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Agronomic characteristics of intercropped legume and cereal crops

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AGRONOMIC CHARACTERISTICS OF INTERCROPPED LEGUME AND CEREAL CROPS

by

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SIGNED: ______________________

To the memory of my Father,

Francisco Alexandre de Menezes

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TABLE OF CONTENTS

TABLE OF CONTENTS--Continued

LIST OF TABLES

LIST OF TABLES--Continued

LIST OF TABLES--Continued

LIST OF TABLES--Continued

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS--Continued

ABSTRACT

Research was conducted in the summers of 1985 and 1986 at the University of Arizona Marana Agricultural Center, with the objectives of (1) determining the best intercropping species combination under near optimum irrigation, using three cereals (sorghum (*Sorghum bicolor*), maize (*Zea mays*), and pearl millet (*Pennisetum americanum*) and three legumes (field bean (*Phaseolus vulgaris*), cowpea (*Vigna unguiculata*), and soybean (*Glycine max*)in all combinations, and (2) identifying species genotypes best adapted to intercropping. Results from 1985 determined sorghum x soybean as the most appropriate intercropping combination for the environment of the Marana Agricultural Center. In the 1986 cropping season, three sorghum genotypes (Pioneer 8493, Funks G-522DR, and California IO80H40) were combined with three soybean genotypes (Asgrow A6242, Asgrow A6520, and Rillito), to identify the best genotype combination for intercropping. Both 1985 and 1986 experiments were carried out in a randomized complete block design with four replications. Pearl millet was the cereal with the greatest decrease in yield when intercropped, indicating that this cereal was not a good competitor with legumes. Sorghum was the best cereal competitor with the legumes and soybean was the best legume

competitor with the cereals. Among the three sorghum genotypes studied in 1986, only Pioneer 8493 showed higher yield in monocrop whereas the other two genotypes yielded higher in intercropping, indicating some benefit from this system. On the average, all three sorghum genotypes showed intercropping to be advantageous, with high Land Equivalent Ratio values. Soybean genotypes showed drastic decreases in yield when intercropped. Asgrow A6520 soybean had the highest yield in intercropping. Sorghum # 3 (California IO80H40) and soybean # 3 (Rillito) were chosen as the most appropriate genotypes for intercropping, for the environmental conditions of the study.

CHAPTER 1

INTRODUCTION

The lack and non-uniformity of pluvial precipitation are serious problems of agricultural production in arid and semi-arid regions. Rainfall may be heavy and concentrated in very short periods of time, followed by long dry periods. The affected crops usually suffer from drought throughout their life cycles, which becomes critical during the flowering and grain filling stages. This very often causes significant decreases in grain yield and even complete loss of yield.

To diminish the risk of losing the entire grain yield, farmers have adopted intercropping systems, where two or more crops are grown together in the same area. The crops are not necessarily sown at exactly the same time and their harvest times may be quite different, but they are usually "simultaneous" for a significant part of their growing periods. This distinguishes intercropping from "relay" cropping in which the growing periods only briefly overlap (Willey, 1979a).

Intercropping has also been adopted under non-drought conditions, where there is a large supply of hand labor, for more intensive utilization of the land.

Intercropping is the main cropping system in northeast Brazil, generally a cereal x legume combination. Among the various intercrop combinations adopted by the small farmers, maize with field bean is the most utilized. According to Francis et al. (1976), it is estimated that 80% of the field bean and 50% of the maize produced in Latin America are grown in intercropping systems. In Brazil, 70 to 90% of the field bean are produced in intercropping (Vieira, 1980).

Intercropping was neglected for many years by the agricultural research and extension services in most developing countries which concentrated their attention on monocropping systems, mainly because these systems are easily adapted to high technology (Vieira, 1984). However, the small farmers in northeast Brazil continue to adopt intercropping and only recently have research organizations started to give attention to such an important area for the Brazilian semi-arid tropical region.

All the technology adopted by farmers in intercropping has been based on experimental results from monocropping. Besides some other important factors, it is extremely necessary to define the best intercropping system for each sub-region, as well as the genotypes best adapted to the drought conditions in those areas.

The objectives of these studies were (1) to determine the best intercropping combination under near optimum irrigation, using three cereals (sorghum, maize, and pearl millet) and three legumes (field bean, cowpea, and soybean) in all combinations, and (2) to identify genotypes well adapted to an intercropping an system.

CHAPTER 2

LITERATURE REVIEW

Intercropping had been neglected for many years, being considered a cropping system adopted only by small farmers that would some day be replaced by monocropping. Recently, however, a greater interest in intercropping has increased and the scientific community has recognized its importance as a profitable system which may even be practiced by increasing numbers of peasant farmers. This literature review focuses on the most important agronomic aspects of intercropping with special emphasis on legume/cereal combinations.

Advantages and Disadvantages of Intercropping

Associated cropping systems which predominate on small farms in the tropics represent the evolution of low-input, low-income but low-risk agriculture which allows farmers in many areas to harvest some of their subsistence needs and to participate in the market economy (Francis and Sanders, 1978).

When two or more crops are grown on the same areas of land, with a given level of inputs and their life cycles overlap, their production will be related in one of three basic ways. The two crops may be "competitive", wherein the output of one crop can only be increased at the expense of the other; or "complementary", wherein an increase in the output of one crop will also bring about an increase in the production of the other; or "supplementary", wherein the output of one crop tends to be independent of the output of the other (Flinn, 1979).

Multiple cropping systems are particularly prevalent on small farms in tropical latitudes where seasonal fluctuations in temperature are minor and crops can be grown year-round if other environmental factors are favorable (Oelsligle et al., 1976). In a sense, multiple cropping helps growers increase crop hectarage thereby helping to meet the ever expanding need for food and feed. At the same time the systems demand careful management for success. They encourage more intensive land use and also more efficient utilization of machinery, labor, and capial investment (Lewis and Phillips, 1976).

According to Andrews (1972), a number of general criteria can be recognized by which increased returns are obtained from intercropping:

1. intercrop competition must be less than intracrop competition,
2. the arrangement and relative numbers of the

contributing crop plants will affect the expression of the difference in competition,

3. the effect of competition between crops is greatly alleviated when their maximum demands on the environment occur at different times; this can be achieved either by selecting crops with differing growth cycles or by planting them at different times,
4. intercropping is more effective where the seasonal period for growth is long enough to permit the operation of the principles (3) above, and
5. legumes may be a necessary rotational component under conditions of poorer fertility.

According to Wrigley (1969, cited by Okigbo and Greenland, 1976), some of the advantages of intercropping include:

1. increased erosion control and insurance against crop failure,
2. labor and harvesting are spread more evenly and storage problems may be minimized,
3. diseases and pests do not spread rapidly,
4. efficient utilization of resources by plants of different heights, rooting systems, and nutrient requirements.

Disadvantages of intercropping include:

1. Mechanization of planting and harvesting is difficult,
2. It is more difficult to apply improved inputs, e.g., fertilizers and herbicides as in sole cropping,
3. Experimentation with intercropping is more complex and difficult to manage than with sole cropping.

An almost inevitable feature of development programs is the emphasis placed on pure crops. Probably the most frequently quoted justification for this emphasis is that as agriculture develops, mixtures become increasingly difficult to manage, particularly when mechanization is introduced. It is also said that some of the possible advantages of mixtures (e.g., a reduced build up of pests and diseases, or the compensation possible if one species fails) may become less applicable as better control is achieved over the various production factors. This reasoning may be quite sound, but it overlooks the fact that there can be advantages of mixtures which may be equally applicable in highly developed agriculture. For instance, mixtures may be able to produce more yield than when the component crops are grown separately because of a more efficient utilization of environmental resources (Willey and Osiru, 1972).

Perrin (1977, cited by Amoako-Atta et al., 1983) summarized some reasons for increased crop turnover within multiple cropping systems as follows:

1. more efficient use of solar radiation,
2. more efficient use of soil moisture and nutrients,
3. maintenance of a dense canopy which smothers weeds and may protect soil from erosion.

Planting Dates and Intercropping

Seed production of component cultivars in an intercropping pattern is determined by such factors as density of seeding of each component, relative competitive ability, plant height, cycle of maturity, and cultivar genotypes. The farmer can control date of planting and choice of cultivar. With simultaneous or near simultaneous planting of two or more intercropped cultivars there is an opportunity to give one species an initial advantage over the other by planting a few days ahead. This advantage may be necessary for one crop to assure its establishment and early growth before being outcompeted by a taller or more aggressive companion crop (Francis et al., 1982a).

According to Rosset et al. (1984), crop phenology and planting time affect crop interaction in polycultures. Crops exhibit a critical period in their growth cycles during which competition significantly decreases yield. Competitive effects on yields of polycultures may depend on the amount of critical period overlap in the phenologies of the associated crops. For example, a short cycle legume intercropped with a longer cycle crop may provide a pulse of N from decaying roots at a critical period in the phenology of the associated crop, thus positively affecting its yield.

In an intercropping study with maize and cowpea (Ezueh and Taylor, 1984), the extent of insect damage in the intercrops was determined by the interaction between time of sowing and cropping method. Planting cowpea 12 weeks after the establishment of maize significantly reduced insect damage and therefore appeared to be the best time to intercrop to achieve some measure of control of pests. The maize crop at this time was completely dry with brown stalks and shriveled leaves. The alternating rows of cowpea in the mixed plots may, therefore, constitute a peculiar ecology which could disturb the normal orientation, particularly of borer moths towards cowpea, resulting, ultimately, in fewer moths entering the intercrop than the sole crop. These findings are relevant to the development of a pest management scheme for cowpea involving the ecological concept.

Regarding the effects of sowing times there appear to be two closely related factors involved (Willey, 1979b). The first is the effect on temporal differences between the crops. Where these differences are reduced, the evidence suggests that yield advantages diminish, presumably because of the reduced temporal complementarity between the crops. On the other hand, where temporal differences are increased, there may be a potential for greater yield advantages. The second factor which determines time-of-sowing effects, and one which may considerably modify the effects discussed, is that an earlier sown crop becomes more competitive and a later sown one less competitive than when they are sown simultaneously. However, Francis et al. (1975, cited by Willey, 1979b), found that sowing bush bean 2 weeks before maize gave the best balance of competition and the highest yield advantages showing that in some circumstances this change in relative competive ability could be beneficial.

Plant Spacing and Populations in Intercropping

The effect of plant density on yield is frequently defined by an asymptotic relationship where yield is unaffected by densities greater than that which produces the maximum, or by a parabolic curve in cases where yield reaches a peak and then declines as density is increased (Willey and Heath, 1969, cited by De Moura and Foster, 1986).

For sole crops, the different aspects of plant population and spatial arrangement are well understood (Willey, 1979b). Plant population defines the number of plants per unit area which determines the size of the area available to the individual plant.

For the intercropping situation, plant population and spacial arrangement aspects are more complex. With regard to plant number, both total population (all components) and component population (each component) have to be distinguished (Willey, 1979b). The main problem here is that, in terms of the plant population pressure on resources, a single plant of one crop is seldom directly comparable to a single plant of another crop (Willey and Osiru, 1972). This can be overcome by regarding optimum population of sole crops as comparable. If these are taken as 100, component populations can then be expressed on a simple relative basis e.g., a simple intercrop treatment having half the sole crop optimum of each of two components is expressed as 50:50 component population. One of the most important aspects which has emerged from recent experimentation is that where intercropping gives a yield advantage, the total population optimum may be higher than that of either sole crop (Willey, 1979b).

Because of possible differences in population response, it has been pointed out that calculations of yield advantages should be made between intercrop and sole crop at their respective optimum populations (Huxley and Maingu, 1978, cited by Willey, 1979b).

In the dry period, under rainfall scarcity, the highest maize populations were the best for the intercropped bean, because due to shading, the soil moisture content was kept higher. Under abundant rainfall, there was no effect of maize populations on the bean (Fontana Netto et al., 1984).

Work by Reis et al. (1985) with arrangement and populations of bean in a mixed cropping with maize showed that the increment of row spacing of the maize had no effect on the grain yield of the intercropping. The results also showed that planting bean within the rows is more advantageous due to the management facilities it provides. The highest bean plant density contributed to better productivity, and there was no effect on the grain yield of maize. The competition effect reduced grain yield of bean by 39% and the pod number was the most affected primary component of grain production because of the reduction of the number of flowers, although the yield from the floral stage was also affected.

Intercropping peanut and soybean with cotton in India, Patel et al. (1979) found that cotton spaced at 180 cm intercropped with two rows of peanut produced significantly the highest gross income among all the treatments involving sole and mixed crops followed by cotton intercropped with one row of peanut. Intercropping cotton with soybean produced significantly higher gross income than sole soybean crop.

Work by Mohta and De (1980) with maize and sorghum intercropped with soybean showed that maize rows planted 120 cm apart and intercropped with two rows of soybean or sorghum planted 90 cm apart intercropped with one row of soybean proved to be the best intercropping pattern. Maintenance of an optimum density of maize at 65000 plants/ha appears to be more important than the row arrangement, for realizing optimum yields of the crop. They also found that orientation of rows in 60 or 120 cm distances or in paired rows 30 cm apart, two such pairs being 90 cm apart, did not make any difference in the grain yield per unit of land area so long as optimum plant population density was maintained for the cultivar used. The modified row pattern invariably allowed sufficient space for accommodating one or more rows of soybean.

Willey and Osiru (1972), in their substitution series of experiments, obtained yield advantages of the order of 38 to 55% when maize or sorghum was grown in various row combinations with bean (*Phaseolus vulgaris*) compared with yields achieved when the legume and cereal crops were grown separately on equivalent land area. The benefits from intercropping are reported to be due to a better utilization of both underground and aboveground resources.

Spatial Arrangement in Intercropping

Spatial arrangement defines the pattern of distribution of plants over the ground which determines the shape of the area available to the individual plant (Willey, 1979b). For crops regularly arranged in rows, spatial arrangement can be concisely defined by the rectangularity, which is the ratio of the inter-row spacing to the intra-row spacing (Holliday, 1963, cited by Willey, 1979b).

