INTERCROPPING OF RELATED VEGETABLES

By

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°C	degrees Celsius
DM	dry matter
ELER	effective land equivalent ratio
EMA	effective monetary advantage
H	height, wind barrier
HI	harvest index
LAI	leaf area index
LER	land equivalent ratio
MA	monetary advantage
RY	relative yield
RYT	relative yield total
SLER	staple land equivalent ratio

CHAPTER I

INTRODUCTION

American farmers produced an average of $2.5 billion per year of government-measured principle vegetables on 1.1 million hectares from 1975 to 1978. This compares with $4.5 billion worth on 1.1 million hectares in 1987. Increased consumption of fresh and frozen vegetables have accounted for all of this increase.

The upswing in vegetable consumption has necessitated greater supplies of high quality fruits and vegetables over a longer period during the year. The three primary states producing fresh market vegetables, California, Florida, and Texas, accounted for 69.2% of the total U.S. production in 1987. The other 30% of the market for fresh vegetables is serviced by specialized production areas for national markets [e.g. southeastern states for sweet potatoes (Ipomoea batatas)] and by small producers selling to their local markets.

Oklahoma currently (1986) grows vegetables on 18,000 hectares with an estimated value of $35.4 million including 12,907 hectares of fresh market production (Motes, 1986). These figures have increased each of the last five years. Oklahoma's principle crops include melons, greens (including spinach) for processing, southernpeas, spinach, potatoes, and tomatoes. Other important horticultural food crops in Oklahoma are peaches and pecans. The majority of the State's production of these crops goes to local fresh and processing markets.

Oklahoma producers have several advantages over those in the large producing states, along with some disadvantages. The advantages include inexpensive land, ample high quality water, a central national location, a still unsaturated local market, and the proximity of several large processors and metropolitan areas. The disadvantages, which prevent the state from playing a large role in national produce marketing, include the temperate, seasonal climate; lack of new technology in all phases of production and marketing; relatively little production; and inexperienced growers and marketers.

To compete for market share, Oklahoma growers must do what they can to maximize production and to better use the local market. Intercropping may be one way the grower can do that. Because intercropping can increase total yield per land unit (Crookston, 1976; Willey, 1979a), the grower can profit more from each hectare harvested.

During this study, related vegetables grew in intercrop. Although most studies show more benefit from intercropping diverse rather than related components, the close relationships were selected for this study because of the intense, specific management needed for vegetable production in Oklahoma. Intercropping unrelated vegetables would likely waste inputs and might even reduce yields due to compromised cultural practices.

This study examined intercrops of solanaceous or leguminous crops for fresh market production. Within each of the two experiments the crops chosen, tomato (Lycopersicon esculentum) and eggplant (Solanum melongena) or snap bean (Phaseolus vulgaris) and southerpea (Vigna unguiculata), had similar cultural requirements and overlapping methods of pest management, minimizing inputs and managerial requirements. The crops selected for each of the two studies were thought to differ enough or bring certain attributes; including varied root systems, different fruit development and harvest times, and the ability to alter wind movement in the field; to the combinations which would improve net return to a grower. Bell pepper (Capsicum annuum) was added in the second year with the intent that its pollination and fertilization would benefit from the wind barrier effects of the eggplant or staked tomatoes.

This study examined the production and economic benefits of the intercrops. It should benefit Oklahoma farmers and others outside the state by illustrating alternative methods for improving crop yield and improving competitiveness of our growers. Researchers will benefit from knowing the value of this type of intercrop in Oklahoma.

CHAPTER II

REVIEW OF LITERATURE

In developed nations, farmers most often plant one crop in the field for a given length of time (Horwith, 1985), a practice called monoculture (Horwith, 1985), or sole cropping (Willey, 1985). Recently, researchers and farmers have begun to look at the combined culture of two or more crops as an alternative to monocropping, the practice of intercropping.

Intercropping involves growing two or more crops on the same land simultaneously (Willey, 1979a). Synonyms for intercropping include polyculture (Gliessman, 1982), interplanting (Crookston, 1976), mixed cropping (Willey, 1979a), multiple cropping (Pearce and Edmondson, 1984), strip cropping (Robinson, 1984), or companion cropping (Horwith, 1985). The intercrop may be in alternate rows (Crookston, 1976), alternate strips of several rows (Robinson, 1984), alternate blocks of the component crops [name for crops in an intercrop (Willey, 1979a)], or the crops may be grown in mixed rows (Crookston, 1976; Willey, 1979a).

Several of these intercropping synonyms have alternate or more precise meanings which limit their use. Alleycropping implies a specific location of the component crops, with crop growing in the alleys of other crops. Companion cropping implies growing two or more crops together for the benefit of one or more of the components.

Polyculture, polycropping, and multicropping seem synonymous with relay cropping, defined below, which relates somewhat to intercropping. Willey (1979a) suggested confining the use of the term mixed cropping to situations of mixed-row or mixed-broadcasted intercropping. The term strip cropping seems best when referring to growing alternate strips of several rows of the component crops.

A practice closely tied to intercropping called relay cropping, deserves mention. Intercropping involves growing component crops with a large overlap in their times in the field; relay cropping applies to situations with brief time overlap among components (Willey, 1979a). Possible synonyms for relay cropping have been discussed here earlier.

Through much of history, agriculture, especially tropical agriculture (Willey, 1979a), has used intercropping techniques. Early American settlers watched indians sow corn, beans and squash together in the same field (Crookston, 1976). Later, as a matter of convenience, American farmers stopped using intercropping (Horwith, 1985), favoring monocultures. Now interest in intercropping has increased again.

In many developed countries, intercropping has gained the attention of many, as a practice (Crookston, 1976; Willey, 1979a) and a research topic (Horwith, 1985; Willey, 1979a). Factors making researchers and farmers look at intercropping include concerns about health and environment (Horwith, 1985), commitment to land use maximization (Crookston, 1976) along with the promises of increased productivity, reduction of input requirements, and greater yield stability (Willey, 1979a).

Intercropping methods vary widely throughout the world. During a discussion of constraints on intercropping research, Willey (1985) listed three general categories of how a farmer may need to select and arrange component crops. The first situation involved maximizing output per land unit. A second category restrained the intercrop to situations where a farmer needed to attain a certain yield ratio from the component crops. The third instance Willey discussed included intercrops by farmers needing a minimum yield of one or more of the component crops. Other considerations farmers must take into account when planning an intercrop include planting and harvest dates, risk management, and capital management. These factors and situations must also be considered by researchers planning intercropping research (Willey, 1985).

Most non-experimental intercropping mixtures contain highly varied component crops. This may be to take advantage of reduced competition between similar plants growing close together as they do in monoculture. The most advantageous intercrops contain corn (Zea mays L.) or sorghum (Sorghum bicolor L.) (Crookston, 1976). These two species, being C4 plants, have three characteristics which set them apart from other crop species and make them valuable in intercrops: 1. They have higher temperature requirements than most crops, 2. they have higher light saturation points, and 3. they utilize CO_2 better than C3 plants. Crookston (1976) cited several reports of a C4 crop in intercrop with a C3 crop such as bean (Phaseolus sp. and Vigna sp.) or sweet potato (Ipomoea batatas).

Specific advantages of intercropping include improved resource use and synergistic effects. The most frequently cited advantage of intercropping is increased yield. This may or may not go along with more efficient land use than under monocropping (Willey, 1985). Wahua (1985) reported better total yield in maize/melon intercrops compared to sole crop yields, although melon seed yield was reduced in intercropping. In a sunflower (Helianthus annuus)/legume intercrop, by Narwal and Malik (1985), seed yield per plant of sunflower and seed weight were reduced. The yield reduction varied depending on the other component in the treatment. The yield of the legume was also reduced by the intercrop. Seed weight also decreased in the intercropped legume, except in peanut (Arachis hypogaea) and greengram (Vigna mungo). Greengram with sunflower proved to be the only suitable intercrop, producing an LER of 1.05. The two researchers reported no consistent changes in protein or oil content of the crops in intercrop versus monocrop. In their work, increased plant population made up for reduced yield per plant, giving an improved total yield (and LER) in the greengram/sunflower intercrop.

The disadvantages of intercropping also become apparent when one looks at the study by Narwal and Malik (1985). Decreased yield of the component crops occurs frequently. If, as Willey (1985) suggested may be the case, a farmer cannot afford loss of any yield of one or more of the component crops, even Narwal and Malik's greengram/sunflower intercrop would not be of value. Another loss farmers concern themselves with involves ease of maintenance and culture on their farms. Several researchers have implied intercropping can increase cultural requirements and costs (Lamberts, 1984; Willey, 1979a). Others have implied these increases do not necessarily occur (Crookston, 1979).

One of intercropping's more noticeable aspects is the altered plant arrangement, which accompanies one of the practice's least noticeable aspects: rhizosphere changes. Increased plants per land unit usually accompanies the altered plant arrangement in intercrops. The general rule of yield and plant population presented by Holliday (1960) indicates that biological yield increases asymptotically as plant population increases. That is, yield increases to a point, with the rate of increase slowing and finally stopping at a maximum as plant population increases to a maximum within the given space. He contrasted this with plant reproductive yield (yield of seeds and fruit) following a parabolic curve as plant population increases. Here, reproductive yield improves as plant density increases until an optimal density is attained, after which reproductive yield decreases until it reaches zero at a certain population.

The difference between vegetative and reproductive yields at various plant populations may play a role in intercropping. These relationships become apparent when one looks at research on a maize/melon intercrop, presented by Wahua (1985). The melon serves a dual purpose in African fields: as a living mulch used to control weeds and erosion, and as a crop plant whose seeds are used locally. Wahua reported findings on changes in biological and reproductive yield of the component crops when they were intercropped using graduations of melon populations from 0 to 20,000 plants per hectare and maize populations of 0 or 40,000 plants per hectare. Melon yield per hectare increased as population increased, with no leveling off or reduction at high populations. In intercrop, melon yield followed the same trend but yields were lower than in comparable monocrop densities. Maize yields declined as melon population increased. On a per plant basis, melon seed yield decreased as population increased, and again, yields in intercrop at the same melon population were lower. When Wahua added together per hectare melon and maize seed yields from intercrop and compared them to corresponding sole crop yields, he found land equivalent ratios were greatest at low and high maize populations, in contrast to Holliday's reproductive yield hypothesis. Perhaps mixtures behave differently than sole crops. Wahua discussed crop shading (within and between the component species) and its relation to seed yield, emphasizing high leaf and bract number at moderate melon populations as a possible cause for low per-plant melon seed yield under those treatments. Wahua also noticed highest melon dry matter (DM) production at the highest melon population. The increased dry matter production and higher reproductive yield per hectare follow Holliday's equations and indicate optimum melon population for maximum DM and seed production was not achieved. Wahua did what Willey (1985) suggested intercropping researchers need to do: He kept the local needs in mind and reported results relevant to the farmers and to other researchers.

As intercropping researchers change plant populations, they must take into account how those populations are arranged in the field, since varying the planting pattern alters the yields of many crops. Robinson (1984) studied three basic intercropping patterns, strip, row and mixture, in sunflower plantings. He concluded sunflower was incompatible to intercropping, although strip arrangements gave better yield than alternate rows or within row mixtures. Another researcher found alternate barley (Hordeum sativum)/field bean (Vicia faba) rows gave higher LERs than within row mixtures, although both out produced comparable monocrops (Martin and Snaydon, 1982). Herbert, et al. (1984) reported similar results from an intercrop of corn (Zea mays L.) and soybean (Glycine max). In their study within-row mixtures having low soybean plant populations did not reduce corn DM production compared to corn in monocrop. In all intercrops total DM and protein production per land unit exceeded those of either monocrop, with per row corn DM yield higher and per row soybean DM lower in the intercrops. Verma, et al. (1985) used various planting ratios to study competition in potato (Solanum tuberosum)/sugarcane (Saccharum officinarum) intercrops. They found a 1:2 ratio of cane to potato rows better met their goals than 1:1 mixtures, within row mixtures or relay cropping.

The planting patterns and choices of component crops in intercrops affect the rhizosphere, influencing root growth, soil structure, soil moisture, nutrient availability, and microbial populations. Researchers should be aware of the root structures of their component crops (Wahua, 1984). Weaver (1927) reported vast differences in rooting pattern between tomato (Lycopersicon esculentum), eggplant (Solanum melongena) and bell pepper (Capsicum annuum). A modern guide for vegetable growers classified tomato as deep rooting and eggplant and bell pepper as moderately deep rooting (Lorenz and Maynard, 1980). In a study of beet (Beta vulgaris) roots by Bleasdale (1966), root weight per plant decreased as plant population increased. He attributed the reduction to reduced total respiration by the leaves.

