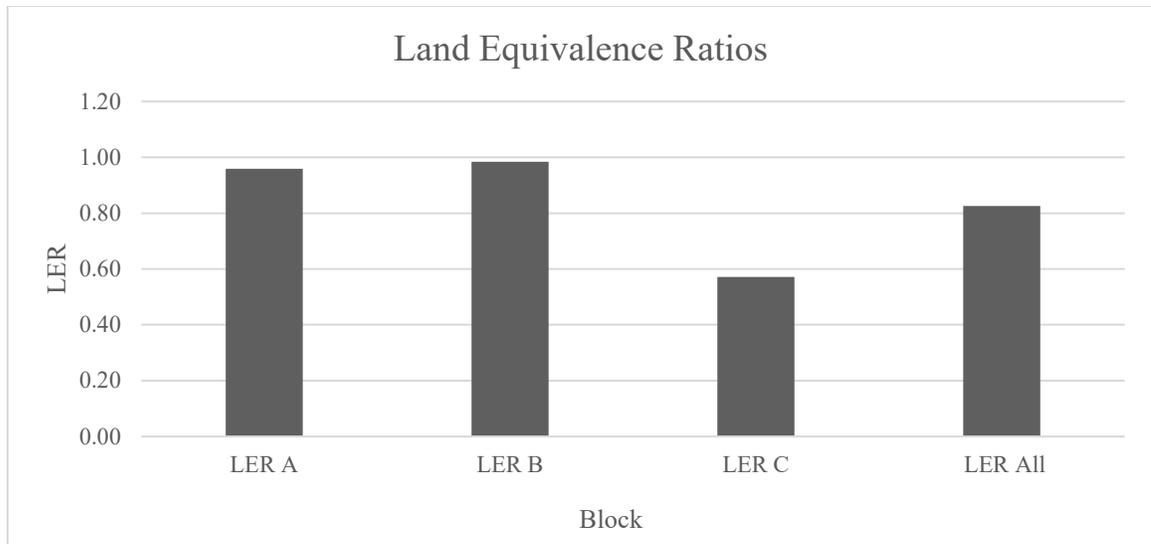

Fig. 5. Land Equivalence Ratios. The land equivalence ratios by block. LER All was calculated using the mean of all intercrop plot yields over the mean of all monoculture plot yields. a