Even when the space allocated to component crops is directly related to component population, the intimacy of the arrangement can still vary. To obtain maximum benefit from any complementary effects, crops should be as intimately associated as possible and there have been experiments which support this theory (Andrews, 1972; International Rice Research Institute, 1973). But results are contradictory and increased intimacy has decreased yield.

In India where the objective is to produce a full cereal crop with some additional yield of a second crop, a common approach has been to manipulate the spatial arrangement of the cereal to create more space for the second crop but without reducing cereal yield. The most effective arrangement has been "pairing" of the cereal rows, e.g., changing a sole crop row width of 45 cm to pairs of rows 30 cm apart with 60 cm between pairs; this allows a second crop to be grown in the 60 cm between pairs (Willey, 1979b).

The advantage of intercropping may be increased by choosing suitable spatial arrangement of component crops. Grouping of crop rows of diverse heights could be advantageous as more solar radiation would be available to the dwarf crop (Waghmare et al., 1982).

Studies on spatial arrangement in sorghum-legume intercropping systems by Singh (1981) showed that spatial arrangement had only a marginal effect on sorghum yield but the yields of all the intercrops were appreciably affected. Paired rows with two rows of intercrops in 90 cm spacing results in maximum yield of all the intercrops. The land equivalent ratio (LER) was also influenced considerably by different intercrops and spatial arrangements.

Work with maize-bean intercropping (Santa Cecilia et al., 1982) showed that the estimates of levels of fertilizers which guarantee larger profits varied in relation to the arrangement, and the highest values were found in the arrangement where bean and maize were planted in the same line.

Natarajan and Willey (1985), working with sorghum-pigeonpea intercropping, found that changing the intercropping row arrangement from 2 sorghum:1 pigeonpea to alternate rows of each crop increased the light interception by the pigeonpea immediately after sorghum harvest and the total energy intercepted thereafter. The increase in total dry-matter yield of the pigeonpea in the alternate row arrangement was less than expected from the improvement in light interception, however. The alternate row arrangement did not offer advantages over the 2 sorghum:1 pigeonpea row arrangement.

Soil and Environmental Factors in Intercropping

Soil conditions influence cropping patterns primarily from the standpoint of water movement and drainage and tillage capability under high rainfall. Native soil fertility is a determinant of cropping patterns primarily in small farm agriculture where cash inputs are scarce or unavailable (Harwood and Price, 1976).

While it has been shown that increased productivity can be achieved by intercropping it is apparent that certain conditions must be met. Adequate soil moisture and fertilizer applications are needed for maximum production in any cropping system (Allen and Obura, 1983).

The most commonly suggested reason for higher yields in intercropping compared with sole cropping is that the component crops make complementary use of resources and therefore achieve better overall use of resources when growing together (Natarajan and Willey, 1980a).

There is undoubtedly a long-standing belief that intercropping advantages may occur only in low-fertility situations and this probably arises from the fact that intercropping predominates in poorly developed agriculture (Willey, 1979b). But experiments have shown intercrop advantages under high fertility and high moisture levels.

The concept of better resource use in intercropping raises the questions of how the yield advantages of intercropping are likely to be affected by the level of resource availability. Where the water resource is concerned, plant populations of intercropping systems might well be very critical in determining whether a potential complementarity effect between the crops results in a yield advantage. If two crops use different parts of a given resource or use that in rather different ways, an intercrop of two crops may be able to make fuller or more efficient use of that resource and so produce higher yields than can be achieved by growing separate sole crops (Natarajan and Willey, 1986).

Osiru and Willey (1972), working with sorghum-bean intercropping, obtained higher yields in intercropping than could be achieved by growing the two crops separately. They explained the yield advantage on the probability that there was better utilization of soil resources because of the very big difference in rooting depths which are known to exist between sorghum and bean. A further possibility is that the different growth cycles of the crops produced a greater overall utilization of resources. In an intercropping study with maize and bean, Willey and Osiru (1972) obtained higher yields in intercropping and concluded that the two crops were able to utilize environmental resources more efficiently and this could have occurred partly because of the different growth cycles of the two crops. They also stated that it may have occurred because the different heights of the two crops gave better utilization of light, or because different rooting depths gave better utilization of soil resources.

Water Use in Intercropping

Any consideration of below-ground resource use inevitably involves a consideration of rooting patterns and studies on these have been few. One possibility is that component crops may exploit different soil depths; thus, in combination they may exploit a greater total volume of soil. The effects of intercropping on water use have received less attention than the effects on nutrient uptake and so far there is little evidence of beneficial effect (Willey, 1979a).

Although little research information is presently available on the water-use pattern of maize and cowpea mixtures, higher water-use efficiencies have been reported for maize/soybean and maize/mungbean intercrops in relation to their respective monocrops (De and Singh, 1981, cited by Hulugalle and Lal, 1985). The Water Use Efficiency (WUE) of intercropped maize and cowpea was significantly greater than that of monocropped maize and cowpea under conditions of high water availability. One of the benefits of intercropping maize and cowpea is higher WUE in relation to monocropping, provided soil water is not limiting (Hulugalle and Lal, 1985).

Crops have varying sensitivities to water deficits at different growth stages and maximum sensitivity is usually at one of those stages where critical steps in the reproductive process occur (Slatyer, 1969, cited by Mahalakshmi et al., 1987). For determinate crops, these are usually the late floral development, flowering, and early-grain filling stages; for indeterminate crops timing of stress may be less critical as the reproductive phase extends over a longer period and provides more opportunity for compensation (Mahalakshmi et al., 1987).

Studying the effect of intercropping on the water relations of sorghum and cowpea, Shackel and Hall (1984) concluded that the two crops exhibited contrasting levels of dehydration avoidance when grown as sole crops, but intercropping did not cause any substantial change in the water relations of either species. They also found that midday xylem pressure potential and osmotic potential of cowpea leaves were slightly higher in the intercropped than in the sole-cropped treatment, presumably as a result of partial shading by the sorghum plants. Plant water deficits exhibited by sorghum and cowpea were not substantially affected by intercropping throughout the season.

Light Interception in Intercropping

Solar radiation is an important energy resource for crop production; and management practices which affect crop production do so, at least in part, through their effect on the interception of solar radiation and/or the efficiency of utilization of the intercepted energy. A knowledge of the effects of management practices on solar radiation interception and utilization is thus necessary if the physiological bases of "improved" practices are to be fully understood (Rees, 1986).

Radiation interception and exchange should be a primary focal point in considering theoretical and practical aspects of multiple cropping systems. First, solar radiation provides the energy for the green-plant photosynthetic apparatus. Obviously, shading in intercropping systems would reduce the energy available to one or more of the crops. Second, solar radiation provides the primary energy source to drive evapotranspiration and sensible heat exchange. Partially shaded plants may be under less water stress than fully-exposed plants. Third, the spectral qualities of radiation will change with depth into plant canopies because leaves absorb solar radiation differently. Change in radiation quality may affect plant photomorphogenic processes (Allen et al., 1976).

If there is to be better spatial use of light, this probably has to be achieved through more efficient use of light rather than greater light interception. This can theoretically occur if light is better distributed over the leaves, either because of better leaf inclination or because of better leaf dispersion (Willey, 1979a). Light is one of the main factors used more efficiently in intercropping and thus better availability of water and nutrients will perhaps only ensure that the light is fully exploited (Willey, 1979b).

Work on bean growth and light interception in a bean-maize intercrop by Gardiner and Craker (1981) showed that with a high maize population the mixed canopy could both intercept and retain more of the available photosynthetically active radiation throughout the growing season than the canopy of a monocrop of bean. The tall stature and leaf development in the upper portion of the maize canopy apparently contributed to more light interception and less light reflection in the mixed bean-maize canopy.

Natarajan and Willey (1980b) in a study with sorghum-pigeonpea, found that prior to sorghum harvest, light interception by the intercrop combination was almost as high as sole sorghum. After sorghum harvest, light interception by the remaining pigeonpea was very poor and it was suggested that pigeonpea yield could be increased with higher plant population density and better plant distribution. The sorghum light efficiency seemed to occur because the sorghum was able to produce the equivalent of a full sole crop yield while growing in only two out of three rows, a spatial arrangement in which it undoubtedly intercepted less light.

Thomas et al. (1982) stated that cassava is planted at a wide spacing of 90 by 90 cm and it has a slow build-up of canopy during its early stage of growth. Normally it takes about 3 to 3-1/2 months to have enough canopy to cover the entire ground, thereby providing ample scope for raising short duration intercrops for the effective utilization of solar energy for productive purpose.

Nutrients and Fertilization in Intercropping

Many soils of the tropics are inherently acid and relatively infertile in their native state, and mineral nutrition is a principal concern for any cropping system (Oelslige et al., 1976).

Multicrop researchers in the Philippines (International Rice Research Institute, 1972), who were studying cropping systems per se, determined the rate(s) of fertilization by summing the estimated requirement for each crop to insure that fertility was not a limiting factor. While technically sound, this approach may not be the most efficient in production agriculture. High fertilizer prices in developing countries dictate that this input be used efficiently. When developing fertilization practices for multiple cropping patterns, particularly for the marginal farmer, it is important that the economics of the practices be considered simultaneously with their biological potential (Oelsligle et al., 1976).

Nutrient competition can be minimized in intercropping systems by selecting species with different rooting patterns (Chang et al., 1969, cited by Mason et al., 1986c), different nutrient requirements, different timing of peak demand for nutrients (Willey, 1979a) or by proper plant spacing. One advantage of intercropping systems is greater total uptake of nutrients from the soil (Dalal, 1974), although this may be a reflection of greater dry matter production due to better use of light or water rather than better nutrient use (Mason et al., 1986c).

When two or more crops are associated in an intercropping pattern, their fertilization becomes more complex. After deciding which nutrients are needed and in what amounts, decisions relative to the source, timing, and placement of fertilizer additions are needed to insure their continued availability. Care must be taken that these nutrients are available to the plant roots in sufficient amounts during the growing season (Oelsligle et al., 1976).

Maize grown in association with cowpea in western Nigeria did not respond to fertilizer N and ^{15}N results indicate a N excretion by cowpea. Since the cowpea was fixing nitrogen in the root nodules it may be hypothesized that its need for soil mineral N was less than that of maize.

Thus a sparing effect allowed a greater N uptake by intercropped maize in comparison with sole-cropped maize, but there was no evidence of a sparing effect of the cowpea. The intercropped cowpea absorbed an amount of fertilizer N not significantly different from the intercropped maize (Eaglesham et al., 1981).

By intercropping maize with pigeonpea, Dalal (1974) found that although the dry matter produced and nutrients absorbed by the pigeonpea in mixed stand or alternate rows were significantly reduced, as compared to pigeonpea in pure stand, the combined dry matter yield and nutrient uptake by both the crops were higher, with maize and pigeonpea grown in mixed stands faring worst. Competition for light and nutrients was greater for both crops when they were grown in the same hill compared with their growth in alternate rows. Maximum increase in mineral nitrogen was observed under pigeonpea and maize grown in alternate rows, which may be why maximum crude protein was produced by this treatment.

Remison (1978), studying various levels of N and P on maize and cowpea, found no competition for nutrients, as the relation between crops was not modified by applying nutrients. Lack of competition for nutrients in maize/legume mixtures may be due to the special nutrient relations involved in the interaction between the components. The author stated that the growth of maize and cowpea is nonsynchronous, since cowpea flowers and matures much earlier than maize. It is therefore expected that their requirements for environmental resources would differ a great deal in time and due to the fact that roots of maize are longer and denser than those of cowpea, resources are presumably exploited at lower soil levels.

In maize-soybean intercropping studies, Tripathi and Singh (1983) concluded that maize yield in trials with half the recommended fertilizer in the intercropped system was similar to that of maize alone supplied with the full fertilizer dose. The results of these studies suggest that with intercropping, maize yields could be sustained with smaller fertilizer utilization.

Kaushik and Gautam (1987) studied the effect of nitrogen and phosphorus on the intercropping of pearl millet with cowpea or greengram and found that nitrogen fertilizer brought about a remarkable increase in yield, growth and yield characteristics of pearl millet up to 60 kg N/ha. There was no marked improvement in yield, growth or yield characteristics due to further increments of nitrogen up to 90 kg/ha. Further increase in nitrogen rates resulted in a decrease in the grain yield of intercrops.

The N, P and K studies by Sharma et al. (1979) in India indicated that the nutrients can be utilized more efficiently when maize is grown in combination with the intercrops than in pure stand. "Moong" without fertilizers when intercropped in maize decreased the maize yield by 226 kg/ha as compared to its yield from pure stand. However, an extra 332 kg/ha of "moong" grain was obtained in addition to the maize yield. The authors stated that increasing nutrients from 25 to 50% did not produce a beneficial effect on either of the crops. Experimental evidence at the International Rice Research Institute (1973) also testifies that the relative advantage of intercropping is greater under low management than it is at high management.

Apart from the possible differences in rooting pattern, the mechanisms by which nutrient uptake is increased in intercropping are far from clear. One possibility is that, even where growing periods are similar, component crops may have their peak demands for nutrients at different stages of growth, a temporal effect which may help to ensure that demand does not exceed the rate at which nutrients can be supplied. But more obvious causes arise, perhaps, from differences among component crops in their nutrient requirements, the forms of nutrients which they can readily take up, and their ability to extract them from the soil (Willey, 1979a).

Oelsligle et al. (1974, cited by Moreno and Hart, 1979) conducted an experiment in Costa Rica on different levels of nitrogen applied to cassava alone, maize alone and cassava and maize intercropped. They found Land Equivalent Ratios (LER) of over 2.0 for the intercropped systems indicating a high level of land utilization potential.

Mason et al. (1986a) concluded that cassava-cowpea and cassava-peanut intercropping systems often lead to more rapid mining of natural soil fertility or require higher fertilizer application rates than the corresponding sole crops.

Working with intercropped maize and sugarcane, Bhoj and Kapoor (1970) found that an extra 112 kg N/ha and three extra irrigations were required to eliminate the competitive effect of maize on sugarcane.

Nitrogen and Nitrogen Fixation by Legumes in Intercropping

Even though intercropping usually includes a legume, applied nitrogen may still confer some benefits to the system, because the cereal component depends heavily on nitrogen for maximum yield (Ofori and Stern, 1986). There are few data on the influence of applied nitrogen on various intercrop systems and these appear to give conflicting results.