Beneficial effects of altered plant populations can also be found. The sugarcane/potato intercrop by Verma,et al. (1985) increased soil nitrogen and decreased soil bulk density compared to sugarcane monocrops, synergistic effects which can influence yield. The increased plant population in many intercrops can adversely affect soil and leaf water potential. When beans (Phaseolus vulgaris) and sugarcane grew together, the cane and soil had lower water potentials than were found in monocrop plots (Leclezio, et al., 1985). If soil moisture is unlimited and a wind barrier effect occurs, intercrops may use water more efficiently (Hulugalle, 1986).

Another facet of the rhizosphere, the bacterial population, can be altered by intercropping. Plots of maize, melon (Colosynthis vulgaris L.) and cowpea (Vigna unguiculata) had higher bacterial counts if any two species grew in intercrop than if any one grew in monocrop (Wahua, 1984).

As Hulugalla and Lal (1986) implied in their water use efficiency study, intercropping can influence wind speed and gas exchange. Wind barriers can increase heat accumulation, prevent damage from wind-blown sand (Peirce, 1987), and improve DM production (Holley, 1985).

Intercropping may further improve plant production and the plant growing environment by altering pest populations (Horwith, 1985). This has not been proven to occur yet. At least one study suggests many companionate intercrops, used by gardeners to reduce insect damage, may be of little value. Cranshaw (1984) found no beneficial reduction in cabbage pests by intercropping with nasturtium

(Trupaeolum majus), thyme (Thymus vulgaris), or rosemary (Rosmarinus officinalis) in Minnesota.

Horticultural crops, when intercropped, follow many of the yield trends found in agronomic intercrops. Yield, environment, and return change if horticultural crops grow together.

Annual crops tend to improve land use efficiency in orchards. Growing radishes (Raphanus sativus) between rows of young pear (Pyrus communis) trees produced LERs approaching 2.0 (Newman, 1986). Grape growers realize greater return if they grow vegetables between the grape rows (David, et al., 1986).

Planting two or more diverse vegetables in the same field has proven beneficial. A mustard green (Brassica juncia)/eggplant relay intercrop out-yielded monocrops of either of the two species (Brown, 1986b). Similar findings occurred in kale (Brassica oleracea, Acephala Group)/muskmelon (Cucumis melo, Reticulatus Group) relay intercrops (Brown, 1986a). Brown (1986c) also reported improved total yield from English pea (Pisum sativum)/tomato relay intercrops, and noted pea yields further increased if tomato rows had a mulch of black polyethylene. Lamberts and Hagen Meadow (1982) found increased total yields in corn/English pea intercrops accompanied by reduced component yields, and protein and calorie yields near those of corn monocrops. Woolley and Rodriguez (1987) reported reduced bean (Phaseolus vulgaris) yields in several intercrops with maize. They found little reduction in maize yields. Using dozens of maize cultivars of several growing habits, the two showed varied affects of the cultivars on bean yield, indicating the need for selection of proper cultivars for the bean/maize intercrops common in Central

America. Earlier, Davis, et al. (1984) showed yield differences in bean/maize intercrops using different bean cultivars, with intercrops containing climbing beans outyielding ones with bush beans. However, both habits performed worse in intercrop than in monocrop. Zimmerman, et al. (1984a) also found varied bean cultivar responses to intercropping with corn. They noted a correlation between monocrop and intercrop bean yields within each cultivar, and went on to note the beans may not be able to be bred specifically for improved performance in intercrops.

In a corn/tomato intercrop, with tomatoes staked to current season's corn stalks, a researcher found higher returns than if the tomato plants grew on traditional stakes (Kotosokoane, 1985). Lower input costs made up for reduced yield in the non-traditional staking trial. In an area where nutritional yield from vegetable crops concerns growers most, Prabhakar, et al. (1985) found benefit from intercropping beets (Beta vulgaris), peas, or kohlrabi (Brassica oleracea, Gongylodes Group) with bell peppers (Capsicum annuum) or okra (Abelmoschus esculentus).

Plant responses in intrafamiliar and intraspecific intercrops have also been investigated. In the 1960's work focused on intraspecific intercrops of agronomic crops. Mixtures of field corn cultivars showed greater yield stability, but no greater yields, than cultivars grown as monocrops (Funk, 1964). Clay and Allard (1969) found the opposite true of barley mixtures. Their results showed slight yield increases with no increase in yield stability when barley cultivars were intercropped. The yield increases varied with cultivars, making the researchers suggest breeding programs be set up to provide cultivars for use in diverse plantings. Using two planting dates, Frey and Maldonado (1968) showed oat (Avena sativa) mixtures outperformed monocrops in more stressful environments. Slight yield increases occurred in mixtures planted later than recommended for Iowa, which meant plantings grew through hot days not present during a normal season. The researchers suggested one cultivar may be making up for damage incurred by another cultivar, creating what the two called an "indeterminant population" from determinant plants.

Recently, the idea of improving yields through closely related intercrops has been investigated in several horticultural crops. This has been brought about by observations that modern equipment and management does not match well with more diverse intercrops (Lamberts, 1984). A group of sweet potato researchers showed yield increases of 30 to 40% when they planted alternate rows of deep and shallow bulking sweet potato cultivars (Mishra, et al., 1983). The yield improvements increased as plant population increased, suggesting the alternate row plant arrangement reduced competition between plants.

Non-food crops have also been evaluated for performance in intrafamiliar intercrops. No changes in flower quality occurred when tulips and lilies for cut flowers grew in intercrop, although tulip harvest required extra care to prevent damaging the yet-to-be-harvested lily crops (Greef and Hendriks, 1985).

The research on closely related intercrops has been picked up by vegetable growers in Florida, who grow cucumbers (Cucumis sativus) with summer squash (Cucurbita pepo var. melopepo) and eggplant with chili peppers (Capsicum annuum and C. frutescens) in alternate strips or rows (Lamberts, 1984).

Several researchers have studied snap bean as a potential component crop for intercropping. Clark and Francis (1985) reported reduced pod number and pod dry weight (DW) in maize/bean intercrops. Later in the same season, the yield reductions increased, as the maize became more competitive. Growing Phaseolus vulgaris for dry beans, Zimmerman,et al. (1984b) showed a correlation between seed weight and grain yield in intercrops with maize and in bean monocrops. Harvest index also correlated well with grain yield, but only in sole crops, showing the different growth habits of intercropped versus sole cropped beans. Izquierdo and Hosfield (1983) suggested how intraspecific intercropping of Phaseolus vulgaris could improve yields if cultivars with poor growth habits were cropped with architecturally superior strains. Another study also reported reduced bean yields in intercrops with maize and sorghum, but the intercrop treatments had relative yield totals (RYTs) of 1.35 and 1.37, respectively. The intercrop treatments gave more stable yield than monocrop treatments over multiple seasons and locations.

Southernpeas have been used as an agronomic crop and as a horticultural crop in intercrop studies. In a study by Faris, et al. (1983) mentioned earlier in the discussion of bean intercrops, RYTs for maize/southernpea and sorghum/southernpea were 1.31 and 1.30, respectively. Intercrop yield stabilities exceeded those of the monocrops. Another maize/southernpea intercrop produced an LER greater than 1.0 (Ofori and Stern, 1987). In that study, LER for the intercrops trended higher as southernpea sowing dates became earlier, relative to maize sowing dates. LER also increased as total plant population increased over monocrop populations. Nutritionally, intercrop plots had similar protein yields, regardless of relative sowing dates. In maize grain, however, nitrogen yield per hectare decreased as sowing date became later relative to southernpea sowings. Investigating biological and reproductive yield of maize/southernpea intercrops at several nitrogen fertility regimes, Ofori and Stern (1986) found varied results. At a given nitrogen level, leaf area index (LAI) decreased for maize and southernpea when grown in intercrops. In monocrop, LAI increased for both crops as nitrogen fertility level went up. In intercrop, LAI increased for maize and remained steady for southernpea as nitrogen levels increased. Nitrogen uptake in intercropped maize and southernpea exceeded uptake in monocropped plants, although total nitrogen concentration in the plants remained unaffected by cropping system. DM production for the two species decreased when the crops grew in intercrop, compared to sole crop DM production at a single fertility level. Maize DM production increased in both cropping systems as fertility increased, but increased nitrogen levels only improved southernpea DM production in sole crop treatments. Seed yield per hectare of southernpea decreased in intercrops, although harvest index (HI) increased. Combining component yields gave LERs ranging between 1.2 and 1.7. Per hectare yields of southernpeas declined more in intercrop than did yields of maize.

Working with intraspecific southernpea mixtures, Erskine (1977) found no increase in yield over the means of the component monocrop yields. He did show increased yield stability. This improvement came from individual cultivars buffering the yield alterations rather than the whole population producing added compensation for population changes from the monocrop.

Interfamiliar and intraspecific tomato intercrops have been studied. Growing tomatoes with okra produced RYTs from 1.27 to 1.42 in a study by Olasantan (1985). Relative yields (RYs) of the tomatoes varied by cultivar. Yield of a local variety decreased little when intercropped and yields of two improved cultivars declined 30% when intercropped. Odland (1949) found no yield increases over monocultures when he intercropped two cultivars of tomato. Neither did intercropping affect fruit size. In the intercrops, decreased spacing increased yield per hectare, but reduced yield per plant.

Although many experimental designs and analytical procedures adequately meet intercropping researchers' objectives, the 1980's have brought refinements in designs and analyses used by intercropping researchers.

Researchers have recently consolidated guidelines for selecting intercropping experimental procedures. First, one must consider the objectives of the research program about to begin. Practical and basic objectives must enter into the experimental design (Willey, 1985). Pearce and Edmondson (1984) suggested that preliminary questions intercropping researchers should ask include: Do the intercrops need to succeed in a specific or in varied climates; yield a certain amount, proportion of components, or with a minimum consistency? The two also suggested experimental designs consider microclimate changes produced by component crops which may require isolation of treatments from one another.

Several researchers have cautioned against inappropriate comparisons between dissimilar sole and intercrop treatments (Willey, 1985; Gilliver, 1983). Many early intercropping studies compared sole and intercrop treatments with different plant spacings and populations without considering these differences (Willey, 1985). An intercrop experiment must not be designed simply for ease of data analysis (Willey, 1979b).

Willey (1979b) suggested varied spacing and population need immediate study by intercropping researchers. He reported the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) was, in 1979, studying optimum total and component plant densities by altering only within-row spacings. This and any of four planting patterns presented by Willey can reduce guard row numbers and improve a factorial design's efficiency. He also showed larger factorials to be more efficient than smaller ones, since percentage of intercrop plots increases as the number of treatments in a factorial increases. Willey claimed all studies must have sole crop plots of each component used in the intercrop treatments.

Pearce and Edmondson (1982) presented a method for designing intercrops in tropical areas. The two researchers used botanical information, historical yield and weather data, combined with knowledge of the needs of area farmers, in determining component ratios. The two suggested preliminary data could be gleaned from sole crop studies to reduce incorrect treatment selection by intercropping researchers. Since their work was done in the tropics, with subsistence farmers in mind, Pearce and Edmondson also developed methods for determining a cropping system's risk of failure to meet minimum requirements of farmers. In a later paper, Pearce and Edmondson (1984) reproted that tropical crop selection must take climate into account. They wrote that an intercrop of two crops which prosper in the same season (e.g. rainy or dry) may not be the best choice when the two components are grown for the same purpose. This combination of components would be a poor choise because intercropping has less benefit for similar component crops than for more varied crops Weather would also affect the two components similarly.

Pearce and Edmondson (1984) also described methods of site selection for intercropping experiments. For the tropics, they advised use of multiple sites over multiple growing seasons. They wrote the sites should be distant from one another, and possess varied climatic and physical characteristics. In the Pearce and Edmondson article readers can also find general guidelines for evaluating potential sites, based on climate and soil. The two researchers suggested planting solecrops at each site, evaluating their performances, and then drawing conclusions about the sites' suitabilities for proposed intercropping work.