16
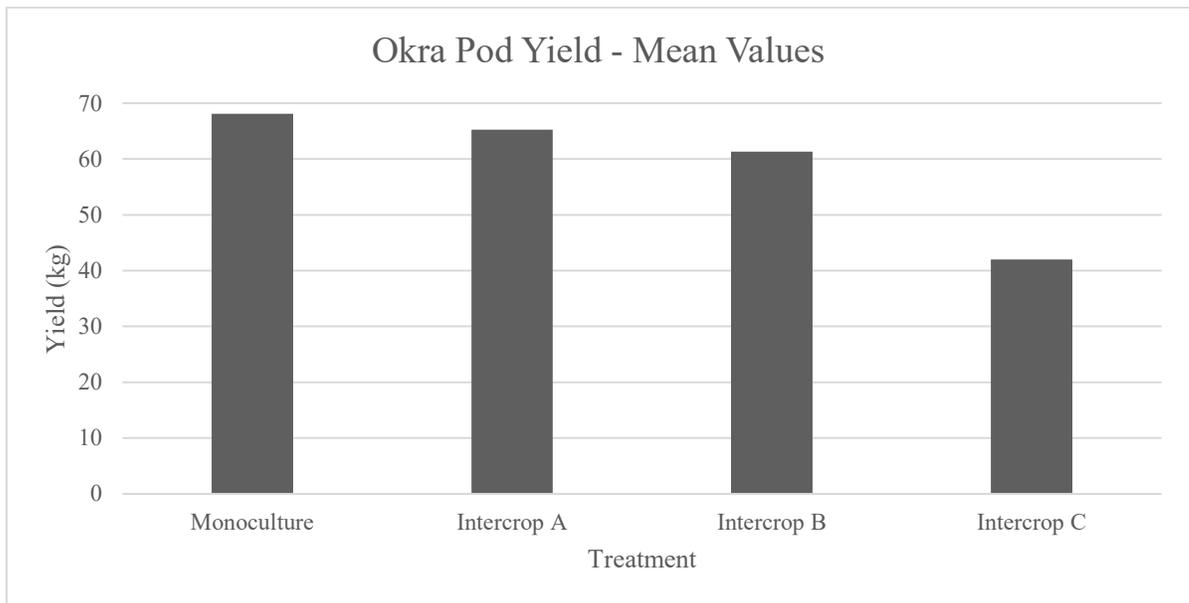
Fig. 6. Okra Pod Yield. The monoculture yield is a mean value of all three monocrop plots. The intercrop yields are mean values by block.
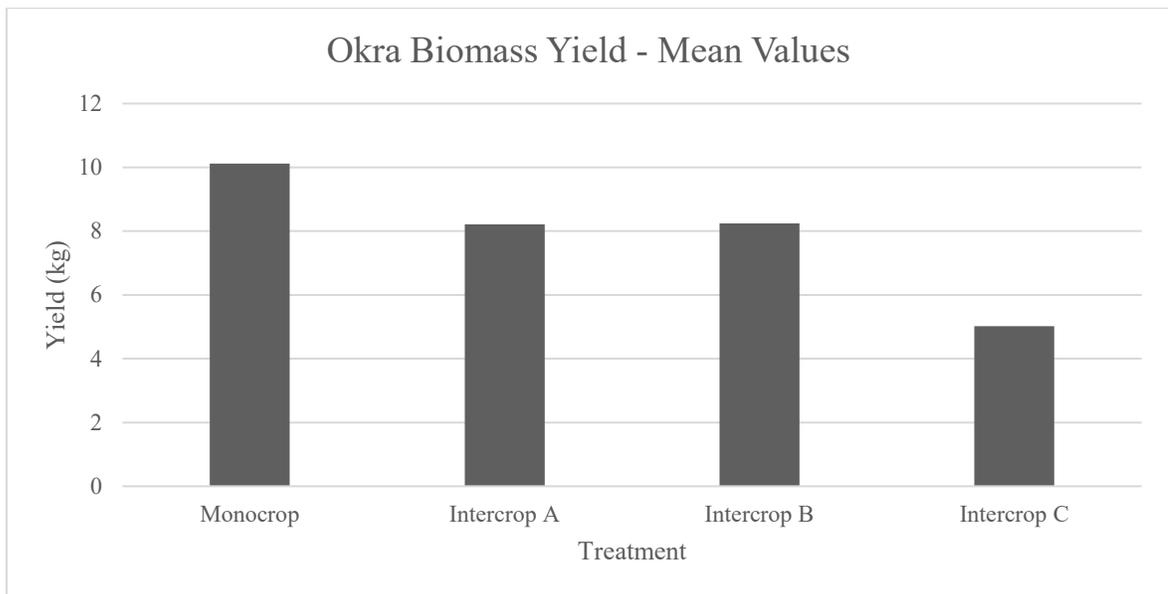
Fig 7. Okra Biomass Yield. The monoculture yield is