Wahua (1983) suggested that large applications of nitrogen cause excessive vegetation growth in the cereal, thus shading the legume and so depressing its yield.

According to Searle et al. (1981), two beneficial effects may be present when one of the intercrops is a legume: (1) reduced competition for soil nitrogen, and (2) increased residual nitrogen available to a following crop. When a legume is one of the intercrops it is therefore important in the assessment of a cropping pattern to measure not only the intercrop yields, but also the available residual nitrogen.

Possible mechanisms of N transfer are: (1) direct excretion, (2) sloughing of nodules and root system decay, (3) leaching from leaves, and (4) decomposition of fallen leaves (Burton et al., 1983).

Prerequisites for N transfer include a low N soil and, ideally, different N utilization peaks. Nodulation of the legume and adequate light for N_2 fixation are also essential (Wahua and Miller, 1978).

Yadav (1981), working with pigeonpea and maize, concluded that pigeonpea increased the soil N content due to substantial nodulation, but as an intercrop it did not increase the yield of maize at any level of nitrogen. Sugarcane grown after pigeonpea yielded 43% more than when grown after maize. So intercropping pigeonpea in maize would be more beneficial than growing a pure crop of maize before planting sugarcane. Pigeonpea, a good N fixer, increased the soil N content due to substantial nodulation. Apart from N fixation by nodules, increases in soil after pigeonpea were also due to decomposition of fallen leaves, which added 30 to 36 kg N/ha (Sheldrake and Narayanan, 1979, cited by Yadav, 1981). Nitrogen excretion by an intercropped legume gives significant benefit to the associated crop only in conditions of low soil mineral N status and cannot be demonstrated where mineral N is plentiful (Wahua and Miller, 1978).

Intercropping studies with sorghum and legumes (Waghmare et al., 1982) demonstrated that sorghum plants in sole cropping failed to express themselves fully and the main effect of intercropping was to provide extra nitrogen which was made available by the companion legumes. Maximum advantage was obtained from fodder cowpea and this may be attributed to the fact that the cowpea was removed for fodder at the 55-day stage, thereby allowing the nitrogen fixed in the nodules to be used by the sorghum without at the same time suffering competition for light or other soil nutrients.

Cereals might benefit indirectly from N fixation since legumes do not compete with cereal for soil nitrogen owing to variations in rooting patterns (Singh, 1981). Chan (1971, cited by Singh, 1981) observed that alfalfa began transferring nitrogen to fescue after 6 weeks of growth and continued up to 18 weeks. During this period, the total transfer was 4.9 to 5.8% of the total nitrogen fixed by the alfalfa. He further observed that water stress and shading increased nitrogen transfer to 9.1 to 7.9%, respectively.

In a sorghum-legume intercropping, Waghmare and Singh (1984) found that the protein content of the sorghum grain was appreciably increased by intercropping with greengram and cowpea (both for grain and fodder). Yields of all the legume intercrops were increased by fertilizer nitrogen, which improved plant growth and increased the number of pods per plant. This positive response to applied nitrogen up to 120 kg/ha is unusual for legumes, but could be explained if shading reduced plant vigor so that biological nitrogen fixation was insufficient for grain development. Nodule studies supported this hypothesis but without pure legume plots it could not be confirmed.

Work by Hegde (1981) concluded that intercropping of medicinal yam with kidney-bean and cowpea reduced the optimum N requirement by 30 to 95 kg/ha, which may be attributed to the contribution of N from the root nodules of legume intercrops during their regeneration. Thus, intercropping medicinal yam with cowpea and kidney-bean not only gave additional returns but also reduced the N requirement.

In maize-legume intercropping systems, Searle et al. (1981) obtained increased yields as high as 36.5% for soybean and peanut. Since there was no depression in maize grain yield with intercropping there was a clear bonus of a protein grain of at least 532 kg/ha in soybean and 378 kg/ha in peanut.

Considering the many intercropping studies which have included legume/non-legume combinations, it may seem surprising that so little information is available from field situations (Willey, 1979a). But one of the problems is that experimental designs do not often allow a specific nitrogen benefit to be distinguished. It must be appreciated, however, that even when some of the nitrogen fixed by a legume component is transferred to a non-legume component, this does not necessarily mean there is an advantage of intercropping. Strictly speaking, a genuine intercropping advantage occurs only if the fixation process, or the eventual use of fixed nitrogen by other crops, is more efficient than when the crops are grown separately but in some suitable sequence.

Competition and its Effects on Plant Characters in Intercropping

Horwith (1985) considered that interactions between species include both negative (competition) and positive (facilitation) components. For example, one species, even while diminishing the supply of available nutrients, may provide the shade necessary for successful establishment of a second. Yet at a later stage both species may compete for light. In addition the second species may produce toxins that slightly inhibit the first but prevent growth of competitive weeds. Understanding ecological interactions like these in agricultural systems, rather than focusing only on the net outcome, may suggest ways to change the outcome by manipulating the system.

Planting both crops together in the same field, or intercropping them, provides an additional benefit because the resources that become available through the failure of one species can be used by the surviving crop (Willey, 1979a). The remaining companion crop can use resources, such as synthetically produced fertilizers, which would otherwise have been lost due to leaching or run-off, thus increasing the efficiency with which these expensive inputs are used (Horwith, 1985).

Competition between two species is strongest when they both require a resource that is in short supply. Thus, addition of scarce resources can alleviate competition between the two crops, and allow both to yield better (Boucher, 1986).

Horwith (1985) commented that when the distance between plants reaches some critical point, they begin to compete for at least some of their resources. He also stated that given a set of fixed conditions (environment, planting pattern, etc.), competitive interactions between two intercropped species can have three possible outcomes:

- Intraspecific competition can be less than interspecific competition for both species.
- Intraspecific competition can be greater than interspecific competition for both species.
- Intraspecific competition can be less than interspecific competition for one species, while the reverse is true for the other species.

It is highly improbable that intraspecific competition will always be less than interspecific competition for all resources. If intraspecific competition were always less, however, then from the standpoint of competition alone it would be better to grow each crop in monoculture. But even in this case, factors other than competition, such as pest insect reduction and weed control, might still argue for intercropping.

Competition for nutrients between component species in intercropping systems often occurs. Early studies suggested that competition between intercropped species occurs first for the mobile resources of water and N since the depletion zones around roots for these resources would occur most rapidly, be the largest, and overlap first (Kurtz et al., 1952; Bray, 1954).

The LER can be greater than 1.0 if mixtures are less affected by pests or pathogens than pure stands, or if the two crops do not compete fully for one or more environmental resource. Incomplete competition could occur if the crops use different forms of a given resource (e.g., one fixes gaseous N_2 while the other uses soluble nitrate), or if they use the same resource at different times or from different zones of the environment (Trenbath, 1976, cited by Martin and Snaydon, 1982).

Studying competition between bean and tomato in Costa Rica, Rosset et al. (1984) concluded that bean production can be obtained from tomato fields without detrimentally affecting tomato yields. Just as Gause's axiom states that two species will co-exist if they do not use the same resources, Vandermeer's "interference production principle" predicts that a polyculture will overyield if the mutual interference of two crops is sufficiently weak, i.e., if interespecific competition is less than intraspecific competition.

Several studies have been conducted to investigate the effect of competition on plant characters, such as leaf area index, yield components, dry matter, etc.

In studies with legume-cereal intercroppings, Enyi (1973) found that fresh weight yield of the cereal crops at time of anthesis was positively and linearly related to their leaf area indices. Intercropping reduced fresh weight yield of the cereal crops mainly by reducing their leaf area indices. Grain yields were also linearly and positively related to leaf area indices at time of anthesis. Intercropping appears to have reduced grain yield in maize mainly by decreasing leaf area indices, but in sorghum, reduction in grain yield due to intercropping, was probably mainly due to lower efficiency of the leaves due to the shading effect of the legume crops on the sorghum.

Reduction in cassava tuber yield by 33.1% has been recorded with cowpea as an intercrop, as a result of retardation of plant growth by 47 cm more than pure cassava (Muthukrishnan and Thamburaj, 1979).

Work with cassava showed that intercropping generally reduces the leaf area index of the lower canopy crop and may reduce that of the upper canopy crop where competition for water or nutrients occurs (Zandstra, 1979). Although the leaf area duration of each of the intercrop components is reduced, the overall leaf area duration of the mixed canopy can be greatly increased, particularly where relay cropping is used.

Anwarhan (1977, cited by Zandstra, 1979) found that net assimilation rates of soybean were reduced significantly when canopy density was increased by intercropping maize and by increased fertilization rates.

Natarajan and Willey (1980a), working with sorghum-pigeonpea intercropping, found that sorghum growth was not affected by the presence of pigeonpea, and the farmers' primary objective of maintaining a "full" sorghum yield was achieved if the density of the intercropped sorghum was equivalent to the sole crop optimum. The initial growth of pigeonpea was very much suppressed by the presence of sorghum but some compensation in growth after sorghum harvest, and a much higher ratio of seed yield to total above ground dry matter resulted in seed yields of up to 73% of a sole pigeonpea yield.

Saeed et al. (1986) stated that in sorghum, two main components, number of seed and seed size, determine the final yield though other subcomponents can affect yield through their effects on these main components.

When sorghum was intercropped with legumes, Bandyopadhyay and De (1986) found that sorghum plants showed a higher leaf area index in mixed stands after the associated legume crop had completed or had almost completed its peak period of vegetative growth and the number of grains, grain weight per panicle and 1000 - grain weight of sorghum were influenced significantly by intercropping treatments.

Wahua and Miller (1978) found that soybean yields were reduced by 18% with short sorghum and by 76% with tall sorghum, when compared to sole crop yields.

Radke and Hagstrom (1976), working with soybean-maize intercropping, concluded that soybean rows near the interplanted maize rows were protected as soon as the maize plants were slightly taller than the soybean plants. These sheltered soybeans responded by growing slightly taller. As the effective wind barrier height increased, more soybean rows showed an increase in plant height over the unsheltered soybean. A graph of soybean plant height between successive corn wind barriers would show a bowl-shaped curve which becomes shallower with time because the maize barriers protect more of the soybean rows.

Andrews (1972) considered that the main source of gain in the intercrops investigated came from planting early maturing and slow maturing crops together since no one crop alone can efficiently utilize the whole wet season in Nigeria. The relative stature and sizes of different crops, together with a knowledge of their growth cycles and the seasonal period available for growth, can assist in predicting which crops can be successfully intercropped.

In cassava-peanut and cassava-cowpea intercroppings in Colombia, Mason et al. (1986a) commented that cowpea and peanut yield reductions due to intercropping were associated with the production of approximately 3.5 fewer pods per plant. Even though yields of component crops were reduced by intercropping, the cassava-cowpea and cassava-peanut intercropping system resulted in 15 to 35% greater land use efficiency for the 11-month growing season than resulted from the sole cropping systems. Data by Mason et al. (1986b) indicated that rapidly growing cowpea and peanut were able to use space between rows of cassava during the first 100 days after planting with minimal effect on cassava growth.

Pest Management in Intercropping

One of the most significant advantages of intercropping is that there may be lower abundances of herbivorous insects on their host plants in certain kinds of intercrops.

Not only has multiple cropping been suggested as a means for maximizing capture of solar energy, but also as a probable control method for diseases and pests (Thung and Cock, 1979). This pest control could be of tremendous importance for the small farmer with limited resources who cannot use purchased inputs to control disease and pests. The same authors commented that the monoculture system has been criticized because the genetic and stand uniformity results in continued pest susceptibility. Multiple cropping systems, on the other hand, are praised because the diversity of vegetation within the crop area can be used to give integrated pest management.

According to Pimentel (1961) and Root (1973), both cited by Altieri et al. (1978), in experimental conditions diversity and activity of natural enemies have been higher in monocultures than in polycultures, mainly due to migration of agents from diversified plots, and a marked concentration of preys and hosts in moncultures. Factors other than natural enemies are responsible for many of the observed differences between simple and diverse habitats. Altieri et al. (1978) stated that in addition to their taxonomic diversity, diversified systems have a relatively complex physiognomy and associate pattern of microclimates; thus insects may experience further difficulty in locating spots of favorable microclimatic conditions. The biotic, structural, chemical, and microclimatic complexity of these polyculture habitats results in an associational resistance of the community that ameliorates the herbivore pressure.

As the petrochemical industry developed, inexpensive and potent insecticides became widespread (Horwith, 1985). Initially these were used to control pest outbreaks, which are frequently more severe in monocultures than in intercrops. One explanation offered for the greater pest problems in monocultures is that their lower plant diversity supports a less diverse insect community. Because many pesticides are relatively nonspecific, they kill both the pests and their natural enemies, further reducing diversity in the insect community.

Litsinger and Moody (1976) affirm that research on pests has normally been done on a single-crop basis. In multiple cropping, it is necessary to study pests over the entire cropping period, because the pests of one crop might be influenced by the previous crop(s) as well as by companion crops in intercropping patterns. The use of pesticides will need to be reevaluated with respect to drift and phytotoxicity problems in new crop combinations and their residual effects on nontarget hosts on relay or sequential croppings.

Pinchinat et al. (1976) suggested that integrated control methods of diseases, insects, and weeds with a minimum use of chemical should be developed; the outlook appears promising through the combined practice of intercropping, rotation, and use of resistant varieties, along with appropriate timing of planting.

Where a mixture consists of tall and short components, the short ones may be invisible to insects or birds sensing the plants from directly above (Litsinger and Moody, 1976). The more complete cover provided by a mixture of crop species reduces light penetration to the soil, which reduces weed growth. Cleave (1974, cited by Litsinger and Moody, 1976) argued that mixed intercropping patterns may have evolved specifically to minimize the labor costs of weed control. But a closed canopy has negative effects as the microclimate becomes more humid and is a favorable condition for growth of fungal diseases (Trenbath, 1974).