Two cultivar selection methods for intercropping were also reviewed by Pearce and Edmondson (1984). An easy method would involve growing new cultivars in intercrop and comparing results with those from standard cultivars for the same region. Their more abstract method involved investigating characteristics which make standard cultivars successful in intercrops, and selecting a new cultivar based on whether or not it possesses some or all of those characteristics. They noted this information would also benefit other intercropping researchers.

After one designs and completes an intercropping study, several data analysis methods become available. Since component crop and total intercrop populations usually differ from sole crop populations, researchers have developed several ways of combining component data for comparison with sole crop data. To date, as noted by Pearce and Edmondson (1984), most statistical formulas for analyzing intercropping data do not get much use by researchers.

For comparison of sole crop and intercrop yields, most researchers have used land equivalent ratio (LER) or relative yield total (RYT). Pearce and Edmondson (1984) and Willey (1985) discussed the formula:

$$L, LER = p/a + q/b, \qquad (1)$$

where L or LER = land equivalent ratio, p = intercrop yield of crop A, a = sole crop yield of crop A, q = intercrop yield of crop B, and b = sole crop yield of crop B, all on a per land unit basis. This gives the amount of land needed in sole crops to produce the same yield from one land unit of intercrop. Willey mentioned relative yield total (RYT) as being equivalent to LER, only expressed as yield given by one land unit of intercrop compared to one unit of sole crop sown at a population ratio identical to that of the intercrop. The formula for RYT was expressed as:

$$RYT = \frac{\text{intercrop yield A}}{\text{sole crop yield A}} + \ldots + \frac{\text{intercrop yield i}}{\text{sole crop yield i}} \qquad (2).$$

Each term equals a relative yield (RY) for that component.

When the requirements for a certain yield ratio among component crops cannot be met one could use variations of LER presented by Willey (1985), and Pearce and Edmondson (1984). To calculate a yield advantage from a combination of sole and intercropping, Willey wrote one should add the relative yields of the sole cropped and intercropped areas, based on proportions of the component crops, to arrive at a usable cropping ratio. He illustrated how effective land equivalent ratio (ELER) would always be less than LER since sole cropped areas do not contribute to the yield advantage of the combined cultures. Another way LERs can be used is to calculate the advantage of growing at least a minimum of a staple crop in combination with an extra crop, using both sole and intercropping. This staple land equivalent ratio (SLER) would always be less than LER. However, he pointed out adjusted LERs have been little used, perhaps because of their theoretical nature.

Later in his review of procedures for studying intercropping, Willey (1985) showed how to use a monetary value to convert LER into monetary advantage (MA) using:

MA = value of intercrop*(LER-1)*LER (3)

When combining sole cropping and intercropping, one can also find an effective monetary advantage (EMA), using:

EMA = (value of a land unit of combined intercrop and extra sole crop*(ELER-1))/LER (4)

Others have discussed ways of analyzing LERs and other conversions of yield data from intercrops. Pearce and Edmondson (1984) proposed a statistical formula for testing significant differences between calculated LERs. Earlier, working with Gilliver, Pearce (1983) questioned the value of converting yield data into terms like LER for single variate analysis, concurring with a point brought up earlier by Willey (1979b). To get around the single-variate question Gillever and Pearce (1983) described methods for using bivariate analysis on intercropping data. Their method used expected and actual yield, with study of significant interactions between treatment factors, to evaluate intercropping advantages. A caveat they discussed was an assumption of constant correlations between species over treatments that may not occur in intercrops.

Intercropping researchers today are investigating many possible causes of the changes the culture causes in the field. The scope of experimentation continues to broaden. People are refining statistical tools used to evaluate intercrops. Intercropping is beginning to be used in more intensively farmed areas.

CHAPTER III

INTERCROPPING TOMATO (Lycopersicon esculentum) WITH EGGPLANT (Solanum melongena) OR BELL PEPPER (Capsicum annuum) AND EGGPLANT WITH BELL PEPPER

Introduction

America produced $4.5 billion worth of vegetables in 1987. In 1986, Oklahoma produced $35.4 million worth of vegetables on 18,000 hectares. Of these, 12,907 hectares were devoted to fresh market production. Tomatoes are one of Oklahomas primary fresh market vegetable crops. Eggplant and bell pepper are grown but are minor crops.

Like all growers, those in Oklahoma concern themselves with improving yield and monetary return. Intercropping can accomplish both (Willey, 1979; Kotosokoane, 1985).

In this study, two solanaceous crops were grown in alternate-row intercrops to try and take advantage of differences between them. These differneces could facilitate higher yields. Similarities between the crops would permit use of intense management practices inhibitted by more diverse cropping systems. The crops chosen required similar culture and methods of pest management, minimizing inputs and magagerial requirements. The three crops were thought to have enough differences or to bring certain attributes to the combinations which would affect yield and return to the grower.

Materials and Methods

These experiments were conducted during the summers of 1986 and 1987. The 1986 study was conducted at three sites: the Oklahoma State University Nursery Research Center at Stillwater on an Easpar loam; the O.S.U. Fruit Research Station at Perkins on a Teller sandy loam, and the O.S.U. Vegetable Research Station at Bixby on a Severn very-fine sandy loam. Only the Bixby site was used in 1987.

On 4 March, 1986, seeds of eggplant cv. Classic were sown in Rediearth peat lite mix at a 51 mm X 51 mm spacing. On 8 March, seed of tomato cv. Sunny were sown in the same medium at a 25 mm X 51 mm spacing. The eggplant and tomato seedlings were thinned on 12 March and 23 March, respectively. The seedlings received two applications of nitrogen at 230 ppm while in the greenhouse (26 March and 3 April). They also received one spray of methomyl at 15.4 kg a.i. per hectare on 9 April for control of thrips and fungus gnats.

The 1986 sites were prepared for planting. This work included application of trifluralin herbicide at 0.227 kg a.i. per hectare and nitrogen from ammonium nitrate at 33.6 kg ha^{-1}. The eggplant and tomato were transplanted at 0.6 m in-row and 1.8 m between row spacing and eight plants per plot. The plants received 225 ml of transplant solution containing nitrogen (33.6 kg ha^{-1}) from Peter's 15-30-15 and diazinon at 0.65 kg a.i. per hectare. Transplanting occurred 22 April, 23 April and 24 April at Perkins, Stillwater and Bixby, respectively. Replacement plants were set 3 May and 5 May at

Stillwater and Perkins, respectively. Replacement plants received transplant solution as applied to the preliminary plantings, but without diazinon.

The tomato plants were supported on a stake and weave trellis system as described by Konsler and Shoemaker (1980).

The 1987 experimental procedures were like the 1986 procedures but only the Bixby site was used. In 1987 bell pepper cv. Early Calwonder was added to the study. Pepper plant spacing was 0.4m in-row and 1.8m between-row in double rows, with 0.3m between the doubled rows, giving 24 plants per plot. Replacement plants were set 5 May 1987.

During the two growing seasons, insects and diseases were controlled with weekly sprays of a tank mix containing copper hydroxide (2.24 kg a.i. per hectare), methomyl (0.3465 kg a.i. per hectare) and mancozeb (0.896 kg a.i. per hectare). During harvest, chlorthalonil (1.523 kg a.i per hectare) substituted for mancozeb in the mix. On 21 May, 1986 the Stillwater site received an application of diphenamid (3.36 kg a.i. per hectare) for continued preemergent weed control.

Supplemental irrigation was supplied to all sites, both years, when weekly rainfall did not exceed 2.54 cm. In 1986, overhead irrigation supplied water for Perkins and Stillwater, with the overhead irrigation at Stillwater replaced 1 July by a trickle system. The Bixby site received water from a trickle irrigation system in both 1986 and 1987. The drip tube ran next to all tomato and eggplant rows and between the double rows of bell peppers.

All cultural practices were based on recommendations from the Oklahoma State University Cooperative Extension Service (McCraw, et al., 1987, McCraw and Motes, 1987, Motes and Criswell, 1987).

This study compared yield and economic returns of eggplant, tomato and bell pepper in monocrop and intercrops with one another. Fruit yield was the main criterion for treatment comparisons.

The studies were arranged in a randomized complete block design. In 1986, each site had three replications. The Bixby test had five replications in 1987. Treatments were: monocrop tomato, monocrop eggplant, monocrop bell pepper, and alternate-row intercrops of tomato-eggplant, bell pepper/tomato, and bell pepper/eggplant. Double or triple guard rows buffered each treatment plot within each replication. Fruit from all plants in each test row was used in analyses.

Harvest of tomato and eggplant occurred three days per week, with bell pepper being harvested once, and sometimes twice, weekly, in 1987. Eggplant and bell pepper fruit were harvested at horticultural maturity for fresh eggplant and green bell peppers. Tomatoes were harvested at the mature green, breaker, or pink stage, depending on the fruit. All fruit were then graded into marketable and cull, with marketable tomatoes being further sorted into U.S. No. 1 and U.S. No. 2 (Anon., 1978).

Using prices reported at the Dallas Terminal Market, marketable yields were converted into dollar amounts. Land equivalent ratios (LER) were calculated using equation (1) and monetary advantages (MA) were done similarly with equation (3). Using enterprise budgets from the O.S.U. Cooperative Extension Service (Schatzer, et al., 1986), returns were calculated and MAs were figured.

Results

In 1986, tomato and eggplant grew in intercrop and monocrop at three locations. No significant location X culture interactions (P = 0.05) were found. In 1987, one location was used for the study, with treatments including a bell pepper monocrop, bell pepper with eggplant and bell pepper with tomato, in addition to the 1986 treatments.

All tomato yields declined in 1987, compared to 1986, due to hail on 30 May, which damaged the first and second clusters of fruit. Higher disease pressure in 1987 also adversely affected tomato and bell pepper yields.

Intercropping did not affect total tomato yield in 1986, except at Bixby, where intercropping produced greater total yield than monocropping (Table 1). This same increase was found in other yield components at Bixby, including total number of fruit, marketable, No. 1 and No. 2 yield and fruit numbers. Mean fruit weight remained constant for each component over treatments, within each location (Table 2). Yields from Bixby significantly exceeded those of Perkins and Stillwater for each treatment and yield component.

When 1986 yields are broken into three equally-long harvest periods, few significant differences between treatments, within a harvest period, occurred (Table 3). At Bixby, intercropping produced more of each yield component during the middle harvest period, except for mean fruit weights, which culture did not influence (Table 4).

Table 1. Tomato[z] yields in monocrop and alternate-row intercrops in 1986.

Location	Culture	Total yield ($kg \cdot ha^{-1}$)	Total fruit/ hectare	Marketable yield ($kg \cdot ha^{-1}$)	Marketable fruit/ hectare	No. 1 yield ($kg \cdot ha^{-1}$)	No. 1 fruit/ hectare	No. 2 yield ($kg \cdot ha^{-1}$)	No. 2 fruit/ hectare	Cull yield ($kg \cdot ha^{-1}$)	Cull fruit/ hectare
Bixby	Monocrop	115688 b[y]	672072 b	79247 b	400463 b	64043 b	319444 b	15204 b	81019 b	36441 a	271605 a
	Intercrop w/ eggplant[x]	133856 a	751157 a	95960 a	481481 a	76371 a	378858 a	19588 a	102623 a	37896 a	269676 a
Perkins	Monocrop	44332 c	251539 c	35038 c	185185 c	26901 c	140432 c	8137 c	44753 c	9294 b	66358 c
	Intercrop w/ eggplant	40965 c	285880 c	29268 c	173997 c	24113 c	143133 c	5156 c	30864 d	11697 b	111883 b
Stillwater	Monocrop	44227 c	242280 c	35546 c	182099 c	28181 c	143904 c	7365 c	38194 cd	8681 b	60185 c
	Intercrop w/ eggplant	45402 c	257720 c	34880 c	180170 c	27602 c	138889 c	7278 c	41281 cd	10522 b	77546 bc

[z]Tomato cv. Sunny.
[y]Mean separation, within columns, by Duncan's new multiple range test, 5% level.
[x]Eggplant cv. Classic.

Table 2. Mean tomato[z] fruit weights in monocrop and alternate -row intercrops in 1986.