a mean value of all three monocrop plots. The intercrop yields are mean values by block.
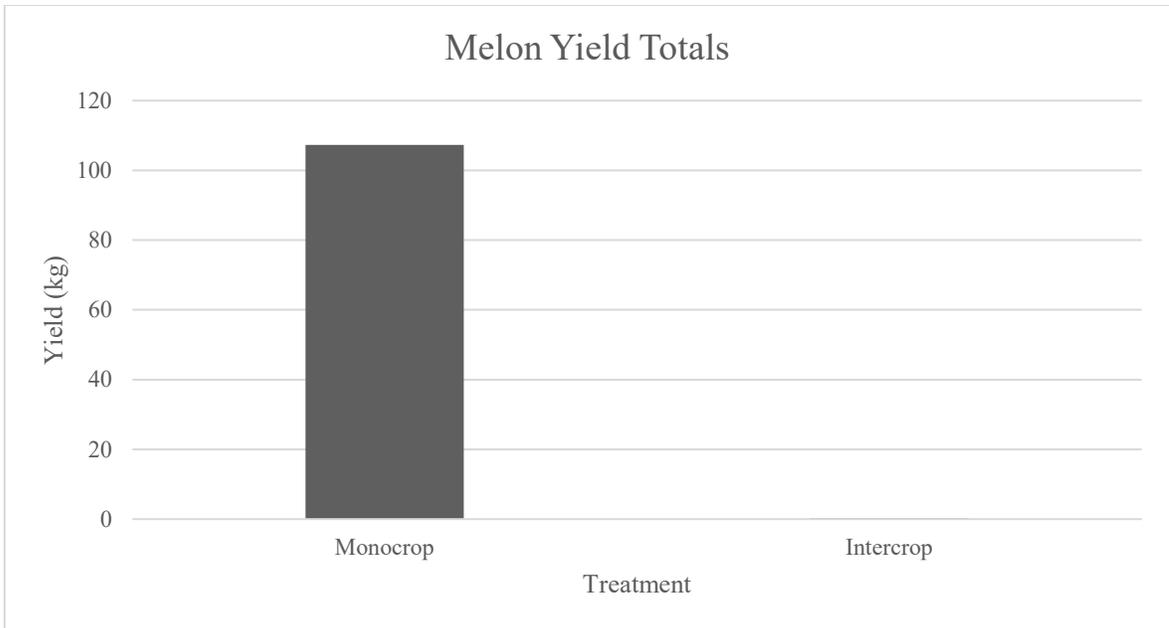
**Fig. 8.** Melon Yield. Yield totals by treatment.
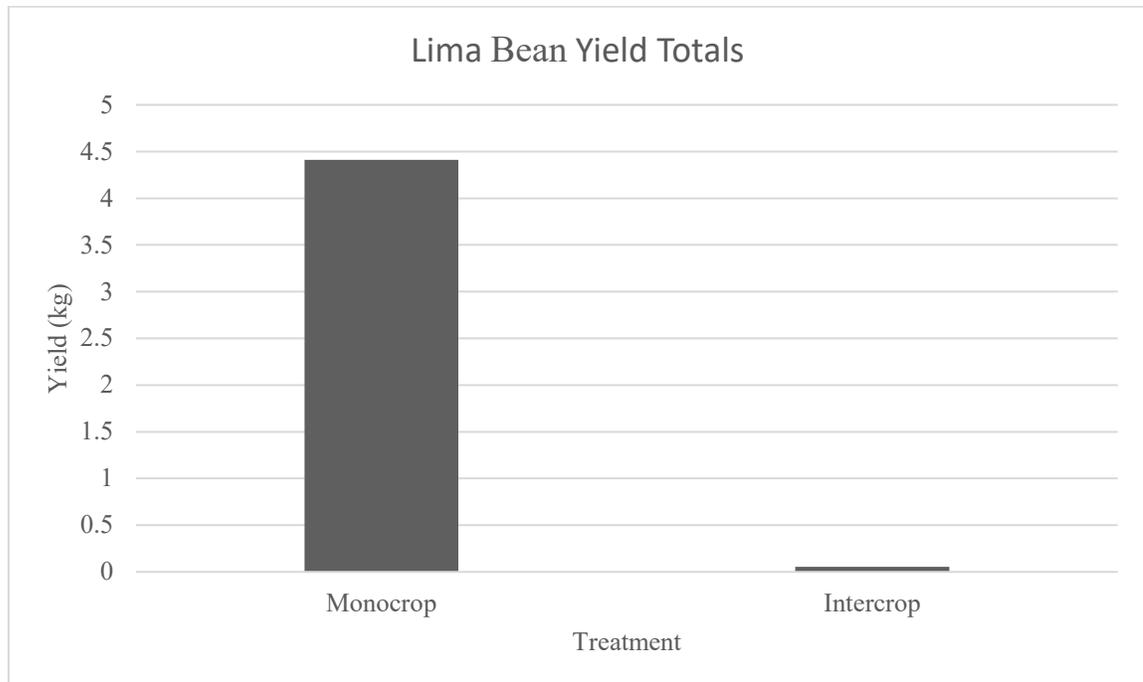
Fig. 9. Lima Bean Yield. Yield totals by treatment.