Horwith (1985) reported that the benefit from compensation can be equally significant when biological agents cause crop failure. In an experimental test of this "compensation" hypothesis, researchers at the University of

Michigan released hornworms (Manduca spp.), a caterpillar pest on tomato but not cucumber plants, into half of the tomato cucumber intercrop plots. Cucumber yields were higher in the plots where hornworms were released. Although hornworm defoliation of tomato plants reduced tomato yields, the resulting increase in light increased the cucumber yields. Cucumber yields increased more than tomato yields decreased, and consequently there was overyielding of the system as a whole.

Amoako-Atta et al. (1983), studying maize, cowpea, and sorghum intercropping, concluded that interplanting noncereal-cereal combinations delays the relative specialist Chilo partellus (stem-borer) colonisation and establishment processes and that damages on cowpea pods could be reduced by such intercropping combinations.

Altieri et al. (1978) commented that it is critical to select the correct plant diversity for a given micro-climatic/biotic situation. A specific diversity in the same system can be beneficial in one place but harmful in another. For example, in Tanzania and California intercropping maize and cotton increased Heliothis virescens damages but in Peru this system favored the control of Heliothis (Southwood and Way, 1970, cited by Altieri et al., 1978).

Intercropping maize with cotton has been variously reported to reduce and increase infestations of bollworms, *Heliothis* spp. on cotton (Smith and Reynolds, 1972 and Henry and Adkisson, 1965, both cited by Ezueh and Taylor, 1984). Intercropping of peanut and maize was found to reduce infestation by the maize stalkborer (*Eldana saccharina* Wlk.) (Anon., 1960, cited by Ezueh and Taylor, 1984).

Simultaneous intercropping of cowpea and maize significantly increased infestation of cowpea by the pod-borer, *Maruca testulalis*. Insecticidal control of these pests was better in the monoculture cowpea than in the mixed-crop except in the case of flower thrips (Ezueh and Taylor, 1984).

In laboratory feeding experiments, beetles actually ate significantly more of the diseased squash leaves from interplant treatments with maize and bean than the healthy leaves from monocrops. Downy mildew infestations are usually more serious in more shaded areas with high humidity (MacMillan, 1943, cited by Risch, 1980). In this study the differences in beetle numbers between monocrops and inter-crops apparently resulted not from differences in rates of parasitism or predation of the beetles, nor from difference in beetle birth rates, but principally from differences in overall patterns of beetle movements. Data showed that beetles avoided feeding on host plants shaded by maize and that maize stalks interferred in other ways with flight movements of the insects.

Taylor (1976, cited by Matteson, 1982) compared infestation of flower thrips *Megalurothrips sjostedti* (Trybom), and damage caused by pod borer, *Maruca testulalis* Geyer, and pod moth, *Laspeyresia ptychora* (Meyrick), on both intra and interrow intercrop and monocrop cowpea under a minimum insecticide regime. *M. testulalis* damage was significantly less in the intrarow intercrop but on a bushy cultivar, *L. ptychora* damage was more severe. In contrast, Perfect et al. (1977, cited by Matteson, 1982) found that flower thrips were significantly fewer in an intercrop, especially in an interrow intercrop.

Adesiyun (1983) reported that the population of lepidopterus stalk-borer *Bussea fusca* and the damage due to it can be reduced in the field if sorghum and millet are interplanted in alternate stands within the same row.

Amoako-Atta (1983) found that cowpea plant infestation by *Alcidodes leucogrammus* (striped bean weevil) was low in sorghum/cowpea dicrop. Apparently the sorghum plants present a natural barrier, which obstructs the horizontal movement of the weevil from the one cowpea row through the intercropped sorghum to the next cowpea row.

Periodical counts of the nymphal population of *Empoasca kraemeri* in bean monoculture and a bean-maize association showed that in the association, peaks were reduced considerably and the fluctuations in the population were smooth throughout the period of observation, suggesting that insect damage in the associated system should have been small as compared to bean monoculture (Leihner, 1979).

Field studies on the effects of intercropping cowpea with maize on the severity and rate of spread of pathogens indicate that diseases may either be enhanced or reduced, the outcome depending upon complex interactions between several factors (Allen and Skipp, 1982). Maize pollen stimulated conidial germination of *Colletotrichum lindemuthianum* (Sacc. and Magn.), a fungal pathogen which causes anthrachnose in cowpea. Maize pollen, however, strongly inhibited the development of necrotic local lesions in cowpea.

Dissemination of cowpea mosaic virus and cowpea chlorotic mosaic virus in cowpea monoculture has been frequently faster than among cowpea intercropped with maize (Gonzales et al., 1975, 1976, cited by Moreno, 1979). A significant delay on the onset of cowpea powdery mildew (*Erysiphe polygoni* D.C.) was achieved by interplanting cowpea with maize, cassava, and plantain (Moreno, 1979). Intercropping with cassava delayed the time needed to reach a 100% incidence up to 85 days.

Egunjobi (1984) found that NPK fertilizer application increases the numbers of *Pratylenchus brachyurus* Godgrey (nematoda) more in soil under monoculture maize plots than in plots sown with maize in association with cowpea, peanut, or greengram.

Leihner (1979) working with cassava-legume intercropping systems, found that introducing bean as an intercrop with cassava reduced weed growth drastically, whereas with frequent weeding, no big difference in weed growth was observed between cassava monocrop and the cassava-bean association. At the early growth stages, the intercropping system without any additional inputs was as efficient in reducing weed infestation as was a preemergent herbicide mix in cassava monoculture.

It is critical to develop new and high yield cropping patterns without creating conditions that favor new and equally high potentials for pest damage (Altieri et al., 1978).

Development of pest management technology for multiple cropping systems must take into account the resources of the farmer. Pest control tactics differ for large-scale and small-scale farmers as each has a different resource base of capital, labor, power, land, and management capability (Litsinger and Moody, 1976).

Land Equivalent Ratio (LER)

Willey (1979a) concluded that the most generally useful single index for expressing the yield advantage of intercropping is probably the Land Equivalent Ratio (LER), defined as the relative land area required as sole crop to produce the same yields as intercropping LER can be written:

$$LER = L_A + L_B = Y_A/S_A + Y_B/S_B$$

where L_A and L_B are the LERs for the individual crops, Y_A and Y_B are the individual crop yields in intercropping, and S_A and S_B are their yields as sole crops (Mead and Willey, 1980).

The advantages of the LER are that (1) it provides a standardized basis so that crops can be added to form combined yields, (2) comparison between individual LERs (L_A and L_B) can indicate competition effects (Willey, 1979a), (3) of primary importance the total LER can be taken as a measure of the relative yield advantage, e.g., and LER of 1.2 indicates a yield advantage of 20% (or, strictly speaking, that 20% more land would be required as sole crops to produce the same yields as intercropping).

To help judge whether a series of $\underline{m}$ crops should be grown as an m-component intercrop rather than sole crops, the concept of Land Equivalent Ratio (LER) has been used (International Rice Research Institute, 1974, 1975). If this LER is unity, the various yields harvest from the intercrop could have been obtained from the unit area planted to sole crops, each occupying an appropriate fraction of the total area (Trenbath, 1976). When LER = 1, the overall yield per unit area of intercrop is never greater than that of the most productive sole crop. If however the LER exceeds unity and the sole crop yields are identical an LER of 1 + x implies that the intercrop outyields the sole crops by 100 x%. If x is large enough, such a yield advantage can provide a clear justification for intercropping. On the other hand, for a given x, if the sole crop yields are sufficiently different, the LER will not be large enough to imply an overall yield advantage for the intercrop.

To avoid an effect on LER due simply to plant density the intercrop and the sole crops with which it is to be compared may be grown at a uniform overall density (Trenbath, 1976). The LER value calculated will then be the Relative Yield Total (RYT) of de Wit and van den Bergh (1965, cited by Trenbath, 1976).

A criticism of the LER concept, according to Willey (1979a) is that intercropping is effectively being compared with sole crop areas which are not predictable by the farmer and which cannot, therefore, form a realistic alternative. The LER has great merit that it gives an accurate assessment of the greater biological efficiency of the intercropping situation.

Francis et al. (1982a), working with bean and maize in intercropping, showed that 19 of the 20 intercrop combinations had LER values greater than unity. Highest LER values above 1.5 indicate a biological potential for intercropping to produce 50% more than monoculture under those conditions.

Statistics in Intercropping

Techniques and procedures in both agriculture and in statistics are well developed for sole cropped experiments but are in a very primitive state for intercropping, relay-cropping, and mixed cropping experiments (Wijesinha et al., 1982). In this type of research, there are many items of interest in a single experiment, which involves yields from more than one crop, and it is often difficult or impossible to identify a single criterion on which to base a statistical analysis, an evaluation, or an interpretation.

According to Willey (1979b), an important point is that the experiment must include proper "controls" (i.e., sole crop treatments). As a general rule, controls should be included for all crops being examined in order that a valid assessment of yield advantages can be made. An exception may be where intercropping aims to achieve a full yield of a "main" crop with some additional yield of a second crop.

Statistical analyses may be performed on the yields of individual crops, or on some function of the combined yields. To date, published literature focuses on the former (Wijesinha et al., 1982).

Yield Stability and Economics in Intercropping

The economic situation of a farmer dictates how many and what kind of resources be has to work with is as important in determining a feasible cropping system as are his soils and climate (Hildebrand, 1976). Because it is the farmer who makes the decision whether or not to utilize any particular cropping system he needs a unit of comparison between systems which is meaningful to him and which he can interpret in his decision framework. The union of agronomy and economics is essential in multiple cropping systems.

In developing farming systems for small producers, testing for yield stability through crop management should be of foremost importance as its lack has been the main cause of shifting cultivation in the tropics. Other studies should evaluate income stability of the farming systems involving crops (annual and perennial, and food and nonfood species) and animals (Pinchinat et al., 1976).

Francis and Sanders (1978) reported that monoculture beans are most profitable at a wide range of relative prices if the farmer is able to introduce an intensive package of technology on a small and manageable area and can reduce the support costs with family labor and local materials. Increasing yields of either component crop in the systems increases profits, but the choice of an optimum system is not very sensitive to small changes in yields.

Harwood and Price (1976, cited by Faris et al., 1983) questioning the compensation effect of intercropping concluded that crop failures often occur after considerable intercrop competition and that sole cropping often produces greater stability. Willey (1981, cited by Faris et al., 1983) suggested that one obvious way to determine intercropping stability was to compare sole crops and intercrop performance over a wide range of environments.

By estimating the probability of monetary returns falling below given disaster levels using data from 94 experiments on sorghum/pigeonpea intercropping, Rao and Willey (1980b) found that for a particular "disaster" level, sole pigeonpea would fail one year in five, sole sorghum one year in eight, but intercropping only one year in 36. Several mechanisms might bring about improved stability of yield in intercropping, e.g., if one crop fails, or grows poorly, the other to some extent may compensate; such compensation clearly cannot occur if the crops are grown separately. The same authors (Rao and Willey, 1980b) also stated that intercropping could also provide greater stability if its yield advantages, compared with sole cropping, were greater under stress than non-stress conditions, since this would mean that intercropping yield in seasons of stress would not decrease as much as yields of sole crops. They also say that a further mechanism for improving stability could occur where intercropping provides a buffer against pests and diseases, for example where one crop acts as a barrier against the spread of a pest or disease of the other crop.

Reddy et al. (1980) found that growing intercrops between the pairs of base crops was found to be feasible, with significantly increased returns. Gross returns increased by 75.8, 38.5, 31.5, and 24.5% with sarson, wheat, safflower and peanut as intercrops, respectively, in a base crop of maize during winter.

Breeding for Intercropping

Breeding and selecting plant cultivars for mixed cropping systems is extremely important for improving traditional farming systems in the tropics. Peasant farmers cannot fully benefit from improvement programs if cultivars bred only for sole-cropping systems, and therefore unadapted to mixed cropping systems, are released to them (Wahua et al., 1981). However, results obtained by McBroom et al. (1981) suggested that separate breeding programs are not required to develop cultivars for monoculture or intercropping including soybean and small grains.

In north-eastern Brazil, because of the semi-arid conditions, there is a strong case for introducing sorghum to replace some of the maize that is so commonly grown in association with cowpea. However, plant breeders have not concentrated on producing improved genotypes for this system, mainly because it is used in subsistence agriculture, and this sector of the economy cannot finance investment in breeding (Galwey et al., 1986). These authors stated that in both sole and intercrop, grain yield and yield components of sorghum genotypes are largely related to the method by which those genotypes have been bred. Variables measured in sole crops largely explain sorghum or cowpea yield variation in intercrop, indicating that preliminary selection could be carried out in a sole crop. However, even when only one component crop is considered, variables measured in an intercrop explain yield variation more fully. On one hand varieties used in traditional production systems, which have remained unchanged for decades or longer, are still practiced by a large number of small farmers in tropical America in spite of the existence of the much-heralded "modern technology." On the other hand, the local agricultural experiment stations are testing new technological packages, with resources and approaches totally different from those of the small farmer (Pinchinat et al., 1976).

Research Needs

Multiple crops for food production are in widespread use by farmers in the warmer parts of the world at all levels of agricultural technology. Under conditions of "low level equilibrium" farming, as exists in much of the developing world, farmers operate with difficulties arising from low capital, unfavorable price relations, unsophisticated markets and rudimentary infrastructure (Andrews and Kassam, 1976).

In traditional scientific spheres there is a general belief that small farmers make up a subsistence group, producing only for food consumption. In Latin America, however, although a good portion of the small farmer's crop production is consumed by his immediate family, a sizeable portion is sold for cash to satisfy other needs (Pinchinat et al., 1976).

In the future much of the food needed by the rural and urban population of the world in the areas presently under conditions of low level equilibrium farming will have to be produced by farming communities under conditions of change in agricultural technology (Andrews and Kassam, 1976).

Most machinery has been developed for sole crop production and adaptations are necessary, depending on the multiple cropping pattern to be used, the level of mechanization involved, the crop species to be grown, and the edaphic and climatic conditions in which the crops will be grown (Erbach and Lovely, 1976). Determination of the number and size of machines needed must be based on an economics analysis of the conditions of each farm (Camper et al., 1972). When small grains or vegetables are intercropped with a perennial crop--such as in an orchard when the young trees are developing or in a coconut (*Cocos nucifera*) plantation--the equipment must be maneuverable (Nair et al., 1974).