Location	Culture	Mean No. 1 fruit weight (kg)	Mean No. 2 fruit weight (kg)	Mean cull fruit weight (kg)
Bixby	Monocrop	0.20a[y]	0.19 a	0.13 a
	Intercrop with eggplant[x]	0.20 a	0.19 a	0.14 a
Perkins	Monocrop	0.19 ab	0.18 a	0.14 a
	Intercrop with eggplant	0.17 b	0.16 a	0.11 a
Stillwater	Monocrop	0.19 ab	0.19 a	0.15 a
	Intercrop with eggplant	0.20 a	0.17 a	0.14 a

[z]Tomato cv. Sunny.
[y]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.
[x]Eggplant cv. Classic.

Table 3. Tomato[z] yields in monocrop and alternate-row intercrops, by harvest period, in 1986.

Location	Harvest period[y]	Culture	Total yield ($kg \cdot ha^{-1}$)	Total fruit/ hectare	Marketable yield ($kg \cdot ha^{-1}$)	Marketable fruit/ hectare	No. 1 yield ($kg \cdot ha^{-1}$)	No. 1 fruit/ hectare	No. 2 yield ($kg \cdot ha^{-1}$)	No. 2 fruit/ hectare
Bixby	Early	Monocrop	12398 fg[x]	55556 efg	10592 f	47068 gh	8909 gh	38194 hi	1684 e	8873 g
		I. w/ eggplant[w]	13626 f	61725 ef	11241 f	48611 gh	9908 g	42438 ghi	1333 ef	6173 ghi
	Middle	Monocrop	55556 b	250382 b	48138 b	214506 b	41789 b	189815 b	6348 c	24691 ef
		I. w/ eggplant	71987 a	329861 a	61342 a	275463 a	51084 a	233410 a	10259 a	42052 bc
	Late	Monocrop	47734 c	366123 a	20518 de	13889 cd	13345 efg	91435 de	7172 bc	47453 ab
		I. w/ eggplant	48243 c	359572 a	23376 d	157407 c	15379 def	103009 cd	7997 b	54398 a
Perkins	Early	Monocrop	3227 h	17361 h	2560 g	11960 i	2455 i	11188 j	105 f	772 hi
		I. w/ eggplant	5647 gh	31632 fgh	4682 g	22762 hi	4296 hi	21219 ij	386 ef	1543 ghi
	Middle	Monocrop	36581 d	203704 c	30303 c	160494 c	23604 c	124614 c	6699 bc	35880 cd
		I. w/ eggplant	31443 de	225694 bc	22833 de	140818 cd	19167 cd	117670 cd	3665 d	23148 f
	Late	Monocrop	4524 h	30475 fgh	2175 g	12731 i	842 i	4630 j	1333 ef	8102 gh
		I. w/ eggplant	3876 h	28553 fgh	1754 g	10417 i	649 i	4244 j	1105 ef	6173 ghi
Stillwater	Early	Monocrop	13731 f	70984 e	11434 f	58256 g	10136 g	52083 fgh	1298 ef	6173 ghi
		I. w/ eggplant	17905 f	84873 e	16151 ef	75617 fg	15432 def	72145 ef	719 ef	3472 ghi
	Middle	Monocrop	28988 e	159193 d	24113 d	123843 de	18045 de	91821 de	6068 c	32022 de
		I. w/ eggplant	25305 e	152396 d	18501 de	103781 ef	12065 fg	66358 efg	6436 c	37423 cd
	Late	Monocrop	1508 h	13113 h	0 g	0 i	0 i	0 j	0 f	0 i
		I. w/ eggplant	2192 h	20451 gh	228 g	772 i	105 i	386 j	123 f	386 hi

continued on next page

Table 3. Continued

Location	Harvest period[y]	Culture	Cull yield ($kg \cdot ha^{-1}$)	Cull fruit/ hectare
Bixby	Early	Monocrop	1806 e[x]	8488 g
		I. w/ eggplant[v]	2385 e	13117 g
	Middle	Monocrop	7418 c	35880 ef
		I. w/ eggplant	10645 b	54398 d
	Late	Monocrop	27217 a	227237 a
		I. w/ eggplant	24867 a	202160 b
Perkins	Early	Monocrop	666 e	5401 g
		I. w/ eggplant	965 e	8873 g
	Middle	Monocrop	6278 cd	43210 de
		I. w/ eggplant	8610 bc	84877 c
	Late	Monocrop	2350 e	17747 fg
		I. w/ eggplant	2122 e	18133 fg
Stillwater	Early	Monocrop	2297 e	12731 g
		I. w/ eggplant	1754 e	9259 g
	Middle	Monocrop	4875 d	34336 ef
		I. w/ eggplant	6804 cd	48611 de
	Late	Monocrop	1508 e	13117 g
		I. w/ eggplant	1964 e	19676 fg

[z]Tomato cv. Sunny.
[y]Harvest periods: Early, 6/21 to 7/14; middle,7/15 to 8/7 ; late, 8/8 to 9/18.
[x]Mean seperation, within columns, by Duncan's New Multiple Range Test, 5% level.
[v]Eggplant cv. Classic.

Table 4. Mean tomato[z] fruit weights in monocrop and alternate-row intercrops, by harvest period, in 1986.

Location	Harvest period[y]	Culture	Mean No. 1 fruit weight (kg)	Mean No. 2 fruit weight (kg)	Mean Cull fruit weight (kg)
Bixby	Early	Monocrop	0.23 ab[x]	0.19 de	0.22 a
		I. w/ eggplant[w]	0.23 b	0.22 bc	0.18 abcd
	Middle	Monocrop	0.22 bc	0.26 ab	0.22 a
		I. w/ eggplant	0.22 bcd	0.24 bc	0.20 ab
	Late	Monocrop	0.15 i	0.15 ef	0.12 e
		I. w/ eggplant	0.15 i	0.15 ef	0.12 e
Perkins	Early	Monocrop	0.22 b	0.14 f	0.12 e
		I. w/ eggplant	0.20 cdef	0.25 bc	0.13 de
	Middle	Monocrop	0.19 defg	0.19 de	0.14 bcde
		I. w/ eggplant	0.16 ghi	0.16 ef	0.11 e
	Late	Monocrop	0.18 efgh	0.16 def	0.13 de
		I. w/ eggplant	0.15 hi	0.18 def	0.13 e
Stillwater	Early	Monocrop	0.19 cdef	0.21 cd	0.20 ab
		I. w/ eggplant	0.21 bcde	0.21 cd	0.19 ab
	Middle	Monocrop	0.20 cdef	0.19 de	0.14 bcde
		I. w/ eggplant	0.18 fgh	0.17 def	0.14 cde
	Late	Monocrop	0.00 j	0.00 g	0.12 e
		I. w/ eggplant	0.27 a	0.31 a	0.10 e

[z]Tomato cv. Sunny.

[y]Harvest periods: early, 6/21 to 7/14; middle, 7/15 to 8/7; late, 8/8 to 9/18.

[x]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.

[w]Eggplant cv. Classic.

Several yield components exhibited opposite treatment responses at Perkins and Stillwater. Intercropping tended to reduce marketable yield, No. 2 yield, No. 2 fruit number, and cull fruit number at Perkins and No. 1 yield at Stillwater.

Unlike 1986, culture did influence total tomato yield in 1987 (Table 5). The eggplant/tomato intercrop treatment had greater total yield than the tomato/pepper treatment. Neither intercrop showed a significant change in total yield compared to the intermediate-yielding monocrop. This relationship held true for total fruit number, No. 1 yield and No. 1 fruit number. The tomato/pepper intercrop produced significantly greater No. 1 mean fruit weight than the monocrop (Table 6). The monocrop produced higher mean cull fruit weights than the tomato/eggplant intercrop.

Among the three harvest periods, only during the middle harvest period did differences between treatments become apparent (Table 7). During that period, the tomato/eggplant treatment outproduced the tomato/pepper treatment for all yield components, except No. 1 fruit number and mean No. 1, No. 2 and cull fruit weights (Table 8), and outyielded the monocrop in No. 1 yield. The tomato/eggplant intercrop produced smaller culls than the monocrop. During the intermediate harvest period the monocrop outyielded the tomato/pepper intercrop cull fruit number and total yield.

The only other differences between treatments appeared during the late harvest period. Then, the monocrop showed greater mean cull fruit weight than the tomato/eggplant treatment, and the tomato/pepper intercrop produced larger No. 1 fruit than the monocrop.

Table 5. Tomato yields[z] in monocrop and alternate-row intercrops at Bixby in 1987.

Culture	Total yield ($kg\cdot ha^{-1}$)	Total fruit/ hectare	Marketable yield ($kg\cdot ha^{-1}$)	Marketable fruit/ hectare	No. 1 yield ($kg\cdot ha^{-1}$)	No. 1 fruit/ hectare	No. 2 yield ($kg\cdot ha^{-1}$)	No. 2 fruit/ hectare	Cull yield ($kg\cdot ha^{-1}$)	Cull fruit/ hectare
Monocrop	59101 ab[y]	289815 a	32407 a	146296 ab	18613 ab	83565 ab	13794 a	62731 a	26694 a	143519 a
Intercrop with eggplant[x]	67666 a	340480 a	38603 a	172309 a	24686 a	108275 a	13917 a	64034 a	29063 a	168171 a
Intercrop with pepper[w]	52083 b	256019 a	26557 a	112963 b	15646 b	65278 b	10911 a	47685 a	25526 a	143055 a

[z]Tomato cv. Sunny.
[y]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.
[x]Eggplant cv. Classic.
[w]Bell pepper cv. Early Calwonder.

Table 6. Mean tomato^z fruit weights in monocrop and alternate-row intercrops at Bixby in 1987.

Culture	Mean No. 1 fruit weight (kg)	Mean No. 2 fruit weight (kg)	Mean cull fruit weight (kg)
Monocrop	0.221 b^y	0.223 a	0.193 a
Intercrop with eggplant^x	0.229 ab	0.221 a	0.171 b
Intercrop with pepper^w	0.241 a	0.230 a	0.187 ab

[z]Tomato cv. Sunny.
[y]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.
[x]Eggplant cv. Classic.
[w]Bell pepper cv. Early Calwonder.

Table 7. Tomato[z] yields in monocrop and alternate-row intercrops, by harvest period, at Bixby in 1987.

Harvest period[y]	Culture	Total yield (kg·ha⁻1)	Total fruit/ hectare	Marketable yield (kg·ha⁻¹)	Marketable fruit/ hectare	No. 1 yield (kg·ha⁻1)	No. 1 fruit/ hectare	No. 2 yield (kg·ha⁻¹)	No. 2 fruit/ hectare	Cull yield (kg·ha⁻¹)	Cull fruit/ hectare
Early	Monocrop	23906 a[x]	126620 a	12247 b	59259 b	5755 cd	27546 bcd	6492 a	31713 a	11658 ab	67361 a
	Intercrop with eggplant[w]	25633 a	133652 a	13530 b	63706 ab	7062 bc	32909 bc	6467 a	30797 ab	12103 a	69946 a
	Intercrop with pepper[v]	22043 abc	114583 a	10469 bc	46759 bc	4735 cd	20602 cd	5734 a	26157 ab	11574 ab	67824 a
Middle	Monocrop	23001 ab	104861 ab	14468 ab	62037 ab	9364 b	40972 b	5103 ab	21065 bc	8533 abcd	42824 b
	Intercrop with eggplant	29324 a	140307 a	19803 a	84828 a	14257 a	60397 b	5547 a	24431 ab	9539 abc	55478 ab
	Intercrop with pepper	14752 cd	68981 bc	9638 bc	40046 bc	6713 bcd	28241 bcd	2925 bc	11806 cd	5114 d	28935 b
Late	Monocrop	12195 d	58333 c	5692 c	25000 c	3493 d	15046 d	2199 c	9954 d	6503 cd	33333 b
	Intercrop with eggplant	12691 d	66522 bc	5270 c	23775 c	3367 d	14969 d	1904 c	8806 d	7421 bcd	42747 b
	Intercrop with pepper	15288 bcd	72454 bc	6450 c	26157 c	4198 cd	16435 d	2252 c	9722 d	8838 abcd	46296 ab

[z]Tomato cv. Sunny.
[y]Harvest periods: Early, 6/20 to 7/5; middle, 7/6 to 7/20; late, 7/21 to 8/7.
[x]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.
[w]Eggplant cv. Classic.
[v]Bell pepper cv. Early Calwonder.

Table 8. Mean tomato[z] fruit weights in monocrop and alternate-row intercrops, by harvest period, at Bixby in 1987.