The ANOVA Single Factor tool in Excel was used to test the null-hypothesis that there would be no significant difference in orka pod yield between monoculture and intercrop (Table 1).

Table 1. Results of ANOVA for okra pod yield.

Okra Pod Yield						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Monocrop	3	204.41	68.14	26.99		
Intercrop	9	505.86	56.21	232.64		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	320.23	1	320.23	1.67	0.23	4.96
Within Groups	1915.14	10	191.51			
Total	2235.37	11				

Similarly, there was no significant difference in okra vegetative biomass between the monoculture and intercrop plots (Table 2).

Table 2. Results of ANOVA for okra biomass yield

Okra Biomass Yield						
SUMMARY						
Groups	Count	Sum	Average	Variance		
Monocrop	3	717.46	239.15	208.01		
Intercrop	9	1560.97	173.44	3700.45		
ANOVA						
Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	9716.18	1	9716.18	3.24	0.10	4.96
Within Groups	30019.60	10	3001.96			
Total	39735.78	11				

Yields of lima bean and melon in the intercrop were negligible so statistical analysis was not done on either crop's yields.

Since the intercrop yields were lower than monocrop yields soil tests of nitrate, phosphate, and potassium were performed for each plot and analyzed using ANOVA.

There was no significant difference in soil nutrients between the monocrop and intercrop treatments for any of these plant nutrients (Table 3 - 5).

Table 3. Results of ANOVA for soil nitrate.

Soil Nitrate

SUMMARY

Groups	Count	Sum	Average	Variance
Monocrop - N	9	173.03	19.23	17.31
Intercrop - N	9	181.23	20.14	43.43

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	3.74	1	3.74	0.12	0.73	4.49
Within Groups	485.89	16	30.37			
Total	489.63	17				

Table 4. Results of ANOVA for soil phosphate.

Soil Phosphate

SUMMARY

Groups	Count	Sum	Average	Variance
Monocrop - P	9	168.75	18.75	41.97
Intercrop - P	9	146.75	16.31	20.95

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	26.89	1	26.89	0.85	0.37	4.49
Within Groups	503.35	16	31.46			
Total	530.24	17				

Table 5. Results of ANOVA for soil potassium.

Soil Potassium

SUMMARY

Groups	Count	Sum	Average	Variance
Monocrop - K	9	2808.75	312.08	4300.78
Intercrop - K	9	2722.50	302.50	2635.94

ANOVA

Source of Variation	SS	df	MS	F	P-value	F crit
Between Groups	413.28	1	413.28	0.12	0.73	4.49
Within Groups	55493.75	16	3468.36			
Total	55907.03	17				

VII. DISCUSSION

Land Equivalence Ratios

The intercrop treatment only produced notable yields of okra, while the beans produced very little, and only one melon came from the intercrop treatment. The LER for blocks A and B were 0.96 and 0.96 respectively, whereas the LER for block C was 0.57. The high LER in blocks A and B can be attributed to the lack of intercrop production, and therefore a lack of competition. The lower LER in block C was the result of lower okra production in two of the plots, one only produced about 40 kg of okra pods and the other just over 23 kg. The average okra pod yield of all the intercrop plots being 56.21 kg.

Okra Yields

According to documents produced by Texas A&M AgriLife Extension, anticipated yields of okra under conventional practices should range from about 8,960 - 11,200 kg. per ha., melon should range from about 15,700 – 20,170 tons per acre, and dry beans should range from about 1,120 – 2,240 kg per ha. Converting these estimates to the planted area of each crop (0.04 ha.), okra should be expected to produce about 360 - 450 kg., melon should produce about 630 - 800 kg., and dry beans should produce about 40 – 90 kg. This field produced a total of 642.05 kg. of okra, 107.52 kg. of melon, and 4.46 kg. of dry bean. It is important to note that conventional practices include the application of fertilizers of which this project had none.

The ANOVA for okra pod yield produced a p-value of 0.23, indicating the variation in yields were not attributable to the planting treatment. The p-value exceeding

0.05 means we fail to reject the null-hypothesis that there is no significant difference between the monocrop and intercrop treatments.

The ANOVA for okra biomass yield produced a p-value of 0.01, indicating the variation in yields were not attributable to the planting treatment. The p-value exceeding 0.05 means we fail to reject the null hypothesis that there is no significant difference between the monocrop and intercrop treatments.

The two okra plots which were outliers may have been the result of a shallower soil profile in that area of the field, as the Tarpley soil series is known for hard limestone layers at depths as shallow as 33 cm.

Melon and Lima Bean Yields

The lack of melon and lima bean production in the intercrop treatment could be the result of several different factors: time of planting, plant spacing, or allelopathy.

Transplanting melons was delayed by 3.5 weeks to prevent melon vines from choking out the okra and beans, as was seen with watermelon in the first-year of the study done by Franco et al. (2014). In that year, peanut was planted just one week before watermelon and the peanut did not yield while the watermelon accounted for most of the yield in all 5 intercrop combinations. In future attempts at intercropping melon and okra it is recommended to only delay melon one or two weeks, alternatively transplanting both crops at the same time may produce better results.