Because the small farmer ordinarily respects traditions and possesses a low level of literacy, patience must be taken in transferring research results to him. Considerable and direct technical assistance especially in the early phases of the process of technology transfer, will be required. Adoption by the small farmer of new techniques is likely to be easier the more he directly participates in the development of such techniques, is convinced of their practical value, and finds them compatible with his beliefs (Pinchinat et al., 1976).

CHAPTER 3

MATERIALS AND METHODS

The data presented in these studies were obtained in the summers of 1985 and 1986. The experiments were planted at the University of Arizona Marana Agricultural Center, in a Pima Clay Loam soil. Both field experiments were carried out with near optimum moisture availability from rainfall and supplemental water. The supplemental water was applied by furrow irrigation whenever necessary but usually after some signs of moisture stress were observed. All cultural practices were carried on uniformly over all the experimental units.

Meteorological Data

The amounts and distribution of monthly rainfall and supplemental water applied through irrigation from May through November of 1985 and 1986 are presented in Tables 1 and 2. Maximum and minimum temperatures from May through November of 1985 and 1986 are presented in Table 3. These meteorological data were obtained at the University of Arizona Marana Agricultural Center.

Table 1. Amount and distribution of monthly rainfall and irrigation water at the University of Arizona Marana Agricultural Center from May through November of 1985.

Month	Day	Rainfall (mm)	Irrigation Water (mm)	Monthly Total (mm)
May	-	0.00	0.00	May: 0.00
June	21		144.04	
	28		80.52	June:224.56
July	16	4.06		
	17	7.62		
	19	3.05		
	24		45.97	
	27	1.52		
	30	4.57		July: 66.79
August	01	5.08		
	12	3.05		
	13		36.07	
	20	2.79		
	26		49.28	
	28	1.78		
	30	4.06		August:102.11
September	12	7.62		
	18	1.78		
	19	10.41		
	28	10.16		September: 29.97
October	11	8.13		
	17	6.35		October: 14.48
November	12	10.67		
	13	8.63		
	25	2.54		
	26	17.78		November: 39.62
Season Totals		121.65	355.88	477.53

Table 2. Amount and distribution of monthly rainfall and irrigation water at the University of Arizona Marana Agricultural Center from May through November of 1986.

Month	Day	Rainfall (mm)	Irrigation Water (mm)	Monthly Total (mm)
May	2	0.76		
	17		182.37	May:183.13
June	6	0.51		
	24		60.71	June: 61.22
July	2	1.78		
	4	2.03		
	11		80.26	
	14	5.08		
	15	6.35		
	16	1.27		
	20	4.32		
	21	24.38		
	29		63.25	July:188.72
August	6	13.46		
	7		59.44	
	9	4.57		
	11	1.02		
	17	19.81		
	20		45.72	
	22	4.32		
	25	1.02		
	29	3.81		
	31	1.78		August:154.95
September	9		64.77	
	24	6.86		September: 71.63
October	5	1.27		
	11	5.59		
	12	17.27		October: 24.13
November	2	2.54		
	3	8.13		
	7	5.08		November: 15.75
Season Totals:		143.01	556.52	699.53

Table 3. Maximum and minimum temperatures at the University of Arizona Marana Agricultural Center from May through November of 1985 and 1986.

		Temperature			
Year	Month	Av. High (C)	Av. Low (C)	Month High (C)	Month Low (C)
1985	May	35	16	39	10
	Jun	41	21	45	13
	Jul	39	23	44	18
	Aug	38	22	44	16
	Sep	33	17	40	11
	Oct	29	13	37	9
	Nov	22	7	32	-2
1986	May	37	15	43	10
	Jun	42	21	46	17
	Jul	39	22	46	19
	Aug	39	23	46	20
	Sep	36	17	42	11
	Oct	30	12	35	7
	Nov	23	8	28	1

Experimental Layout and Field Plot Design

The field experiments for both years (1985 and 1986) were carried out in a randomized complete block design with four replications. The whole plots consisted of nine rows, having six legume rows and three cereal rows, which gave a 2:1 (legume:cereal) spatial arrangement. The portion of this whole plot to be the harvested plot consisted of six central rows, four of the legume and two of the cereal, in order to maintain the spatial arrangement of 2:1 (legume:cereal) (Figure 1).

Summer 1985

This experiment was planted in moisture on June 25, 1985. Three cereals (sorghum, maize, and pearl millet) and three legumes (field bean, cowpea, and soybean) were used in all combinations, resulting in nine intercropping treatments. The scientific names of each crop are presented in Table 4. The cultivars of each crop and initial number of plants per plot row (after thinning) are presented in Table 5.

Nitrogen and phosphorus fertilizers were applied before planting at the rate of 448 kg/ha of the formula 16-20-0, which gave 72 kg/ha of N and 90 kg/ha of P_2O_5. No chemical control was conducted for insects and diseases. Weeds were mechanically controlled through cultivation at early stages and hand-controlled later in the season.

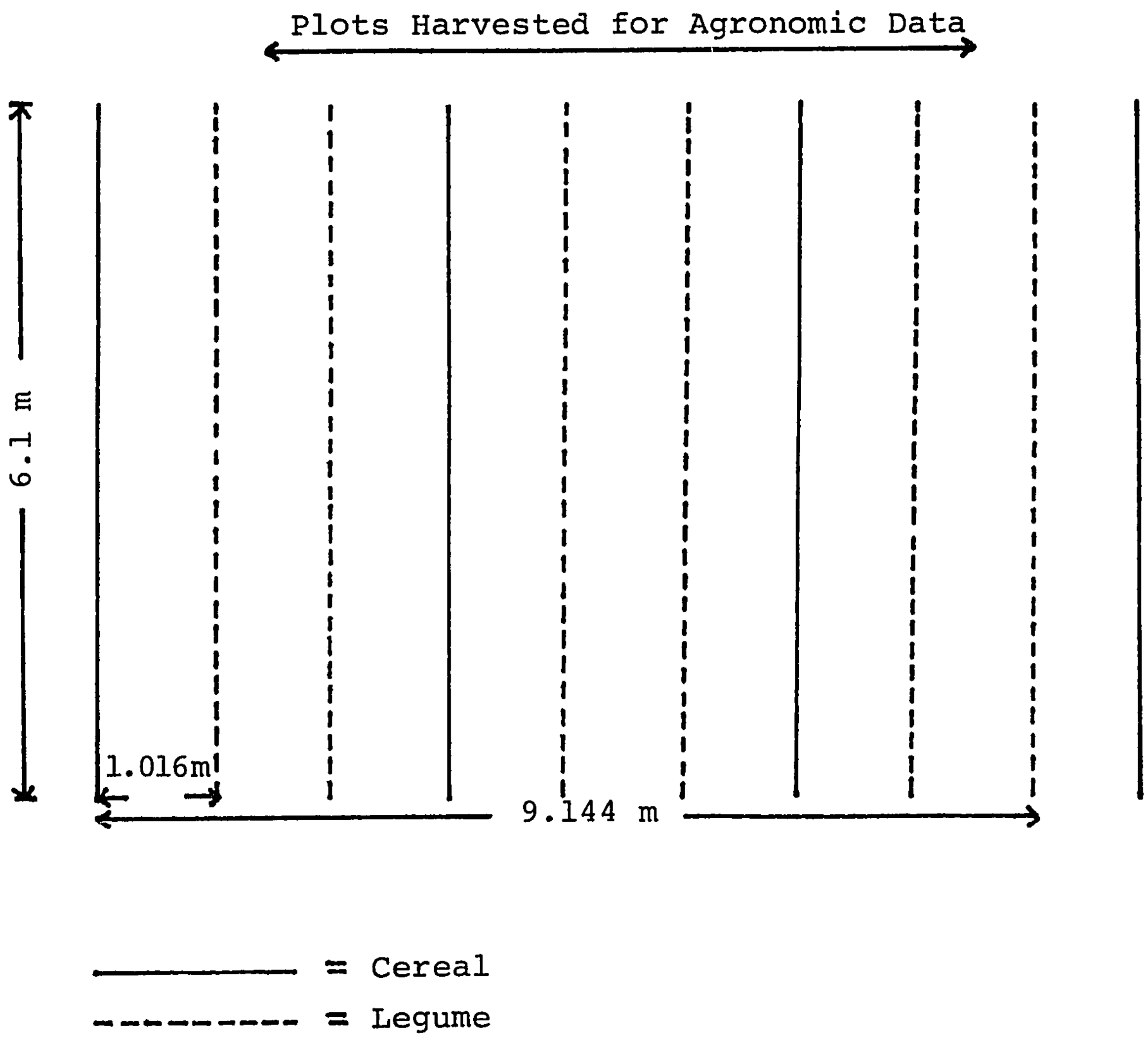

Figure 1. Planting pattern of cereals intercropped with legumes in a 2:1 spatial arrangement at the University of Arizona Marana Agricultural Center in 1985 and 1986.

Table 4. Cereal and legume scientific names used in an intercropping experiment at the University of Arizona Marana Agricultural Center in 1985.

Crop	Scientific name
Sorghum	*Sorghum bicolor* (L.) Moench
Maize	*Zea mays* L.
Pearl millet	*Pennisetum americanum* (L.) Leeke
Field bean	*Phaseolus vulgaris* L.
Cowpea	*Vigna unguiculata* (L.) Walp
Soybean	*Glycine max* (L.) Merrill

Table 5. Cereal and legume cultivars and initial number of plants/plot row used in an intercropping experiment at the University of Arizona Marana Agricultural Center in 1985.

Crop	Cultivar	Number of plants per plot row (after emergence)
Sorghum	Pioneer 8493	80
Maize	Hybrid XL 73	40
Pearl millet	Series'81-2532	80
Field bean	UI 114 10#	90
Cowpea	Calif. Blackeye no. 5	24
Soybean	Asgrow A6242	180

Evaluation Procedures of 1985 Intercropped Species

Agronomic data were collected on the cereals for date of 50% bloom or half bloom, plant heights, and number of heads or ears per plot row. Average mature plant heights were measured prior to harvest, from the ground level to the top of the panicles for sorghum and pearl millet and to the top of the tassel for maize. Data on date of 50% bloom or half bloom were collected on the three legumes but plant heights were not taken due to their prostrate growth habits. All agronomic data measurements for both cereals and legumes were taken from their respective portions of the harvested plots.

Sorghum and pearl millet harvested plots were mechanically harvested with a Massey-Ferguson 35 combine. Plot grain weights for sorghum and pearl millet were obtained directly from the combine and later corrected for possible bird damage or plot gaps. Maize ears were hand-picked, put in cloth bags and hung up under a roof to air dry. The ears were then shelled in a hand-cranked sheller and the grain cleaned in an air-blast cleaner to remove pieces of cob and other debris other than grain. Plot grain weights were then taken.

Field bean and cowpea have indeterminate growth habits for flowering and seed production, necessitating hand-picking the maturing pods as they dry at several times during the harvest season. The low humidity of the environment of this research caused pod-shattering as soon as they dried. The pods from these hand harvests were placed in cloth bags and hung up to dry under a roof. Soybean plants were cut by hand with clippers at ground level, put in cloth bags and hung up under a roof to dry. After achieving a suitable low pod moisture level, all three legumes were threshed with a spiked-tooth Vogel thresher. The seeds were then cleaned with an air-blast cleaner to remove debris other than seeds.

All the cleaned cereal and legume grain samples were allowed to air dry to a low, uniform moisture content and then final grain yields and thousand-seed weights were taken. Table 6 shows the dates of harvests of the intercropped cereal and legume species.

Sole (monocrop) plots of each crop were grown in the same test area as a base for evaluating each intercropping combination and to estimate the Relative Efficiency or Land Equivalent Ratio (LER). These values were calculated as follows:

LER= (Intercropping yield of crop A)/
(Sole (monocrop) yield of crop A) +
(Intercropping yield of crop B)/
(Sole (monocrop) yield of crop B)

Table 6. Dates of harvests of intercropped species at the University of Arizona Marana Agricultural Center in 1985.

	Dates of Harvests		
Crop Species	1st	2nd	3rd
Sorghum	22.11.85	-	-
Maize	31.10.85	-	-
Pearl millet	22.11.85	-	-
Field bean	15.10.85	22.11.85	-
Cowpea	12.09.85	01.10.85	29.11.85
Soybean	22.10.85	-	-

A cash price was obtained or estimated for what a farmer may have received for his crop in 1985. This gave a simple economic evaluation of each intercrop combination. No estimates of production costs were made for each species which, admittedly, varied considerably. Hand-harvested legume crops would have much higher production costs.

Summer 1986

The overall objective for the 1986 (second year) experiment was to study in some detail a specific species intercrop combination. It was necessary to choose the most appropriate single intercropping combination from 1985 for a genotype evaluation study. Several factors were taken into consideration to choose the best intercropping treatment. A combination of yield, LER, cash price, adaptability, and appropriateness to an intercropping system in the environment of this research. The sorghum x soybean intercrop combination was chosen as most appropriate for the Marana Agricultural Center environment. One of the main items of the intercrop combination study in 1986 was to obtain some estimate of the form and degree of variability among the genotypes evaluated of each of the two species intercropped. Three genotypes of each of the two species to be evaluated in intercrop were selected (Table 7) and combined in all combination for a total of nine intercropping combinations (Table 8). Sole (monocrop) plot entries of each cultivar

Table 7. Sorghum and soybean cultivars and initial number of plants/plot row used in an intercropping experiment at the University of Arizona Marana Agricultural Center in 1986.

Crop	Cultivar	Plants/6 m row
Sorghum 1	Pioneer 8493	80
Sorghum 2	Funks G-522DR	80
Sorghum 3	California IO80H40	80
Soybean 1	Asgrow A6242	180
Soybean 2	Asgrow A6520	180
Soybean 3	Rillito	180

Table 8. Intercropping and monocropping treatments used at the University of Arizona Marana Agricultural Center in 1986.