Harvest period[y]	Culture	Mean No. 1 fruit weight (kg)	Mean No. 2 fruit weight (kg)	Mean cull fruit weight (kg)
Early	Monocrop	0.205 c[x]	0.209 c	0.180 abc
	Intercrop with eggplant[w]	0.213 bc	0.211 c	0.171 bc
	Intercrop with pepper[v]	0.234 ab	0.219 abc	0.176 bc
Middle	Monocrop	0.234 ab	0.244 ab	0.206 a
	Intercrop with eggplant	0.240 ab	0.229 abc	0.175 bc
	Intercrop with pepper	0.237 ab	0.248 a	0.193 abc
Late	Monocrop	0.224 bc	0.212 bc	0.194 ab
	Intercrop with eggplant	0.236 ab	0.224 abc	0.166 c
	Intercrop with pepper	0.258 a	0.225 abc	0.193 abc

[z]Tomato cv. Sunny.
[y]Harvest periods: Early, 6/20 to 7/5; middle, 7/6 to 7/20; late, 7/21 to 8/7.
[x]Mean seperation, within columns by Duncan's new multiple range test, 5% level.
[w]Eggplant cv. Classic.
[v]Bell pepper cv. Early Calwonder.

Total eggplant yield showed no increase from intercropping, at any location, in 1986 (Table 9). Breakdown of that total into marketable yield, fruit number and mean fruit weight, along with cull yield did not show any differences between the two cultures. Number of cull fruit declined under the Bixby intercrop. Intercropping increased mean cull fruit weight at Bixby and reduced it at Perkins.

Total yield during the three harvest periods was unaffected by culture, with the exception of late yield at Perkins, where monocropping outyielded the tomato intercrop (Table 10). Intercropping also reduced total fruit number, marketable fruit yield and number, and cull yield and fruit number during Perkins' late harvest period. During the early harvest period at Bixby, intercropping produced lower total fruit number than monocropping.

Several treatment differences appeared in 1987 (Table 11). The tomato/eggplant intercrop produced higher total marketable eggplant yield than the eggplant/pepper intercrop, but neither resulted in significant differences in No. 1 yield from the intermediate-yielding monocrop. The monocrop produced the lowest total cull yield and cull fruit number, with the eggplant/pepper treatment yielding the most cull tonnage and fruit number.

During the three harvest periods, few treatment differences appeared in the eggplant data (Table 12). The tomato intercrop had a higher yield total than the other treatments during the middle harvest period. In the late harvest period, the two intercrops outproduced the monocrop in cull yield, cull fruit number, total yield and total fruit number.

Table 9. Eggplant[z] yields and mean fruit weights in monocrop and alternate-row intercrops in 1986.

Location	Culture	Total yield ($kg \cdot ha^{-1}$)	Total fruit/ hectare	Marketable yield ($kg \cdot ha^{-1}$)	Marketable fruit/ hectare	Mean Marketable fruit size (kg)	Cull yield ($kg \cdot ha^{-1}$)	Cull fruit/ hectare	Mean cull fruit size (kg)
Bixby	Monocrop	88840 a[y]	241127 a	56362 a	138503 a	0.41 a	32478 a	102623 a	0.32 b
	Intercrop	86209 a	217207 a	57116 a	138503 a	0.41 a	29093 ab	78704 b	0.37 a
Perkins	Monocrop	55976 b	162809 b	29146 b	73302 b	0.40 a	26831 bc	89506 ab	0.30 b
	Intercrop	46822 b	133873 b	23990 b	60957 b	0.39 a	22832 c	72917 b	0.31 b
Stillwater	Monocrop	43371 b	119599 b	28356 b	73688 b	0.39 a	15015 d	45910 c	0.33 b
	Intercrop	43929 b	119599 b	28760 b	71759 b	0.40 a	15169 d	47840 c	0.32 b

[z]Eggplant cv. Classic.
[y]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.
[x]Intercrop was tomato cv. Sunny.

Table 10. Eggplant[z] yields and mean fruit weights in monocrop and alternate-row intercrops, by harvest period, in 1986.

Location	Harvest period[y]	Culture	Total yield (kg·ha⁻¹)	Total fruit/ hectare	Marketable yield (kg·ha⁻¹)	Marketable fruit/ hectare	Mean Marketable fruit size (kg)	Cull yield (kg·ha⁻¹)	Cull fruit/ hectare	Mean cull fruit size (kg)
Bixby	Early	Monocrop	38265 a[x]	109954 a	23025 ab	60571 a	0.38 defg	15239 a	49383 a	0.31 efgh
		Intercrop[w]	34652 ab	94522 b	20553 bc	55170 a	0.37 efg	14099 a	39352 ab	0.36 abcd
	Middle	Monocrop	15748 cd	48225 cde	9294 defg	24306 bcde	0.38 defg	6453 efgh	23920 cde	0.27 g
		Intercrop	14327 cde	39352 cdef	9647 defg	25463 bcde	0.38 defg	4682 ghi	13889 defg	0.34 cde
	Late	Monocrop	34830 ab	82948 b	24043 ab	53627 a	0.45 ab	10785 bc	29321 bc	0.37 abc
		Intercrop	37230 a	83333 b	26919 a	57870 a	0.46 ab	10311 bcd	25463 cd	0.41 a
Perkins	Early	Monocrop	19904 c	56713 c	10504 def	28164 bcd	0.37 defg	9400 cde	28549 bc	0.33 cdef
		Intercrop	18711 c	54398 c	10557 def	28549 bcd	0.37 efg	8154 cdef	25849 cd	0.32 cdefg
	Middle	Monocrop	7769 e	18133 g	3648 g	7716 fg	0.48 a	4121 hi	10317 fg	0.41 ab
		Intercrop	10767 de	30478 efg	4717 fg	12345 ef	0.39 defg	6050 fghi	18133 cdefg	0.33 cdef
	Late	Monocrop	28304 b	87963 ab	14994 cd	37423 b	0.39 def	13310 ab	50540 a	0.27 fg
		Intercrop	17344 cd	48997 cde	8716 efg	20062 cdef	0.42 bcd	8628 cdef	28935 bc	0.30 defg
Stillwater	Early	Monocrop	17663 cd	52469 cd	10224 def	29707 bcd	0.35 g	7439 defg	22762 cde	0.33 cdef
		Intercrop	19132 c	53241 cd	11995 de	32793 bc	0.36 fg	7137 efgh	20448 cdef	0.35 bcde
	Middle	Monocrop	10908 de	27006 fg	7786 efg	18904 cdef	0.40 def	3121 i	8102 g	0.42 a
		Intercrop	11136 de	31636 efg	6278 efg	16204 def	0.39 defg	4858 ghi	15432 defg	0.32 cdefg
	Late	Monocrop	14801 cde	40123 cdef	10347 def	25077 bcde	0.42 bcde	4454 ghi	15046 defg	0.29 efg
		Intercrop	13661 cde	34722 defg	10487 def	22762 cde	0.46 ab	3174 i	11960 efg	0.27 g

[z]Eggplant cv. Classic.
[y]Harvest periods: Early, 6/21 to 7/24; middle, 7/25 to 8/22; late, 8/23 to 9/29.
[x]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.
[w]Intercrop with tomato cv. Sunny.

Table 11. Eggplant[z] yields and mean fruit weights in monocrop and alternate-row intercrops at Bixby in 1987.

Culture	Total yield $(kg \cdot ha^{-1})$	Total fruit/ hectare	Marketable yield $(kg \cdot {}^{h}a^{-1})$	Marketable fruit/ hectare	Mean marketable fruit size (kg)	Cull yield $(kg \cdot ha^{-1})$	Cull fruit/ hectare	Mean cull fruit size (kg)
Monocrop	125084 a[y]	402083 a	77630 ab	233565 a	0.336 a	47453 b	168519 b	0.327 a
Intercrop with tomato[x]	136551 a	438166 a	82999 a	250289 a	0.332 a	53552 ab	187876 ab	0.312 a
Intercrop with pepper[w]	130724 a	417824 a	71191 b	214352 a	0.335 a	59532 a	203472 a	0.333 a

[z]Eggplant cv. Classic.
[y]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.
[x]Tomato cv. Sunny.
[w]Bell pepper cv. Early Calwonder.

Table 12. Eggplant[z] yields and mean fruit weights in monocrop and alternate-row intercrops, by harvest period, at Bixby in 1987.

Harvest period[y]	Culture	Total yield ($kg \cdot ha^{-1}$)	Total fruit/ hectare	Marketable yield ($kg \cdot ha^{-1}$)	Marketable fruit/ hectare	Mean Marketable fruit size (kg)	Cull yield ($kg \cdot ha^{-1}$)	Cull fruit/ hectare	Mean cull fruit size (kg)
Early	Monocrop	43697 bc[x]	107870 c	33375 a	82176 ab	0.432 a	10322 c	25694 c	0.434 a
	Intercrop w/ tomato[w]	43571 bc	109404 c	33186 a	82755 ab	0.410 a	10385 c	26649 c	0.393 a
	Intercrop w/ pepper[v]	41604 c	101157 c	27936 ab	67361 b	0.426 a	13668 c	33796 c	0.444 a
Middle	Monocrop	32270 d	110185 c	22401 bcd	78241 ab	0.286 b	9870 c	31944 c	0.297 b
	Intercrop w/ tomato	32773 c	114034 c	22256 bcd	79282 ab	0.283 b	10516 c	34751 c	0.293 b
	Intercrop w/ pepper	30871 d	107639 c	20160 d	70602 ab	0.283 b	10711 c	37037 c	0.281 b
Late	Monocrop	49116 b	184028 b	21854 cd	73148 ab	0.299 b	27262 b	110880 b	0.265 b
	Intercrop w/ tomato	60208 a	214728 a	27556 abc	88252 a	0.314 b	32652 a	126476 a	0.267 b
	Intercrop w/ pepper	58249 a	209028 a	23096 bcd	76389 ab	0.309 b	35154 a	132639 a	0.292 b

[z]Eggplant cv. Classic.
[y]Harvest periods: Early, 6/20 to 7/15; middle 7/16 to 8/15; late 8/16 to 9/7.
[x]Mean seperation, within columns by Duncan's new multiple range test, 5% level.
[w]Tomato cv. Sunny.
[v]Bell pepper cv. Early Calwonder.

Only one significant treatment difference occurred over the whole season for the bell peppers (Tables 13 and 14). During the middle harvest period the tomato/pepper intercrop yielded a greater total weight of peppers than the other treatments. In the late harvest the two intercrops outproduced the monocrop in total yield, total fruit number, cull yield, and cull fruit number.

For each treatment LERs and the values of each term of equation (1) were calculated (Table 15), as were gross returns, net returns, and MAs.

In 1986, the tomatoes in the tomato/eggplant intercrop had an intercrop:monocrop ratio significantly greater than 1 for total, marketable, and No. 1 yield. This, combined with the moderating effect of the eggplant ratio, resulted in no significant deviation from 1 for the LERs.

The trends and differences in LERs were transferred directly to gross and net returns, and monetary advantage (Tables 16 and 17).

Discussion

Some general observations about the sites used during the two year study should be made before discussing the results. The Bixby site, in 1986 and 1987, performed better than the 1986 Stillwater or Perkins sites. The Stillwater site has a clayey soil which had standing water for several periods during the growing season. These puddles affected some plots more than others. Weeds, including bermudagrass, yellow nutsedge and elm stumps (from the field's prior use as a nursery) also increased variation in crop growth. Perkins' main drawback was the southwest winds buffeting the plots throughout

Table 13. Bell pepper[z] yields in monocrop and alternate-row intercrops at Bixby in 1987.

Culture	Total yield[y] ($kg \cdot ha^{-1}$)	Total fruit/ hectare	Marketable yield ($kg \cdot ha^{-1}$)	Marketable fruit/ hectare	Mean marketable fruit wt. (kg)	Cull yield ($kg \cdot ha^{-1}$)	Cull fruit/ hectare	Mean cull fruit wt. (kg)
Monocrop	21223 a	198843 a	13889 a	108796 a	0.12 a	7334 a	81481 b	0.10 a
Intercrop with tomato[x]	21780 a	205324 a	13321 a	108102 a	0.12 a	8460 a	97222 a	0.11 a
Intercrop with eggplant[w]	20907 a	190278 a	12984 a	105787 a	0.12 a	7923 a	93056 a	0.09 a

[z]Bell pepper cv. Early Calwonder.
[y]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.
[x]Tomato cv. Sunny.
[w]Eggplant cv. Classic.