While it was expected to see suppressed yields in the delayed planting of melon and lima bean, the severity of the results was not anticipated. This may have been compounded with the use of 100 percent recommended density. Bulson et al. (1997) saw best results at 75 percent recommended density, however they were able to report

overyielding at 50, 75, and 100 percent recommended density in their wheat and bean trials. In their alpine meadow study of facilitation and biomass-density relationships, Chu et al. (2008) found the largest total biomass at intermediate densities. Gardiner and Craker (1981) saw a reduction in light intercepted by bean of 50 percent compared to monoculture in their lowest maize density of 18,333 plants per ha. and less than 20 percent light interception by beans in the highest density of 55,000 plants per ha.

The use of 100 percent recommended density and a within-row design means there was only about 30 cm. between okra and melon plants. This spacing, along with the delay in melon transplanting, likely caused competition for solar radiation with the okra eventually shading out the melon to the point of crop failure.

It was expected that there would be edge effect witnessed in the lima bean rows on the edges of the intercrop plots but these plants performed like their counterparts within the plot. The distance from the drip tape may have played a part in these results. Since there was only a single run of drip tape down the center of each bed, the beans would have been roughly 33 cm. from the tape. Although the spacing was identical in the monocrop plots, which germinated well and produced full stands, the okra may have out competed the lima beans in harvesting water in the intercrop plots.

Alternatively, the suppressed growth of the beans in the intercrop plots may be the result of allelopathic compounds exuded by the okra. This would support the claim that okra is incompatible with beans as sited in the ATTRA document on companion planting, although the primary source for this claim could not be traced (Kuepper, 2001). However, there is evidence of allelopathic extracts from okra pods being effective at

24

inhibiting germination of the noxious grassy weed goosegrass (*Eleusine indica*) (Chuah et al., 2011).

Conclusion

The possible combinations of time, space, and plant selection are innumerable in intercropping trials. However, the literature shows that successful designs can offer various benefits. In the case of okra, melon, and lima bean several adjustments could be made to the design of this project.

Timing of planting has serious repercussions on each species ability to survive in the system. Simultaneous planting, or one to two weeks delay instead of three and a half weeks, could reduce competition resulting in a more even distribution of yield between species. Opting for substitutive density, where densities are closer to 50 percent of recommended density may prove more successful by reducing competition. The use of strip arrangements, where each row is committed to a specific species may also be a better design for intercropping. Strip intercropping allows for each species to form a uniform canopy and take advantage of the rhizosphere without competing too heavily with the other species. Allowing plenty of space between okra and plants with shorter growth habits is highly recommended due to the heavy shade which a healthy okra bush can cast, not to mention the possible allelopathic effects of okra. If using drip tape for irrigation, two lines per bed is recommended when planting multiple rows of plants in the same bed.

WORKS CITED

Altieri, M., & Schmidt, L. (1987). Mixing broccoli cultivars reduces cabbage aphid numbers. *California Agriculture, 41*(11), 24-26.

Altieri, M. A. (1999). The ecological role of biodiversity in agroecosystems. *Agriculture Ecosystems and Environment, 74* (pp. 19-31).

Altieri, M. A., & Trujillo, J. (1987). The agroecology of corn production in Tlaxcala, Mexico. *Human Ecology, 15*(2), 189-220.

Altieri, M. A., Letourneau, D. K., & Risch, S. J. (1984). Vegetation diversity and insect pest outbreaks. *Critical Reviews in Plant Sciences, 2*(2), 131-169.

Blancas, J., Casas, A., Rangel-Landa, S., Moreno-Calles, A., Torres, I., Pérez-Negrón, E., . . . Arellanes, Y. (2010). Plant management in the Tehuacán-Cuicatlán valley, Mexico. *Economic Botany, 64*(4), 287-302.

Boucher, T. J., Ashley, R., Durgy, R., Sciabarrasi, M., & Calderwood, W. (2003). Managing the pepper maggot (diptera: Tephritidae) using perimeter trap cropping. *Journal of Economic Entomology, 96*(2), 420-432.