Treatment #	Identification
1	Sorghum 1 x Soybean 1
2	Sorghum 1 x Soybean 2
3	Sorghum 1 x Soybean 3
4	Sorghum 2 x Soybean 1
5	Sorghum 2 x Soybean 2
6	Sorghum 2 x Soybean 3
7	Sorghum 3 x Soybean 1
8	Sorghum 3 x Soybean 2
9	Sorghum 3 x Soybean 3
10	Sorghum 1 - monocrop
11	Sorghum 2 - monocrop
12	Sorghum 3 - monocrop
13	Soybean 1 - monocrop
14	Soybean 2 - monocrop
15	Soybean 3 - monocrop

were added to the experiment, giving a total of fifteen treatments. The field design for the study was a randomized complete block, with four replications. The intercrop treatment plots had the same 2:1 (legume:cereal) spatial arrangement as in 1985 (Figure 1).

Nitrogen and phosphorus fertilizers were applied to the seedbed before planting at the rate of 336 kg/ha of the formula 16-20-0, which gave 54 kg/ha of N and 67 kg/ha of P_2O_5. The 1986 experiment was planted in moisture on May 28.

In this second year, the soybean was inoculated with a commercial granular inoculant from Nitragen Co., applied with a Gandy applicator, fifteen days after planting.

No chemical control was utilized for insects, weeds or plant diseases. Weeds were mechanically controlled through cultivation at early stages and hand-controlled later. The amount of supplemental water applied through furrow irrigation and the respective dates of application are shown in Table 3.

Evaluation Procedures of 1986 Intercropped Species

The two crop species (sorghum and soybean) were planted at the same time but harvested at different times, according to their seed reproduction and seed characteristics. The developing seed of the sorghum species were allowed to mature and the entire head (grain and other head parts) allowed to air-dry prior to machine harvest. The soybean species is partially indeterminate in seed reproduction, so seed pods are initiated and developed over a period of several days. This small spread in pod maturity subjected the earliest developed pods to maturity and early shattering in the low humidity environment of this research. Therefore, it was necessary to harvest the soybean specie entries while some of the later initiated pods were still green or of high moisture.

During their vegetative growth, periodical weekly measurements of sorghum heights and soybean heights and widths were taken, in order to estimate any influence of intercropping on these characteristics.

The harvested intercropped plot in 1986, as in 1985, consisted of six central rows, four of the legume and two of the cereal, giving the spatial arrangement of 2:1 (legume: cereal), as in Figure 1.

The sorghum mature plants were harvested on November 06, 1986. Plant heights were taken at harvest time, as the distance from the ground to the top of the panicle. The sorghum cultivars were mechanically harvested with a Massey-Ferguson 35 combine. At this time, plot grain weights and samples for moisture determination, test weights, and thousand-seed weights were obtained.

The soybean mature plants were harvested on November 19, 1986. The plants were cut by hand, at ground level, with clippers and threshed in the field with a Chain Manufacturing Company rasp bar small plot combine. The seeds were then put in cloth bags, hung up to air-dry under a roof before cleaning with an air-blast cleaner. After cleaning, the soybean grain samples were allowed to continue to air-dry to a low, uniform moisture content, final grain yields, thousand-seed weights and test weights were then taken.

Land Equivalent Ratios (LER) were calculated for both species in all intercrop combinations.

CHAPTER 4

RESULTS AND DISCUSSION

Summer 1985

The Effects on the Agronomic Characteristics of Cereals from Intercropping with Legumes

Days to 50% Bloom. Each of the three cereal species (sorghum, maize, and pearl millet) when intercropped with all three legume species (field bean, cowpea, and soybean appeared to have a slightly different response in days to 50% bloom as compared to their monocropping days to bloom (Table 9). Pearl millet had no difference in days to 50% bloom between intercrop and monocrop, indicating a stability for this genetic characteristic in intercrop situations. Maize had delays of one to three days (1.7 to 5.2%) in days to 50% bloom across all intercrop situations. No statistical analyses were made of these differences but they indicate the possibility that maize maturities may be subject to delays in intercrop situations. Sorghum had a one day delay when intercropped with soybean. Again, no statistics are available on the significance of this one delay. This may indicate that sorghum has a potential for delays in days to bloom in selected intercrop situations. The delay in bloom response

Table 9. Cereal days to 50% bloom and plant heights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1985.

Treatment	Days to 50% bloom	% diff from monocrop	Plant height (cm)	% diff. from monocrop
Sorghum - monocrop	61		101	
Sorghum/field bean	61	0.0	110	+ 8.9
Sorghum/cowpea	61	0.0	108	+ 6.9
Sorghum/soybean	62	+1.6	91	- 9.9
Maize - monocrop	58		181	
Maize/field bean	59	+1.7	177	- 2.2
Maize/cowpea	61	+5.2	172	- 5.0
Maize/soybean	60	+3.4	135	-25.4
P. millet - monocrop	65		95	
P. millet/field bean	65	0.0	99	+ 4.2
P. millet/cowpea	65	0.0	103	+ 8.4
P. millet/soybean	65	0.0	91	- 4.2

among two of the three cereals indicates that we might expect delays in bloom among other selected cereals when put into intercrop situations.

Heights. Final mature plant heights of all three cereals were, as compared to their monocrop heights, influenced considerably by intercropping with the three legumes (Table 9). Of the three legumes, soybean showed the strongest intercrop influence on all three cereal heights by decreasing maize, sorghum and pearl millet by 25.4, 9.9 and 4.2%, respectively, from their monocrop heights. Conversely, the field bean increased the heights of sorghum and pearl millet by 8.9 and 4.2%, respectively, and cowpea increased the heights of sorghum and pearl millet by 6.9 and 8.4%, respectively, over their monocrop heights. Maize heights were decreased by the intercrop influences of all three legumes. Soybean decreased the heights of all three cereals in intercrop and was the legume with the strongest influence on cereal heights, perhaps due to its own height. It was the tallest legume among the three studied, allowing it to shade more of the lower vegetative part of the cereal plants. The rate of photosynthesis would be decreased in these shaded areas. Field bean and cowpea had poor stands and were less competitive with the cereals for natural resources such as light, water, and nutrients.

Work by Enyi (1973), in Tanzania, showed that at the time of anthesis, bean and cowpea had a greater depressing effect on the growth of the cereal crops (maize and sorghum) than pigeonpea. At that time, both the bean and the cowpea plants were in the reproductive phases, whereas pigeonpea plants had only produced about one-tenth of their final fresh weight yield.

Number of Heads or Ears per Plot Row. The number of heads or ears per plot row of all three cereals were generally increased when intercropped with the three legumes, as compared to cereal monocrop numbers (Table 10). Cowpea in intercrop with sorghum and pearl millet caused increases in head numbers of 7.0 and 13.8%, respectively, and when in intercrop with maize caused an increase in ear number of 5.4%. Field bean in intercrop with sorghum and pearl millet caused increases in head numbers of 3.5 and 9.6%, respectively, and when in intercrop with maize caused an increase in ear number of 5.4%. It can be concluded that there was a beneficial intercropping effect of both field bean and cowpea on the numbers of heads or ears of all three cereals. No nodulation was observed in any of the three legumes, so it is unlikely that additional N from the legumes stimulated the cereals. There were also many gaps on the field bean and cowpea plots, which might have helped the cereals perform better through less interplot competition.

Work by Searle et al. (1981) showed that nitrogen applied to intercropped legumes appeared inhibitory to nitrogen fixation, both directly from increased soil nitrogen and indirectly by stimulation of maize growth and shading of intercropped legumes.

The legume soybean is taller than field bean or cowpea but still shorter than all three cereals. Soybean in intercrop with sorghum and pearl millet caused decreases in head numbers of 9.3 and 8.5%, respectively, but increased maize ear numbers by 5.4%. These results would be expected when soybean intercepted more of the light from the sides of the cereal rows, thereby reducing their production. Maize was able to attain a height of 48% more than sorghum or pearl millet in intercrop with soybean. Thus maize was able to intercept proportionally more light, making possible ear number production similar to the numbers produced in intercropping with the two shortest legumes.

Grain Weight of Heads or Ears. There was marked influence from the intercropped legumes on the cereal average grain weight of heads or ears (Table 10). Sorghum had an increase in average grain weight per head over monocrop when intercropped with each of the three legumes. Maize had an increase (although very small) in average ear grain weight when in intercrop with cowpea and soybean, but a decrease in ear grain weight when in intercrop with field bean. Pearl

Table 10. Cereal number of heads or ears per plot row and grain weight of heads or ears in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1985.

Treatment	No. of heads or ears/ plot row	% diff. from monocrop	Ave. grain wt. of heads/ ears (g)	% diff. from monocrop
Sorghum - monocrop	86		38.64	
Sorghum/field bean	89	+ 3.5	53.88	+39.4
Sorghum/cowpea	92	+ 7.0	55.93	+44.7
Sorghum/soybean	78	+ 9.3	48.70	+26.0
Maize - monocrop	37		41.90	
Maize/field bean	39	+ 5.4	40.07	- 4.4
Maize/cowpea	39	+ 5.4	50.13	+19.6
Maize/soybean	39	+ 5.4	42.15	+ 0.6
P. millet - monocrop	94		13.34	
P. millet/field bean	103	+ 9.6	13.87	+ 4.0
P. millet/cowpea	107	+13.8	14.66	+ 9.9
P. millet/soybean	86	- 8.5	11.49	-13.9

millet showed increases in average grain weight per head when intercropped with field bean and cowpea but a decrease in average grain weight per head when intercropped with soybean. Although sorghum had a decrease in number of heads and seed weight when intercropped with soybean, it increased in grain weight when in intercrop with this legume as compared to monocropping. This can be explained by the increase in grain head weight (26.0%) when in intercrop with soybean. Greater grain sorghum yield was obtained when in intercrop with cowpea and this can be attributed to the greater increase in number of heads, seed weight and grain head weight of sorghum when in intercrop with cowpea. The decrease in grain yield by maize when in intercrop with field bean can be attributed to the decrease in grain ear weight of this cereal when in intercrop with that legume. Pearl millet had a decrease in grain weight per head and grain yield when in intercrop with soybean. Soybean was the tallest legume and this would decrease the light interception in the lower parts of the cereals which would decrease the components of yield.

Number of Seeds/Ear or Head. The three legumes had an influence on the cereal number of seeds per ear or head (Table 11). Sorghum had increases in number of seeds per head when intercropped with all three legumes. All three cereals had increases in number of seeds/ear or head when intercropped with cowpea. Field bean caused an increase in

Table 11. Cereal thousand-seed weights and number of seeds per ears or heads in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1985.

Treatment	1,000-seed weight (g)	% diff. from monocrop	No. of seeds/ ear or head	% diff. from monocrop
Sorghum - monocrop	29.1		1328	
Sorghum/field bean	31.3	+ 7.6	1721	+29.6
Sorghum/cowpea	32.8	+12.7	1705	+28.4
Sorghum/soybean	27.2	- 1.9	1790	+34.8
Maize - monocrop	210.8		199	
Maize/field bean	230.0	+ 9.1	174	-12.6
Maize/cowpea	234.4	+11.2	214	+ 7.5
Maize/soybean	190.9	- 9.4	221	+11.1
P. millet - monocrop	8.5		1569	
P. millet/field bean	9.0	+ 5.9	1541	- 1.8
P. millet/cowpea	8.8	+ 3.5	1666	+ 6.2
P. millet/soybean	8.3	- 2.4	1384	-11.8

number of seeds/head in sorghum but a decrease in number of seeds/ ear in maize and in number of seeds/head in pearl millet. Soybean caused an increase in number of seeds/head in sorghum and in number of seeds/ear in maize but a decrease in number of seeds/head in pearl millet.

From these data the sorghum species appeared to have the potential to increase its number of seeds/head in intercrop situations much more than either of the other two cereal species. Consequently, maize and pearl millet would not be expected to increase or decrease seeds/ear or head very much in intercrop situations compared to their monocrop values. Yield increases in maize and pearl millet would then have to come more from increases in ear or head numbers or larger sized seeds.

Seed Weights. Seed weights of 1000 seeds of all three cereals were deviated considerably from their monocropping seed weights by intercropping with the three legumes (Table 11). Field bean in intercrop with the three cereals caused increases in seed weights of sorghum, maize and pearl millet of 7.6, 9.1, and 5.9%, respectively. Cowpea in intercrop caused increases in seed weights of sorghum, maize and pearl millet of 12.7, 11.2, and 3.5%, respectively. However, soybean when in intercrop caused decreases in seed weights of sorghum, maize and pearl millet of 1.9, 9.4 and 2.4%, respectively, indicating that this legume was the most competitive of the three legumes for this character. This could be explained by the soybean height, since this legume was the tallest among the three. Soybean heights caused more shading on the cereals than the other legumes did and hence decrease in intensity of the cereal light interception, which decreased plant heights, number of heads or ears and seed weights. This would be the explanation based on the above-ground competition and it could be hypothesized that there was stronger below-ground competition from soybean plants than from field bean and cowpea plants but this was not investigated.

Gangwar and Kalra (1982), working with maize intercropped with legumes (blackgram, peanut, greengram, and cowpea), determined that the yield of maize increased when it was intercropped with legumes, because growing of legumes favorably affected the dry weight/plant and number of grains/plant. This was due to less weed competition at early stages of crop growth and release of N from the decaying of legume root nodules at later stages of crop growth.

Grain Yields. Grain yields of the three cereals in intercropping were calculated based on equal areas of land, as in monocropping, as shown in Table 12.

In most of the situations, the cereals showed higher grain yields when intercropped with the legumes. Highest increases in grain yields were shown by sorghum when in

Table 12. Grain yields of the three cereals (sorghum, maize, and pearl millet) in monocropping and in intercropping relative to equal areas of land at the University of Arizona Marana Agricultural Center in 1985.

Intercropped legume	Yield of sorghum (kg/ha)* 1/	% diff. from monocrop	Yield of maize (kg/ha)* 1/	% diff. from monocrop	Yield of pearl millet (kg/ha)*	% diff from monocrop
Field bean	7995 A	+47	2541 A	- 2	2376 AB	+15
Cowpea	8877 A	+64	2736 A	+ 6	2706 A	+31
Soybean	6189 B	+14	3189 A	+24	1716 B	-17
Cereal/monocrop	5421		2581		2065	

1/ Means followed by the same letter do not differ statistically by the Newman-Keul's Test at the 5% level of significance.