Table 14. Bell pepper[z] yields in monocrop and alternate-row intercrops, by harvest period, in 1987.

Harvest period[y]	Culture	Total yield ($kg \cdot ha^{-1}$)	Total number of fruit/ hectare	Marketable yield ($kg \cdot ha^{-1}$)	Marketable fruit/ hectare	Mean marketable fruit wt. (kg)	Cull yield ($kg \cdot ha^{-1}$)	Cull fruit/ hectare	Mean cull fruit wt. (kg)
Early	Monocrop	6829a[x]	49074 b	4809 a	32639 a	0.14 a	2020 bc	16435 b	0.12 a
	Intercrop w/ tomato[w]	7607 a	56250 b	5027 a	35648 a	0.14 a	2536 b	20602 b	0.13 a
	Intercrop w/ eggplant[v]	7313 a	57176 b	4819 a	35648 a	0.14 a	2494 bc	21528 b	0.12 ab
Middle	Monocrop	6566 a	53704 a	5250 a	39352 a	0.13 a	1315 c	14351 b	0.09 ab
	Intercrop w/ tomato	5871 a	47917 b	4503 a	33333 a	0.13 a	1368 bc	14583 b	0.09 ab
	Intercrop w/ eggplant	5934 a	50463 b	4388 a	32870 a	0.13 a	1547 bc	17593 b	0.10 ab
Late	Monocrop	7828 a	87500 a	3830 a	36806 a	0.10 b	3998 a	50694 a	0.08 ab
	Intercrop w/ tomato	8302 a	96900 a	3746 a	39120 a	0.09 b	4556 a	57870 a	0.11 ab
	Intercrop w/ eggplant	7628 a	91667 a	3746 a	37269 a	0.10 b	3883 a	54398 a	0.07 b

[z]Bell pepper cv. Early Calwonder.
[y]Harvest periods: Early, 6/25 to 7/5; middle, 7/6 to 7/16; late 7/17 to 7/27.
[x]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.
[w]Tomato cv. Sunny.
[v]Eggplant cv. Classic.

Table 15. Land equivalent ratios for alternate-row, solanaceous[z] intercrops during two seasons.

Year	Location	Component	Total yield L[y]	Total yield LER[x]	Marketable yield L	Marketable yield LER	No. 1 yield L	No. 1 yield LER
1986	Bixby	Tomato	0.60*[w]	1.10	0.61*	1.11	0.60*	1.10
		Eggplant	0.50		0.51		0.51	
	Perkins	Tomato	0.44	0.86	0.42	0.83	0.45	0.86
		Eggplant	0.41		0.41		0.41	
	Stillwater	Tomato	0.49	1.00	0.49	1.00	0.49	1.00
		Eggplant	0.51		0.51		0.51	
1987	Bixby	Tomato	0.55	1.09	0.57	1.09	0.62	1.15*
		Eggplant	0.55		0.53		0.53	
		Tomato	0.44	0.95	0.44	0.95	0.42	0.90
		Bell pepper	0.51		0.51		0.48	
		Eggplant	0.52	1.01	0.45	0.92	n.a.	n.a.
		Bell pepper	0.49		0.47		n.a.	

[z]Crop cultivars: tomato cv. Sunny, eggplant cv. Classic, bell pepper cv. Early Calwonder.
[y]Ratio of intercrop component yield to monocrop yield.
[x]Land equivalent ratio, sum of component Ls for that intercrop.
[w]*, significantly different from yields in monocrop.

Table 16. Gross and net returns from alternate-row, solanaceous intercrops at three locations in 1986.

Location	Culture	Component	Component gross returns[z] ($/ha) All	No. 1	No.2	Intercrop gross returns ($/ha)	Fixed costs ($/ha)	Variable costs ($/ha) All	No. 1	No. 2	Component net return ($/ha) All	No. 1	No. 2	Culture net return ($/ha)	MA[y] ($/ha)
Bixby	Monocrop	Tomato[x]	50631	42268	8362		5510	15453	12488	2965	29668	29780	5397		
		Eggplant[w]	49599				1209	15105			33285				
	Intercrop	Tomato	30589*[v]	25203*	5387*	55720	2755	9356	7446	1910	18478*	17757*	3477*	35350	3889
		Eggplant	25131				605	7654			16872				
Perkins	Monocrop	Tomato	22230	17755	4475		5510	6832	5246	1587	9888	12509	2888		
		Eggplant	25649				1209	7811			16629				
	Intercrop	Tomato	9375	7958	1418	19931	2755	2854	2351	503	3766	5607	915	10502	-1264
		Eggplant	10556				605	3215			6736				
Stillwater	Monocrop	Tomato	22650	18599	4051		5510	6931	5495	1436	10209	13104	2615		
		Eggplant	24953				1209	7599			16145				
	Intercrop	Tomato	11110	9109	2002	23765	2755	3401	2691	710	4954	6418	1294	13149	0
		Eggplant	12654				605	3854			8195				

[z]Returns from component at population within given culture.
[y]Monetary advantage.
[x]Tomato cv. Sunny.
[w]Eggplant cv. Classic.
[v]*, significantly different from monocrop on a per land unit area, 5% level.

Table 17. Gross and net returns from alternate-row, solanaceous intercrops at Bixby in 1987.

Culture	Component	Component gross returns[z] ($/ha) All	No. 1	No. 2	Intercrop Gross returns ($/ha)	Fixed costs ($/ha)	Variable costs ($/ha) All	No. 1	No. 2	Component net return ($/ha) All	No. 1	No. 2	Culture net return ($/ha)	MA[y] ($/ha)
Monocrop	Tomato[x]	19871	12285	7587		5510	6319	3630	2690	8042	8655	4897		
	Eggplant[w]	68314				1209	20805			46300				
	Bell Pepper[v]	12222				2576	3694			5952				
Intercrop	Tomato	11940	8146	3793	48460*[u]	2755	3764	2407	1357	5421	5739	2436	30214*	5212*
	Eggplant	36520				605	11122			24739				
	Tomato	8164	5163	3001	14025	2755	2589	1525	1064	2802	3638	1937	5603	-266
	Bell pepper	5861				1288	1772			2801				
	Eggplant	31324			37037	605	9540			21179			23877	-1757
	Bell pepper	5713				1288	1727			2698				

[z]Returns from component at population within given culture.
[y]Monetary advantage.
[x]Tomato cv. Sunny.
[w]Eggplant cv. Classic.
[v]Bell pepper cv. Early Calwonder.
[u]*, significantly different from monocrop on a per land unit area, 5% level.

the spring. A wind barrier of several parallel sweet corn rows sown south of the intercrop test gave some protection. The southernpea/snap bean intercrop suffered more than the tomato/eggplant experiment because whole bean and pea leaves were destroyed by blowing sand. The Bixby location showed uniform growth both seasons, had good drainage and irrigation, and had no major pest outbreaks, save a late season infestation of red spider mites on the eggplant in 1987.

In 1986, eggplant cull fruits appeared affected by culture. At two locations, during the middle harvest period, intercropping produced lighter cull fruit than monocropping. At the Bixby location the reverse occurred. The opposite effect at Bixby can be explained by the significantly lower cull fruit number produced by the intercrop. This difference only manifested itself in season totals, not during any of the three harvest periods. It did result in mean cull fruit weights being significantly higher in intercrop than in monocrop over the whole season. The higher cull fruit weight in intercrop offset the reduced cull number in intercrop at Bixby and resulted in no significant cull yield differences between the two treatments.

Total and marketable fruit number trended lower in intercrop at Bixby, further supporting the cause of the increased mean cull fruit weight being reduced fruit yield.

At Perkins and Stillwater, the reduced mean cull fruit weights also appeared linked to the trend of higher cull and total fruit number in those treatments during the middle harvest period.

Throughout the three harvest periods and three locations, these relationships, of higher fruit weight linked with lower fruit number, persisted.

The late harvest period at Perkins produced interesting results. There, monocrop yields exceeded intercrop yields for marketable, cull, and total yield. These results were the opposite of those for the early and intermediate harvest period. They accounted for most of the season total numeric differences between the cultures. During the early and middle harevst periods monocrop yield numbers trended higher than intercrop yields although only the mean cull fruit weight, during the middle period, was significantly different.

In 1987, eggplant yield differences did not appear between treatments until the middle and late harvest periods. The differences in season totals reflect the differences within these harvest periods.

During the middle harvest period, the tomato/eggplant intercrop produced greater total eggplant yield than the other two cultures.

Similarly, in the late harvest period, both intercrops produced higher eggplant cull yields, by weight and fruit number, than the eggplant monocrop. These increases resulted in higher total fruit yield and fruit numbers during the late harvest period when eggplant was intercropped. Intercropping did not influence mean fruit weight during the harvest period.

For the 1987 season, a late season outbreak of spider mites may have caused the large number of culls during the late harvest period. Numerically higher cull yields in the bell pepper intercrop than in the tomato intercrop may reflect lower humidity and higher temperatures, an environment favored by mites. The dense, almost total canopy of the eggplant monocrop would provide higher humidities and lower temperatures, less favorable to spider mites.

Total marketable eggplant yields increased when eggplant was intercropped with tomato, yielding significantly more than the pepper intercrop for the whole season. Perhaps the peppers compete vigorously with eggplant. This effect appears in season cull totals also, resulting in higher cull yields and cull fruit number in the pepper intercrop. The pepper/eggplant intercrop may be more favorable to culling factors, including insects, stress at anthesis, water stress, and nitrogen stress than the other two treatments, especially since total yields were not significantly different between treatments, and the total yield of the pepper intercrop fell between the values of the pepper monocrop and the tomato monocrop numerically, not following either the trend of cull or marketable yields for the three treatments.

Tomato yields also showed varied responses to treatments. In 1986, few yield differences occurred, except at the Bixby location. In 1987, many differences appeared, most during the intermediate harvest period, a period of high stress and heavy fruit production.

The treatment effects in 1986 also mainly appeared during the middle harvest period, but were not apparent in the late period. At Bixby, the effects also appeared in the season totals, except those affecting cull production.

Increases in marketable yield fromthe monocrop at Perkins and Stillwater during the middle harvest period for marketable yield in monocrop can be explained by looking at cull yields, which trended higher in the tomato/eggplant intercrop. This offset the monocrop advantage in marketable fruit, giving no significant differences between the two total yields during the middle harvest periods at each location and the total season yields between the treatments at each location.

These results contradict those found at the Bixby site in 1986. There, marketable and cull yields increased in the intercrop during the middle harvest period resulting in similar improvements in season totals. Mean fruit weight does not account for the differences in yield between treatments. With fruit number and yield improved by intercropping, it appears the tomato/eggplant intercrop gave genuine advantage to the tomato plants over their monocropped counterparts. Reduced disease pressure, insect pressure, nutrient stress, water stress, or heat stress may be responsible for the increases. With the increases occurring in the middle harvest period, a time of high water stress and heat stress in Oklahoma, these stresses likely play a role in affecting yield differences between treatments.

The 1986 treatment effects were similar to those found in 1987. Again the middle period showed the greatest treatment influences, and these translated into season total yield differences. In the middle period, the mean weights of the monocrop cull fruits were greater than those from the intercrop with eggplant, and may be how the plants in the intercrop made up for the increased fruit load. This may mean the intercropped plants, stressed from greater fruit load, mature their damaged fruit earlier. The altered cull fruit size may also relate to better growth in the eggplant intercrop causing fewer fruits, and mainly smaller ones, to be subject to culling. This idea has added merit when one notes that size was a factor in grading with small fruit being culled, even if perfect. Thus if less larger fruit has injury and was culled, a greater percentage of culls would be small, reducing mean cull fruit size.

The yield differences between treatments may have resulted from different responses to heat and water stress between tomato plants in different treatments. The consistent good performance of the tomatoes in intercrop with eggplant and bad performances from the tomatoes in the bell pepper intercrop indicate response differences are real. Tomato may compete better with eggplant than with bell pepper or itself. Above the soil, humidity would likely be highest and day air temperatures lowest in the eggplant intercrop due to the dense eggplant leaf canopy. Below the soil, tomato roots in the eggplant intercrop would have less competition with other plant roots than in monocrop; but more competition, at least near the tomato plants, than in the bell pepper intercrop. Soil temperatures would also be lower in the tomato/eggplant intercrop than in either of the other two treatments.