Brooker, R. W., Bennett, A. E., Cong, W., Daniell, T. J., George, T. S., Hallett, P. D., . . . Karley, A. J. (2015). Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology. *New Phytologist, 206*(1), 107-117.

Bulson, H., Snaydon, R., & Stopes, C. (1997). Effects of plant density on intercropped wheat and field beans in an organic farming system. *The Journal of Agricultural Science, 128*(1), 59-71.

Cao, J., Shelton, A., & Earle, E. (2005). Development of transgenic collards (*Brassica oleracea L., var. acephala*) expressing a cry1Ac or cry1C bt gene for control of the diamondback moth. *Crop Protection, 24*(9), 804-813.

Chacon, J., & Gliessman, S. R. (1982). Use of the "non-weed" concept in traditional tropical agroecosystems of south-eastern Mexico. *Agro-Ecosystems, 8*(1), 1-11.

Chu, C., Maestre, F. T., Xiao, S., Weiner, J., Wang, Y., Duan, Z., & Wang, G. (2008). Balance between facilitation and resource competition determines biomass–density relationships in plant populations. *Ecology Letters, 11*(11), 1189-1197.

Chuah, T., Tiun, S., & Ismail, B. (2011). Allelopathic potential of crops on germination and growth of goosegrass (eleusine indica L. gaertn) weed. *Allelopathy Journal, 27*(1), 33-42.

Crookston, R. K. (1976). Intercropping--a new version of an old idea. *Crops and Soils,76*(2), 7-9.

Franco, J. G., King, S. R., Masabni, J. G., & Volder, A. (2015). Plant functional diversity improves short-term yields in a low-input intercropping system. *Agriculture, Ecosystems & Environment, 203*, 1-10.

Gardiner, T., & Craker, L. (1981). Bean growth and light interception in a bean-maize intercrop. *Field Crops Research, 4*, 313-320.

Gardiner, T., & Craker, L. (1981). Bean growth and light interception in a bean-maize intercrop. *Field Crops Research, 4*, 313-320.

Gastine, A., Roy, J., & Leadley, P. (2003). Plant biomass production and soil nitrogen in mixtures and monocultures of old field Mediterranean annuals. *Acta Oecologica, 24*(2), 65-75.

Giller, K., Beare, M., Lavelle, P., Izac, A., & Swift, M. (1997). Agricultural intensification, soil biodiversity and agroecosystem function. *Applied Soil Ecology, 6*(1), 3-16.

Gliessman, S. R. (1983). Allelopathic interactions in crop-weed mixtures. *Journal of Chemical Ecology, 9*(8), 991-999.

Gliessman, S. R. (1985). Multiple cropping systems: A basis for developing an alternative agriculture. *Innovative Biological Technologies for Lesser Developed Countries Workshop Proceedings. OTA, Washington, DC,* 69-83.

Godfrey, L., & Leigh, T. (1994). Alfalfa harvest strategy effect on lygus bug (Hemiptera: Miridae) and insect predator population density: Implications for use as trap crop in cotton. *Environmental Entomology, 23*(5), 1106-1118.

Jackai, L. E., & Singh, S. (1983). Suitability of selected leguminous plants for development of *Maruca testulalis* larvae. *Entomologia Experimentalis Et Applicata, 34*(2), 174-178.

Kamal, K., Hagagg, L., & Awad, F. (2000). Improved fe and zn acquisition by guava seedlings grown in calcareous soils intercropped with graminaceous species. *Journal of Plant Nutrition, 23*(11-12), 2071-2080.

Kaut, A., Mason, H., Navabi, A., O'Donovan, J., & Spaner, D. (2008). Organic and conventional management of mixtures of wheat and spring cereals. *Agronomy for Sustainable Development, 28*(3), 363-371.

Khan, Z. R., Midega, C. A., Pittchar, J. O., Murage, A. W., Birkett, M. A., Bruce, T. J., & Pickett, J. A. (2014). Achieving food security for one million sub-Saharan African poor through push-pull innovation by 2020. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 369*(1639).

Kuepper, G., & Dodson, M. (2001). In Duncan J. (Ed.), Companion planting & botanical pesticides: Concepts and resources *National Center for Appropriate Technologies (NCAT).*

Li, L., Li, S. M., Sun, J. H., Zhou, L. L., Bao, X. G., Zhang, H. G., & Zhang, F. S. (2007). Diversity enhances agricultural productivity via rhizosphere phosphorus facilitation on phosphorus-deficient soils. *Proceedings of the National Academy of Sciences of the United States of America, 104*(27).