* Yields related to equal areas of land as in monocropping (1 ha).

intercrop with cowpea (63.8%), followed by sorghum in intercrop with field bean (47.5%). However, grain yield decreases were also observed. Maize, when in intercrop with field bean, showed a small decrease in grain yield of 1.5% and pearl millet, when in intercrop with soybean, showed decrease in grain yield of 16.9%. Since soybean caused decrease in number of heads of sorghum and pearl millet and decrease in thousand-seed weights of all three cereals, further decrease in sorghum and pearl millet grain yield would be expected as a result of the decreases observed in the two yield components just mentioned (number of heads and seed weight). Indeed, a decrease in pearl millet grain yield was observed but there was an increase in sorghum grain yield. One explanation would be the increase obtained in average sorghum grain weight per head when intercropped with soybean (Table 10). The increase in maize grain yield when intercropped with soybean can be attributed to the increases in number of ears per plot row and in average grain weight per ear (Table 10). The increases in sorghum and pearl millet grain yields when intercropped with field bean and cowpea, as compared to their monocrop yields, can be explained by the increases in number of heads per row, seed weight, and average grain weight per head. These increases were, on the average, higher when sorghum and pearl millet were intercropped with cowpea and hence higher sorghum and pearl millet grain yields were obtained when these cereals were intercropped with cowpea.

Work by Searle et al. (1981) showed that maize grain yield was not affected by soybean and peanut intercrop, indicating neither competitive depression nor nitrogen transfer from the legume and that the nondepression of maize grain yield was probably due to the lack of competition for nutrients (P, K, Ca, and S were in the basal dressing and N levels appeared adequate for good yields) and water. Beets (1977, cited by Searle et al., 1981) has also noted that when cereals and legumes are grown together, it is usually the cereal which is least affected by the interaction. Mohta and De (1980), working with maize and sorghum intercropped with soybean, found that maize yields were not affected by intercropping with soybean but sorghum yields were reduced.

The Effects on the Agronomic Characteristics of Legumes from Intercropping with Cereals

Days to 50% Bloom. Each of the three legumes (field bean, cowpea, and soybean) when intercropped with all three cereal species (sorghum, maize, and pearl millet) reached 50% bloom in almost the same number of days under intercropping as under monocropping (Table 13). The few differences of only one day were small, indicating that maturity of the three cereal species, as indicted by their days to 50% bloom,

Table 13. Legume days to 50% bloom and thousand-seed weights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1985.

Treatment	Days to 50% bloom	% diff. from monocrop	1,000-seed wt (g)	% diff. from monocrop
Field bean-monocrop	44		266.2	
Field bean/sorghum	45	+2.3	303.0	+13.8
Field bean/maize	45	+2.3	263.8	- 0.9
Field bean/p. millet	44	0.0	306.8	+15.3
Cowpea-monocrop	54		250.1	
Cowpea/sorghum	55	+1.8	249.8	- 0.1
Cowpea/maize	54	0.0	254.9	+ 1.9
Cowpea/p. millet	54	0.0	253.3	+ 1.3
Soybean-monocrop	58		110.2	
Soybean/sorghum	58	0.0	105.0	- 4.7
Soybean/maize	58	0.0	116.7	+ 5.9
Soybean/p. millet	57	-1.7	117.5	+ 6.6

was generally not affected by any intercropping influences of the three legumes.

Remison (1978), in Nigeria, concluded that maize was generally favored when grown in association with cowpea though it performed better in mixed than in pure stand, it had no depressive effect on the performance of cowpea, since days to flowering, number of pods, and weight of pods were not affected significantly by the maize associate.

Seed Weights. As shown in Table 13, there was some influence of the cereals on the seed weight of the legumes. Small differences can be seen, but not enough to be considered as an influence of intercropping on the legume seed weights. There was a 13.8% increase in field bean seed weight when intercropped with sorghum as compared to monocrop, but cowpea and soybean, when intercropped with sorghum, showed a decrease in seed weight of 0.1 and 4.7%, respectively. All three legumes showed an increase in seed weight when in intercrop with pearl millet (15.3% for field bean, 1.3% for cowpea and 6.6% for soybean). Maize in intercrop with the legumes caused small decrease (0.9%) in field bean seed weight, but increases in cowpea and soybean seed weights. One reason that could explain the least competitive ability of pearl millet against the legumes would be its height, since it was the shortest cereal and hence it would cause less shading on the legumes.

Francis, Prager, and Tejada (1982), in Colombia, found that competition from maize reduced bean yield components in four bean cultivars. Beets (1977, cited by Searle et al., 1981), working with maize-legume intercropping, concluded that increased shading probably accounts for the reductions in branches per plant, pods per branch and 100-seed weight in both soybean and peanut, even though total dry matter yield, grain yield and plant height of both legumes were not affected.

Grain Yields. Grain yields of the three legumes in all intercrop combinations are presented in Table 14.

Field bean showed higher grain yields when intercropped with the three cereals as compared to its monocrop yields (126% with sorghum, 28% with maize, and 271% with pearl millet). On the other hand, cowpea and soybean showed higher grain yields only when in intercrop with pearl millet, but lower grain yields when in intercrop with sorghum and maize as compared to their monocrop yields. This indicates a low competitive ability of pearl millet when in intercrop with these three legumes. Higher field bean grain yields when intercropped with sorghum and pearl millet can be attributed to increases in field bean seed weight of 13.8% and 15.3%, respectively. Field bean yield in intercrop was lower when intercropped with maize. Among the three cereals, maize was the tallest and this could explain the low yield of

Table 14. Grain yields of the three legumes (field bean, cowpea, and soybean) in monocropping and in intercropping relative to equal areas of land at the University of Arizona Marana Agricultural Center in 1986.

Intercropped cereal	Yield of field bean (kg/ha)* 1/	% diff. from mono-crop	Yield of cowpea (kg/ha)* 1/	% diff. from mono-crop	Yield of soybean (kg/ha)* 1/	%diff from mono-crop
Sorghum	499 B	+126	852 B	- 6	1323 B	-19
Maize	283 B	+ 28	885 B	- 3	1516 B	- 7
Pearl millet	820 A	+271	1342 A	+47	1827 A	+12
Legume-mono-crop	221		910		1629	

1/ Means followed by the same letter do not differ statistically by the Newman-Keul's Test at the 5% level of significance.

* Yields related to equal areas of land as in monocropping (1 ha).

field bean when intercropped with this cereal, due to shading and less photosynthesis in the legume. All three legumes showed higher grain yields when intercropped with pearl millet which may have been because this cereal was the shortest among the three. Although maize height could cause a grain yield decrease in field bean, it did not have the same effect on cowpea and soybean as evidenced by the grain yields of these two legumes being higher when in intercrop with maize than when in intercrop with sorghum. The reason is that sorghum caused 0.1 and 4.7% decreases in seed weights of cowpea and soybean, respectively, and maize caused 1.9 and 5.9% increases in seed weights of cowpea and soybean, respectively.

Work by Francis, Prager, and Tejada (1982) showed that yields of bean were strongly affected by maize competition and that yield reduction of climbing bean (compared to monoculture) due to intercropping was greater than yield reduction in the other bean cultivars. Mohta and De (1980) found that sole crops of soybean produced the highest grain yield and its yield was significantly less when intercropped with maize or sorghum and also that the decrease in the yield of soybean could be attributed to shading soybean plants by maize or sorghum.

Gardiner and Craker (1981) found economic yield reductions in bean due to a decreased number of pods and decreased seed yields in the intercrop. As compared with monocrop bean plants, seed yield was reduced more than pod numbers under all maize populations used in the study. The data indicate that shading of the bean plants by the maize plants during later growth stages probably reduces the supply of photosynthate for the developing bean seeds (Fisher, 1979).

Land Equivalent Ratios (LER)

Land Equivalent Ratio values were calculated to determine the efficiency of particular intercropping combinations. The LER values of all nine intercrop treatments are presented in Table 15. With only two exceptions, intercropping was more advantageous than monocropping under the conditions studied (LER > 1.0).

Allen and Obura (1983) stated that studies in the United States, done with maize/cowpea and maize/soybean, had LER values showing that intercropping resulted in greater productivity per unit of land than monocultures of the intercrop components.

The greatest individual crop advantages were shown by field bean, followed by cowpea. The best intercropping combination with the highest LER was for pearl millet x field bean (2.85), followed by sorghum x field bean (2.00).

Among all six crops, maize and pearl millet showed the highest decrease in yield (63.5 and 63%, respectively)

Table 15. Percent of grain yield of the nine intercroppings over the respective sole crops and LER values at the University of Arizona Marana Agricultural Center in 1985.

Intercropping	% of Yield over Monocrop		LER
	Cereal	Legume	
Sorghum x field beans	49.15	150.70	2.00
Sorghum x cowpea	54.57	62.43	1.17
Sorghum x soybean	38.05	54.16	0.92
Maize x field bean	32.96	85.20	1.18
Maize x cowpea	41.20	64.74	1.06
Maize x soybean	35.32	62.03	0.97
Pearl millet x field bean	38.35	247.05	2.85
Pearl millet x cowpea	43.70	98.31	1.42
Pearl millet x soybean	27.69	74.74	1.02

when intercropped, which means a greater effect from interspecific competition. The lowest LER values were shown by the three cereals when intercropped with soybean, indicating the high interspecies competition effect of this legume on the agronomic performance of the cereals.

Cash Price to Farmer

Since it is difficult and confusing to compare and discuss yields of six different crops in different combinations, besides the LER values, cash price paid at the farmer level was also estimated in order to have a standard basic comparison.

Taking cash price into consideration (Table 16), sorghum x cowpea had the highest farmer cash income value, followed by sorghum x field bean and pearl millet x cowpea. However, the differences in cost of production were not considered. These costs do differ under actual considerations for the following reasons: (1) cowpea had three harvests because of an indeterminate growth habit and a large range in maturity; (2) field bean had two harvests, also because of its indeterminate growth habit; (3) soybean and the three cereals were all harvested at one time, and (4) sorghum and pearl millet were harvested and threshed in one operation and the other crops needed to be threshed later. These four reasons would make the cost of production differ among the nine intercropping combinations with field bean and

Table 16. Cash price (U.S. dollars/ha) for the nine intercropping treatment combinations at the University of Arizona Marana Agricultural Center in 1985.

Intercropping	Cash Price* (US dollars/ha)
Sorghum x field bean	484.88
Sorghum x cowpea	616.96
Sorghum x soybean	448.81
Maize x field bean	186.95
Maize x cowpea	374.61
Maize x soybean	322.05
Pearl millet x field bean	321.76
Pearl millet x cowpea	474.57
Pearl millet x soybean	318.36

* Harvesting season of 1985.

cowpea highest due to intensive labor involved in hand-picking the pods.

Choosing the Most Appropriate Intercropping Combination for Future Studies

It was necessary to choose the most appropriate single intercropping combination for a genotype evaluation study in the summer of 1986.

According to Francis, Prager, and Tejada (1982b), intercropping patterns may be evaluated in terms of total grain yield, protein production, biological efficiency (as compared to monoculture) or net return to the farmer. Not only one factor was taken into consideration to choose the best intercropping treatment, but a combination of yield, LER, cash price, adaptability, and appropriateness to an intercropping system. Considering yield and cash price, sorghum would be chosen among the cereals and cowpea would be chosen among the legumes. Using only LER values in the evaluation, sorghum would be chosen as the cereal and field bean would be chosen as the legume. But as stated earlier, the cost of production would be high for field bean and cowpea, due to their wide ranges in maturities, which would require more intensive labor for hand-picking the pods. So in the overall evaluation, the sorghum x soybean intercropping was chosen as the most appropriate and to be studied in the following year.

Summer 1986

The objectives for the second year of field research (1986) were (1) to identify the most productive intercrop combination of the three different sorghum genotypes and the three different soybean genotypes and (2) to determine the degree, if any, of interspecific and intraspecific variability of various agronomic characteristics of the two species in intercrop.

The Effects on the Agronomic Characteristics of Sorghum from Intercropping with Soybean

Days to 50% Bloom. Each of the three sorghum genotypes when intercropped with all three soybean genotypes reached 50% bloom in almost the same number of days under intercropping as under monocropping (Table 17). The few differences of one day more or one day less were very small, indicating that maturity of three sorghum genotypes, as indicated by their days to 50%, was generally not affected by any intercropping influences of the soybean genotypes.

Heights. Weekly measurements of sorghum heights were taken for three weeks, when it seemed that no more additional growth would occur (Table 18). Sorghum 3 showed the highest weekly increases in height, both in monocropping and in intercropping. Sorghum 1 and sorghum 2 were shorter when intercropped with soybean 3. Sorghum 3 was later in maturity and still earlier in vegetative growth compared to

Table 17. Days to 50% bloom of sorghum and soybean genotypes in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Treatment*	Days to 50% bloom			
	Sorghum	% diff. from monocrop	Soybean	% diff. from monocrop
Sorghum 1 x Soybean 1	64	+ 1.6	58	0.0
Sorghum 1 x Soybean 2	63	0.0	60	0.0
Sorghum 1 x Soybean 3	64	+ 1.6	57	- 3.4
Sorghum 2 x Soybean 1	63	+ 1.6	57	- 1.7
Sorghum 2 x Soybean 2	63	+ 1.6	59	- 1.7
Sorghum 2 x Soybean 3	63	+ 1.6	58	- 1.7
Sorghum 3 x Soybean 1	66	0.0	59	+ 1.7
Sorghum 3 x Soybean 2	65	- 1.5	61	+ 1.7
Sorghum 3 x Soybean 3	67	+ 1.5	60	+ 1.7
Sorghum 1 - monocrop	63			
Sorghum 2 - monocrop	62			
Sorghum 3 - monocrop	66			
Soybean 1 - monocrop			58	
Soybean 2 - monocrop			60	
Soybean 3 - monocrop			59	

* For identification of sorghum and soybean genotypes refer to Table 7.

Table 18. Progressive weekly measurements of sorghum heights in monocropping and in intercropping at the University of Arizona University of Arizona Marana Agricultural Center in 1986.