The bell peppers showed few significant treatment effects, but a couple of interesting observations on fruit quality were made. The monocrop showed a trend toward a higher percentage of marketable fruit, indicating the intercrops may have experienced less stress than the monocrops. Since fruit size was not significantly different over treatments for marketable or cull fruit, heat and water stress were not considered likely as the causes of increased cull percentages in intercrop. The main culling factors included bacterial spot, early hail damage, sunscald, and fruit size. Perhaps a denser canopy in each plant, with better air circulation between rows, helped reduce the percent culls in the monocrop.

A companion study, testing row location effects on bell pepper yield, showed the monocrop pepper yields may be confounded by adjacent plots (Tables 18 and 19). The study had six double rows of bell peppers perpendicular to prevailing southerly winds, with the leeward-most and windward-most rows as guards. It had five replications and compared the yields of the four interior rows of each block. The leeward-most and windward-most test rows exhibited possible border effects, meaning they appeared less subject to between row competition than the two interior-most rows. This left the two interior-most rows for comparison to the monocrops in the intercrop study. Yields of marketable peppers in the monocrop plots doubled those of either test row in the row location study. Since wind barriers affect wind speed and pepper yield up to 10H (ten times effective barrier height) away on their leeward sides (Holley, 1985), the monocrop peppers could have been influenced by a tomato row up to 12.3m away (based on trellised tomato heights of 1.2m), more than six rows in the intercrop study, or by an eggplant row up to 10m away (based on eggplant heights of 1.0m), more than 5 rows in the intercrop study.

The south winds of Oklahoma may desiccate pollen and stigmatic surfaces, inhibiting full pollination and fertilization of bell peppers. The wind study pepper yields may more closely parallel true monocrop yields than those found in the monocrop plots within the intercrop study.

Table 18. Bell pepper[z] yields from different row locations in 1987.

Row location[y]	Total yield[x] ($kg \cdot ha^{-1}$)	Total fruit/ hectare	Marketable yield ($kg \cdot ha^{-1}$)	Marketable fruit/ hectare	Mean marketable fruit weight (g)	Cull yield ($kg \cdot ha^{-1}$)	Cull fruit/ hectare	Mean cull fruit weight (g)
Leeward	17330 a	189815 ab	10101 a	91435 a	108 a	7229 b	98380 b	84 a
Middle leeward	13647 b	154630 c	6376 b	60417 b	102 a	7271 b	94213 b	75 a
Middle windward	14047 b	164815 bc	6713 b	62037 b	104 a	7334 b	102778 b	72 a
Windward	18024 a	217824 a	8355 ab	74306 ab	106 a	9670 a	143519 a	74 a

[z]Bell pepper cv. Early Calwonder.
[y]Four parallel rows, perpendicular to prevailing winds, with one check row outside both the leeward and windward test rows.
[x]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.

Table 19. Bell pepper[z] yields from different row locations, by harvest period, in 1987.

Harvest period[y]	Row location[x]	Total yield[w] ($kg\cdot ha^{-1}$)	Total fruit/ hectare	Marketable yield ($kg\cdot ha^{-1}$)	Marketable fruit/ hectare	Mean marketable fruit weight (g)	Cull yield ($kg\cdot ha^{-1}$)	Cull fruit/ hectare	Mean Cull fruit weight (g)
Early	Leeward	3862 a	35417 a	1989 ab	16435 a	120 b	1873 a	18981 a	99 a
	Middle leeward	3399 a	32870 a	1431 b	11806 a	124 ab	1968 a	21065 a	95 a
	Middle windward	3998 a	39352 a	1778 ab	14120 a	128 ab	2220 a	25231 a	89 a
	Windward	4388 a	38426 a	2241 a	15509 a	142 a	2147 a	22917 a	97 a
Middle	Leeward	7102 a	70139 a	5271 a	46296 a	114 a	1831 a	23843 a	87 a
	Middle leeward	5472 b	58102 ab	2778 b	25231 b	110 a	2694 a	32870 a	82 a
	Middle windward	4651 b	50231 b	2778 b	24769 b	116 a	1873 a	25463 a	74 a
	Windward	5461 b	56944 ab	3009 b	26389 b	116 a	2452 a	30556 a	85 a
Late	Leeward	6366 b	84259 b	2841 a	28704 a	102 a	3525 b	55556 b	79 a
	Middle leeward	4777 b	63657 b	2168 a	23380 a	94 a	2610 b	40278 b	66 ab
	Middle windward	5398 b	75231 b	2157 a	23148 a	92 a	3241 b	52083 b	67 ab
	Windward	8176 a	122454 a	3104 a	32407 a	93 a	5071 a	90046 a	62 b

[z]Bell pepper cv. Early Calwonder.
[y]Harvest periods: Early, 6/25 to 7/5; middle, 7/6 to 7/16; late, 7/17 to 7/27.
[x]Four parallel rows, perpendicular to prevailing winds, with one check row outside both the leeward and windward test rows.
[w]Mean seperation, within columns and harvest periods, by Duncan's New Multiple Range Test, 5% level.

Unfortunately, our intercrop study does not concretely confirm this argument, and so the recommendation against intercropping tomato or eggplant with bell pepper must stand until someone investigates the wind barrier effects of the taller component crops.

Two factors may be responsible for the increases in yields from the middle harvest period in the tomato/eggplant intercrop. The increases may relate to improved plant growth and development during the early harvest period or to reduced floral abortion during the middle harvest period.

According to Wittwer and Aung in Evans (1969), the environment at time of floral differentiation can influence the flower number within an inflorescence. The authors indicated that tomato initiates its first flowers within two weeks of germination. Since the first fruits matured about 100 days after germination, we used 85 days as the time from floral initiation to the time of harvest. For the middle harvest periods, 14 July thru 6 August, 1986 and 6 July thru 19 July, 1987, floral initiation most likely occurred between 21 April and 13 May, 1986 and 13 April and 26 April, 1987. Because these dates occurred before, during and within two weeks after transplanting, the possibility of the intercrop affecting flower initiation in each inflorescence can be ruled out. Furthermore, Varga and Bruinsma, writing in Monselise (1986) claimed flower number has little affect on total tomato yield, except as it influences early flower production. They said percentage of fruit set and the development of those fruit determine most of the yield.

Because altered flower number wass likely not the cause of increased tomato yield in intercrop with eggplant, only development of flowers and fruit near the time of fruit set remains to explain the yield differences found during the middle harvest period. Because fruit size was only slightly affected by the three treatments, differing rates of pollination and water stress during fruit growth only accounts for part of the yield differences, leaving altered fruit set as the probable cause, as suggested by the findings Varga and Bruinsma reported in Monselise (1986). They cite high day or night temperatures and high light intensities as the main factors limiting pollination and fruit set. Since no measurements of these parameters occurred during the study, no speculation as to how they may have influenced pollination or fruit set can be made. No flower counts, fruit set percentages, or observations of flower quality were made. Improved pollen viability, increased stigmatic receptivity, improved embryo survival, and reduced stylar elongation all may have influenced fruit set, as suggested by Varga and Bruinsona in Monsilise (1986).

In 1986, the intercrop of tomato and peppers produced an LER term greater than 0.5 for total, marketable and No. 1 yield. Although these did not result in total LERs > 1 for the intercrop, it did represent the potential value of this intercrop.

During 1987, no component of any intercrop had an LER term significantly greater than 0.5, but the tomato/eggplant intercrop had an LER of 1.15 for No. 1 fruit. This was the only instance where the trend of improved yield totals in the tomato/eggplant intercrop translated into a significant improvement over monocrop at the 5% level.

From a farmer's perspective, the twenty percent marketable tomato yield increase provided by intercropping tomato with eggplant in 1986 may represent a great advantage. According to enterprise budgets produced by the Agricultural Economics Department of Oklahoma State University (Schatzer, et al., 1985), costs to the farmer decrease on a per kilogram yield basis, as yield increases.

For tomato, the marketable yield increases from the eggplant intercrop produced gross revenue increases of over $5000 compared to tomato or eggplant in monocrop. If these increases are transformed into net increases, the return per hectare is $2065 more than from eggplant alone, and $5682 more than from tomato alone.

In 1987, again the yield improvement the tomato/eggplant intercrop produced over monocrop translated into increased monetary returns. Here, no component generated significantly more gross return than monocrop, but the returns combined made the tomato/eggplant intercrop produce a $4368 gross return increase over the average return per hectare of the two monocrops. The eggplant monocrop produced the most revenue on the whole, but when it and the tomato monocrop are compared to the intercrop, at the intercrop populations per hectare, the intercrop grossed more. Further transformation shows the intercrop has a net MA of $5212 per hectare over the monocrops.

When evaluating the value of the intercrops, the added input costs associated with the cropping systems must influence a farm manager's conclusions. Unlike most intercrops, which have increased capital costs (Crookston, 1976; Willey, 1979a), the three used in this study had few input and management changes from those used in the monocrops. The only extra physical inputs these intercrops required involved the added fuel and labor costs of traveling between ends of component rows, past the component not being worked at that time. To travel a hectare of row ends would involve moving an extra 27.7 m, based on 1.8 m spacing and a square hectare. This expense would alter costs little.

Unfortunately, a real cost disadvantage of these, and other intercrops, appears as a need for more intense management. The management increases cannot be valued here monetarily but include: making sure workers tend only the component being worked at that time, monitoring pesticide applications specific to certain components (such as miticide for eggplant), and if harvesting more than one component on a given day, coordinating in-field handling of the harvested crops. These management aspects would be most important for first-year intercrop managers and as they affect new employees.

These experiments have shown potential value for intercrops of related vegetables. The eggplant/tomato alternate-row intercrop may increase net return for a farmer, and offers some land-use advantages over monocropping. The two intercrops using bell pepper may result in reduced net income for a farmer due to reduced yield of the non-pepper component crop.

More work needs to focus on interfamiliar intercrops. Related intercrops may offer the improved yields and returns found in morediverse intercrops, and do not have many of the management problems associated with intercropping in intense agricultural systems.

CHAPTER IV

INTERCROPPING SNAP BEANS (Phaseolus vulgaris) WITH SOUTHERNPEAS (Vigna unguiculata)

Introduction

America produced $4.5 billion worth of vegetables in 1987. In 1986, Oklahoma produced $35.4 million worth of vegetables on 18,000 hectares. Of these, 12,907 hectares were devoted to fresh market vegetable crops. Southernpeas are one of Oklahoma's primary vegeable crops. Snap beans are grown but are a minor crop.

Like all growers, those in Oklahoma concern themselves with improving yield and monetary return. Intercropping can accomplish both (Willey, 1979 and Kotosokoane, 1985).

In this study, two leguminous crops were grown in alternate-row intercrops to try and take advantage of difference between them, which could allow for higher yields. They required similar culture and methods of pest management, permitting the use of intense management practices inhibitted by more diverse cropping systems.

Materials and Methods

This study compared yield of snap bean and southernpea in monocrop and alternate-row intercrops. Reproductive yield, plant growth characteristics at harvest, and economic returns between treatments were compared.

The studies were done during the summers of 1986 and 1987. The 1986 study was conducted at three sites: the Oklahoma State University Nursery Research Center at Stillwater on an Easpar loam, the O.S.U. Fruit Research Station at Perkins on a Teller sandy loam, and the O.S.U. Vegetable Research Station at Bixby on a Severn very-fine sandy loam.

After preparing the 1986 sites for planting, seeds of snap bean cv. Eagle were sown at 32 seeds per meter in rows 0.9 m apart, 10 m long. Sowing dates included 24 April at Bixby and 29 April at Perkins and Stillwater. Southernpea cv. Encore was sown in a like pattern to that of the snap bean, but at a rate of 20 seeds per meter. Planting of the southernpeas occurred 29 April at Perkins and Stillwater and 6 May at Bixby. Sowing dates at Bixby in 1987 were 11 May for both snap bean and Southernpea. A 29 May hail storm necessitated a second sowing of the two crops 5 June. The late sowing and subsequent exposure to high temperature at anthesis resulted in poor snap bean pollination, so the crop was not harvested and no plant characteristics recorded.

Trifluralin herbicide was applied at 0.227 kg a.i. ha^{-1} and 33.6 kg ha^{-1} nitrogen as ammonium nitrate were applied preplant at all locations, both years. To control pod borers, the snap beans received a preventative spray of methomyl at 0.346 kg a.i. per hectare at the pin stage, when pods were 2.5 cm long.