Loreau, M. (1998). Separating sampling and other effects in biodiversity experiments. *Oikos,* 600-602.

Mizell III, R. F., Riddle, T. C., & Blount, A. S. (2008). Trap cropping system to suppress stink bugs in the southern coastal plain. Paper presented at the *Proceedings of the Florida State Horticultural Society, 121,* 377-382.

Moreno-Calles, A. I., Casas, A., García-Frapolli, E., & Torres-García, I. (2012). Traditional agroforestry systems of multi-crop "milpa" and "chichipera" cactus forest in the arid Tehuacán valley, Mexico: Their management and role in people's subsistence. *Agroforestry Systems, 84*(2), 207-226.

Okigbo, B., & Greenland, D. (1976). Intercropping systems in tropical Africa. *American Society of Agronomy, 27,* 63-102.

Peoples, M. B., & Craswell, E. T. (1992). Biological nitrogen fixation: Investments, expectations and actual contributions to agriculture. *Plant and Soil, 141*(1-2), 13-39.

Perrin, R., & Phillips, M. (1978). Some effects of mixed cropping on the population dynamics of insect pests. *Entomologia Experimentalis Et Applicata, 24*(3), 585-593.

Pickett, J. A., Woodcock, C. M., Midega, C. A., & Khan, Z. R. (2014). Push–pull farming systems. *Current Opinion in Biotechnology, 26*, 125-132.

Rosset, P. (2008). Food sovereignty and the contemporary food crisis. *Development, 51*(4), 460-463.

Shelton, A., & Badenes-Perez, F. (2006). Concepts and applications of trap cropping in pest management. *Annu. Rev. Entomol., 51*, 285-308.

Shelton, A., & Nault, B. (2004). Dead-end trap cropping: A technique to improve management of the diamondback moth, *Plutella xylostella* (Lepidoptera: Plutellidae). *Crop Protection, 23*(6), 497-503.

Tilman, D., Cassman, K. G., Matson, P. A., Naylor, R., & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature, 418*(6898), 671.

Tilman, D., Reich, P. B., & Isbell, F. (2012). Biodiversity impacts ecosystem productivity as much as resources, disturbance, or herbivory. *Proceedings of the National Academy of Sciences of the United States of America, 109*(26).

Trenbath, B. (1993). Intercropping for the management of pests and diseases. *Field Crops Research, 34*(3-4), 381-405.

Vandermeer, J. (2011). *The ecology of agroecosystems.* Jones & Bartlett Learning.

Vandermeer, J., & Perfecto, I. (1995). *Breakfast of biodiversity: The truth about rain forest destruction.* Institute for Food and Development Policy.

Vernon, R. S., Kabaluk, T., & Behringer, A. (2000). Movement of *Agriotes obscurus* (Coleoptera: Elateridae) in strawberry plantings with wheat as a trap crop. *The Canadian Entomologist, 132*(2), 231-241.

Vilich, V. (1993). Crop rotation with pure stands and mixtures of barley and wheat to control stem and root rot diseases. *Crop Protection, 12*(5), 373-379.

Watanabe, I., & Liu, C. C. (1992). Improving nitrogen-fixing systems and integrating them into sustainable rice farming. *Biological nitrogen fixation for sustainable agriculture* (pp. 57-67) Springer.

Willey, R., & Osiru, D. (1972). Studies on mixtures of maize and beans (*Phaseolus vulgaris*) with particular reference to plant population. *The Journal of Agricultural Science, 79*(3), 517-529.

Yang, F., Liao, D., Wu, X., Gao, R., Fan, Y., Raza, M. A., . . . Liu, J. (2017). Effect of aboveground and belowground interactions on the intercrop yields in maize-soybean relay intercropping systems. *Field Crops Research, 203*, 16-23.

Yu, Y., Stomph, T., Makowski, D., Zhang, L., & Van Der Werf, W. (2016). A meta-analysis of relative crop yields in cereal/legume mixtures suggests options for management. *Field Crops Research, 198*, 269-279.

Zizumbo-Villarreal, D., Flores-Silva, A., & Marín, P. C. (2012). The archaic diet in mesoamerica: Incentive for milpa development and species domestication. *Economic Botany, 66*(4), 328-343.