Overhead irrigation was supplied at the three 1986 sites and the 1987 site when rainfall did not exceed 2.5 cm per week.

Cultural practices followed recommendations of the Oklahoma

State University Cooperative Extension Service (Cantaluppi, et al., 1983; McCraw and Motes, 1987; Motes, et al., 1983)

The studies were arranged in a randomized complete block design. Each 1986 site had three replications and the 1987 site had six replications. Treatments included monocrop snap beans, monocrop southernpeas, and an alternate-row intercrop of the two species. Double or triple guard rows buffered the plots. Data were collected from two adjacent 1.5 m sections within the test row. Plants near the ends of the rows were not selected.

For snap bean, stand count was recorded. Mean plant height was taken from a plant thought to represent those in the row being sampled. Pod elevation off the ground and plant lodging were rated on a visual scale (1 = pods on ground or all plants lodged, 5 = all pods off ground or no plants lodged). Then, after pulling up the plants in the row, pods were removed, mean pod length recorded from a sample of 20, pod color rated (1 = poor,5 = excellent), and pod curvature observed (1 = all pod curved,5 = no pods curved). In 1987, one 3.0m section of each test row was studied.

The southernpea crop also had its stand counts recorded from two 1.5m sections of row in 1986 and one 3.0m section in 1987. Harvest occurred when fifty percent of the pods had begun to brown, equivalent to harvest at the green-shell stage.

Fresh weight of pods, peas,and stems and leaves were recorded. The samples were oven dried at 40°C for 24 hours, except the 1987 stems and leaves, which were dried for three days in a 45 C greenhouse. After drying, weights of all the materials were recorded, and a 100 seed lot was drawn from each sample and weighed.

The dry weights of stems and leaves, pods, seeds, and the 100 seed sample were recorded.

Analysis of variance using SAS provided treatment comparisons, separated using Duncan's New Multiple Range Test at the 5% level.

For 1986, land equivalent ratios were calculated for the intercrop treatments based on:

$$LER = \frac{\text{intercrop yield A}}{\text{monocrop yield A}} + \frac{\text{intercrop yield B}}{\text{monocrop yield B}} \quad (1)$$

from Willey (1985).

Monetary advantage (MA) was calculated for the intercrops from:

$$MA = \text{Value of intercrop}(1 - LER)(LER) \quad (2)$$

by Willey (1985).

Using the MAs and enterprise budgets from the Oklahoma State University Cooperative Extension Service (Schatzer, et al., 1986) returns and monetary advantages were figured for the intercrop treatments.

Because the 1987 snap bean crop succumbed to hail, no economic results or LERs were calculated for that study.

Results

In 1986, southernpea and snap bean grew in intercrop and monocrop at three locations. In 1987, only one location was used for the study. No significant location X culture interactions were found during 1986. In 1987, a 30 May hail storm destroyed the snap beans, which were subsequently replanted but failed to make a crop due to high temperatures at anthesis.

In the southernpeas no significant differences occurred between cultures, within location, for the yield parameters total reproductive yield, total pea yield, total pod yield, percent shell out, seed weight, or plant population in 1986 (Table 20). Total yield, pea yield and pod yield were higher at Bixby for each culture than at Perkins or Stillwater while 100 seed weight was highest at Perkins.

Several differences between monocrop and intercrop appear in 1987 southernpea yields (Table 21). Fresh yield of peas, reproductive tissue, total yield, along with total dry matter production, dry weight of nonreproductive tissue, seed, pod tissue, and mean seed weight increased in intercrop compared to monocrop. Plant population, fresh and dry percent shell out, fresh nonreproductive yield, fresh pod yield, and fresh mean seed weight remained unchanged among treatments.

Although not analyzed, percent dry matter, percent DM in reproductive tissue, and percent DM in the seed show no large numeric differences among treatments.

Similar to the 1986 southernpeas, Bixby snap bean yields exceeded those of Perkins and Stillwater (Table 22). Location did not influence pod elevation, pod curvature, nor plant lodging.

Within locations, culture did not alter yield, plant population, pod length, plant height, pod elevation, pod curvature, or plant lodging.

During 1986, LER's for the southernpea/snap bean intercrop did not significantly exceed 1.0 (Table 23), ranging from 0.98 at Perkins

Table 20. Fresh southernpea[z] yields in monocrop and alternate-row intercrops with snap beans[y] at three locations, 1986.

Location	Culture	Reproductive yield ($kg \cdot ha^{-1}$)	Pea yield ($kg \cdot ha^{-1}$)	Pod yield ($kg \cdot ha^{-1}$)	Percent shell out (%)	100 seed weight (g)	Plants/ meter
Bixby	Monocrop	2403 a[x]	1942 a	461 ab	80.8 a	16.1 b	12.4 ab
	Intercrop	2544 a	2012 a	531 a	78.9 ab	16.2 b	12.7 a
Perkins	Monocrop	1521 b	1133 b	388 bc	74.2 d	19.2 a	8.6 b
	Intercrop	1660 b	1264 b	395 bc	75.8 bcd	18.5 a	8.6 b
Stillwater	Monocrop	1471 b	1154 b	316 c	78.1 abc	15.7 b	9.7 ab
	Intercrop	1696 b	1292 b	404 bc	75.6 cd	15.9 b	12.2 a

[z]Southernpea cv. Encore.
[y]Snap bean cv. Eagle.
[x]Mean seperation, within columns, by LSD, 5% level.

Table 21. Fresh and dry southernpea[z] yields in monocrop and alternate-row intercrops with snap bean[y] in 1987.

	Culture	
	Monocrop	Intercrop
Total fresh weight($kg \cdot ha^{-1}$)	11139 b[x]	13335 a
Nonreproductive fresh weight($kg \cdot ha^{-1}$)	5691 a	6823 a
Reproductive fresh weight($kg \cdot ha^{-1}$)	5448 b	6511 a
Seed fresh weight($kg \cdot ha^{-1}$)	3711 b	4474 a
Pod fresh weight($kg \cdot ha^{-1}$)	1737 a	2037 a
Fresh percent shell out(%)	68.4 a	68.7 a
Fresh weight of 100 seeds(g)	25.5 a	23.3 a
Total dry wieght($kg \cdot ha^{-1}$)	2721 b	3374 a
Nonreproductive dry weight($kg \cdot ha^{-1}$)	311 b	359 a
Reproductive dry weight($kg \cdot ha^{-1}$)	2410 b	3015 a
Seed dry weight($kg \cdot ha^{-1}$)	1917 b	2403 a
Pod dry weight($kg \cdot ha^{-1}$)	492 b	611 a
Dry percent shell out(%)	79.5 a	79.7 a
Dry weight of 100 seeds(g)	15.0 a	14.1 b
Plants per hectare	76062 a	83364 a

[z]Southernpea cv. Encore.
[y]Snap bean cv. Eagle.
[x]Mean seperation, within rows, by LSD, 5% level.

Table 22. Snap bean[z] yields in monocrop and alternate-row intercrops with southern pea[y] at three locations in 1986.

Location	Culture	Total yield ($kg \cdot ha^{-1}$)	Mean pod length (cm)	Pod curvature rating[x]	Mean plant height (cm)	Pod elevation rating[w]	Plant lodging rating[v]
Bixby	Monocrop	13130 a[u]	4.6 a	3.3 a	17.4 a	3.8 a	3.4 b
	Intercrop	14240 a	4.6 a	3.3 a	17.5 a	4.0 a	3.8 b
Perkins	Monocrop	8076 b	4.3 ab	3.6 a	13.1 b	3.5 a	4.8 a
	Intercrop	7089 bc	4.1 bc	3.8 a	12.3 b	3.3 a	5.0 a
Stillwater	Monocrop	4007 c	4.1 bc	3.4 a	12.7 b	3.3 a	4.6 a
	Intercrop	3637 c	4.0 c	3.3 a	12.4 b	4.0 a	5.0 a

[z]Snap bean cv. Eagle.
[y]Southern pea cv. Encore.
[x]Visual ratings: 1=all pods curved, 5=no pods curved.
[w]Visual ratings of how well pods are held off the ground:1=poor, 5=best.
[v]Visual ratings:1=all plants lodged, 5=no plants lodged.
[u]Mean seperation, within columns, by Duncan's new multiple range test, 5% level.

Table 23. Land equivalent ratios for leguminous[z] intercrops[y] in 1986.

		Total yield	
Location	Component	L[x]	LER[w]
Bixby	Snap bean	0.54	1.07
	Southernpea	0.53	
Perkins	Snap bean	0.44	0.98
	Southernpea	0.54	
Stillwater	Snap bean	0.45	1.03
	Southernpea	0.58	

[z]Crop cultivars: snap bean cv. Eagle, southernpea cv. Encore.
[y]Alternate-row intercrops.
[x]Ratio of intercrop component yield to monocrop yield.
[w]Land equivalent ratio, sum of Ls for that intercrop.

to 1.07 at Bixby. The southernpea component always trended above 0.5 for its term of the LER.

Gross and net returns also did not change between monocrop and the southernpea/snap bean intercrop in 1986 (Table 24).

In 1987, LERs and returns were not calculated because of the failure of the snap bean crop.

Discussion

It appeared intercropping of southernpeas with snap beans had little affect on the two crops. The 1986 data showed no differences between cultures at any location. Although not significant at the 5% level, a trend toward higher (about 5%) yields of southernpea in intercrop emerged. This increase in yield became significant in 1987. This yield represented total reproductive yield of fresh pods and peas, as they would go to market for green shell peas.

The 1987 southernpea yield increases found in intercrop may not represent results a farmer would find. Because poor pollination of the snap beans prevented reproductive growth, and its associated need for limited nutrients and water, the intercropped peas may have had an unintended advantage over the monocropped peas. The lack of normal competition from the alternate bean rows may have given the intercropped peas access to soil water and nutrients which the snap beans would have used in developing fruits.

It should also be noted, during 1987 the trend toward higher southernpea plant populations in intercrop does not fully account for the yield increases. Yield per plant was higher in intercrop.

Table 24. Gross and net returns from alternate-row, leguminous intercrops during 1986.

Location	Culture	Components	Component gross returns[z] ($/ha)	Intercrop gross returns ($/ha)	Fixed costs ($/ha)	Variable costs ($/ha)	Component net return ($/ha)	Intercrop net return ($/ha)
Bixby	Monocrop	Snap bean[y]	12999		717	4018	8264	
		Southernpea[x]	2115		500	726	889	
	Intercrop	Snap bean	7049	8168	359	2179	4511	4996
		Southernpea	1119		250	384	485	
Perkins	Monocrop	Snap bean	7995		717	2446	4832	
		Southernpea	1338		500	459	379	
	Intercrop	Snap bean	3509	4239	359	537	2613	2842
		Southernpea	730		250	251	229	
Stillwater	Monocrop	Snap bean	3967		717	1214	2036	
		Southernpea	1294		500	444	350	
	Intercrop	Snap bean	1800	2546	359	275	1166	1406
		Southernpea	746		250	256	240	

[z]Returns from components at population within given culture.
[y]Snap bean cv. Eagle.
[x]Southernpea cv. Encore.

Intercropping may have delayed maturity in the intercropped plots during 1987. This would have appeared as higher percent dry matter in the monocrop yield with little difference in dry matter production in reproductive tissues. The intercrop would have had higher water content, indicating less maturity. By comparing the dry and fresh weights in table 23, one sees the percent DM in reproductive tissues was 44% and 46%, for monocrop and intercrop, respectively. The seed had 52% and 54% DM in monocrop and intercrop, respectively.

The southernpea/snap bean intercrop did not produce consistent economic advantage. The 1986 returns from the intercrop fell between those of the two monocrops, showing the moderating effect intercropping can have on returns, and the associated risk reduction, although similar risk reduction could have been had by planting the two crops in monocrop.

For equivalent yield, the farmer planting monocrop would also avoid the management problems mentioned in the discussion of the solanaceous intercrops. For the legumes, these include applying the snap bean pod borer spray only to that crop, preventing chemical waste; harvesting the snap beans without damaging the later-maturing southernpeas; and the personnel training aspects described in the aforementioned solanaceous intercrop discussion. Thus, the snap bean/southernpea intercrop cannot be recommended to farmers at this time.

The snap bean/southernpea intercrop should probably be tested again, especially since the 1987 southernpeas yielded more in intercrop. If this yield held up during a normal season, without interfering with the more valuable snap bean yield, the intercrop could be recommended.

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VITA 2

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