Treatment*	Sorghum Height (cm)		
	July 14	July 21	July 28
Sorghum 1 - monocrop	115	115	117
Sorghum 1 x Soybean 1	112	113	122
Sorghum 1 x Soybean 2	115	116	128
Sorghum 1 x Soybean 3	113	117	121
Sorghum 2 - monocrop	123	124	125
Sorghum 2 x Soybean 1	120	123	128
Sorghum 2 x Soybean 2	119	123	124
Sorghum 2 x Soybean 3	121	121	123
Sorghum 3 - monocrop	126	137	166
Sorghum 3 x Soybean 1	128	141	156
Sorghum 3 x Soybean 2	123	130	143
Sorghum 3 x Soybean 3	126	142	155

* For identification of sorghum and soybean genotypes, refer to Table 7.

sorghums 1 and 2, which were nearer their final height at the dates of measurement. Sorghum 3 still attained more height just prior to 50% bloom than sorghums 1 and 2, indicating different height growth rates among sorghum genotypes. Table 19 summarizes the heights of the three sorghum genotypes at harvest time, both in monocropping and in intercropping. Sorghum 3 (California IO80H40) had the tallest final heights compared to the other two sorghum genotypes and decreased in plant height when in intercrop with the three soybean genotypes. Sorghum 1 (Pioneer 8493) showed a small increase in plant height from monocrop to intercrop, with the larger increase of 4.3% when in intercrop with soybean 1. Sorghum 2 (Funks G-522DR) had a small increase of 2.4% in plant height when in intercrop with soybean 1 but had essentially no effect with soybean 2 with an increase of only 0.3%. Sorghum 2 had a decrease in plant height when in intercrop with soybean 3 of 1.5%. Each of the three sorghum individual genotypes had a different but uniform height response when intercropped with the three soybeans. This indicates the existence of intraspecific variability in sorghum for height when in intercrop with soybean.

The final mature plant heights of all three sorghum were statistically analyzed in all intercrop treatments, in combination of intercrop and monocrop treatments and in all monocrop treatments (Table 20). Considering only the inter-

Table 19. Sorghum heights, test weights, and thousand-seed weights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Treatment*	Height (cm)	% diff. from mono-crop	Test wt (kg/ m^3)	% diff. from mono-crop	1000-seed wt (g)	% diff. from mono-crop
Sorghum 1-monocrop	117.4		715.4		24.83	
Sorghum1/soybean1	122.5	+4.3	727.6	+1.7	24.75	-0.3
Sorghum1/soybean2	118.9	+1.3	734.1	+2.6	24.25	-2.3
Sorghum1/soybean3	121.4	+3.4	727.4	+1.7	24.17	-2.7
Sorghum 2-monocrop	125.5		730.7		26.58	
Sorghum2/soybean1	128.5	+2.4	737.2	+0.9	27.05	+1.8
Sorghum2/soybean2	125.9	+0.3	732.7	+0.3	25.96	-2.3
Sorghum2/soybean3	123.6	-1.5	732.0	+0.2	26.21	-1.4
Sorghum 3-monocrop	174.6		678.9		23.91	
Sorghum3/soybean1	165.0	-5.5	687.2	+1.2	25.72	+7.6
Sorghum3/soybean2	168.3	-3.6	689.0	+1.5	25.34	+6.0
Sorghum3/soybean3	167.9	-3.8	677.6	-0.2	26.04	+8.9

* For identification of sorghum and soybean genotypes refer to Table 7.

Table 20. Mean sorghum final heights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

	Mean Height (cm)**		
Sorghum Genotypes*	All Treatments	Inter-cropping Only	Mono-cropping Only
Sorghum 1	120.0 C	120.9 B	117.4 C
Sorghum 2	125.9 B	126.0 B	125.5 B
Sorghum 3	168.9 A	167.0 A	176.6 A

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

cropping treatments, sorghum 3 differed statistically from the other two genotypes, regarding final plant height. If this parameter were the only one to be taken into account for genotype decision, sorghum 1 would be chosen due to its shorter height and consequently less shading effect on the soybeans. Considering all treatments and only the monocropping treatments, all three sorghum genotypes differed statistically from each other regarding final plant height.

Figure 2 shows graphically the mean sorghum heights when in intercrop with the three soybean genotypes. As can be seen, all three sorghum genotypes had a similar pattern, regarding plant height, when in intercrop with soybean.

Test Weights. All three sorghum genotypes showed an average increase in test weight values when in intercrop, except sorghum 3 which showed a decrease of 0.2% in test weight when in intercrop with soybean 3 (Table 19). However, the increase percentages were all small, the highest being 2.6% (sorghum 1 when in intercrop with soybean 2).

The test weights of all three sorghums were statistically analyzed in all intercrop treatments, in a combination of intercrop and monocrop treatments, and in all monocrop treatments (Table 21). In all three analyses the lower test weight of sorghum 3 was significantly different from the other two sorghum genotypes. Sorghum 1 had slightly lower

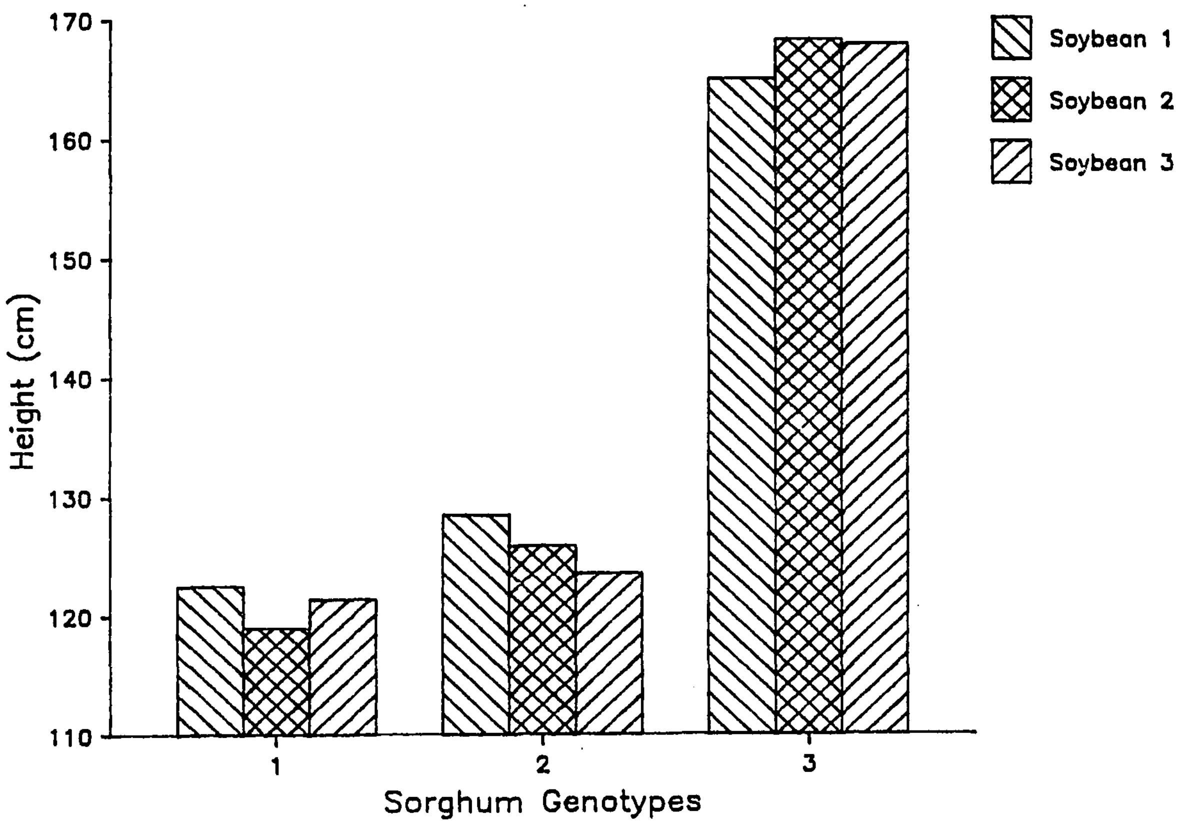

Figure 2. Sorghum heights (cm) when intercropped with three soybean genotypes at the University of Arizona Marana Agricultural Center in 1986.

Table 21. Mean sorghum test weights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Sorghum Genotypes*	Mean Test Weights (kg/m^3)**		
	All Treatments	Inter-cropping Only	Mono-cropping Only
Sorghum 1	726.1 A	729.7 A	715.4 A
Sorghum 2	733.1 A	733.9 A	730.7 A
Sorghum 3	683.1 B	684.6 B	678.9 B

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

test weights than sorghum 2 in all three analyses, which were not significantly different.

Figure 3 shows graphically the mean sorghum test weights when in intercrop with the three soybean genotypes. Each of the three individual sorghum genotypes had different but uniform grain test weight response when intercropped with the three soybeans. This apparent intraspecific difference in response of sorghum to intercrop with soybean may be a result of the height differences among the sorghum genotypes.

Seed Weights. Table 19 summarizes the means of thousand-seed weights for the three sorghum genotypes in monocropping and in intercropping. Sorghum 1 had decreases in seed weights when in intercrop with the three soybean genotypes, with the largest decrease when in specific intercrop with soybean 3 (-2.7%). Sorghum 3 had increases in seed weights when in intercrop with the three soybean genotypes, with the largest increase when in specific intercrop with soybean 3 (+8.9%). The decrease in seed weight observed in sorghum 1 could be attributed to the fact that this genotype was the shortest and suffered from the competition with soybean due to more shading and, consequently, a lower photosynthetic rate. On the other hand, sorghum 3, being the tallest, had an increase in seed weight, perhaps due to much less shading effect from the competitive legumes and allowing greater photosynthesis in the sorghum.

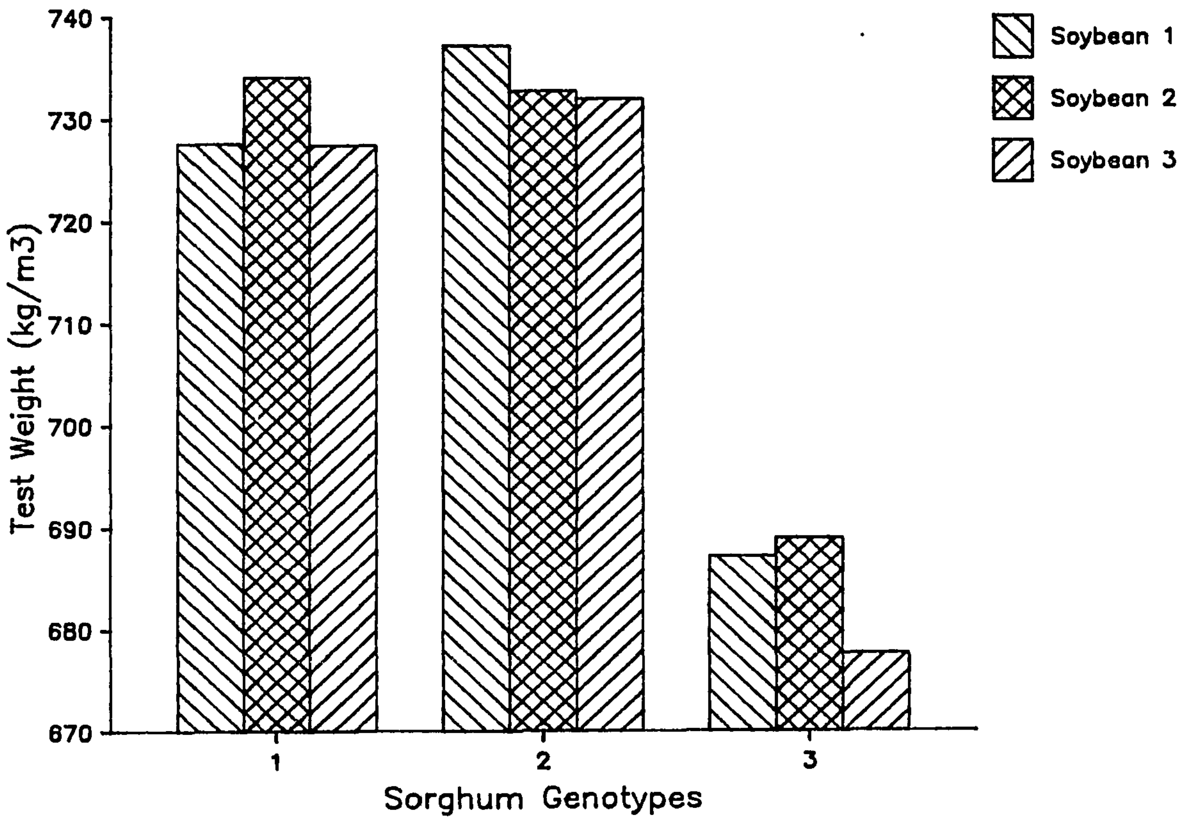

Figure 3. Sorghum test weights (kg/m^3) when intercropped with three soybean genotypes at the University of Arizona Marana Agricultural Center in 1986.

Sorghum seed weight data were statistically analyzed for all treatments in monocropping, intercropping, and in monocropping and intercropping combined (Table 22). When all treatments were taken into consideration, as well as when only the monocropping treatments were considered, sorghum 2 differed statistically from the other two sorghum genotypes, regarding thousand-seed weight and no statistical difference occurred between sorghum 1 and sorghum 3. When only intercropping treatments were taken into consideration for statistical analysis, sorghum 1 differed statistically from the other two sorghum genotypes, regarding thousand-seed weight, while no statistical difference occurred between sorghum 2 and sorghum 3.

Figure 4 shows graphically the mean sorghum thousand-seed weights when in intercrop with the three soybean genotypes. Each of the three individual sorghum genotypes had a different but uniform thousand-seed weight response when intercropped with the three soybeans. This indicates the existence of intraspecific variability in sorghum for seed weight when in intercrop with soybean.

Head Weights. The mean sorghum head weights of two of the three sorghum genotypes (sorghums 1 and 2) were greatly reduced in intercrop with soybean compared to monocrop (Table 23). Sorghum 3 head weights were not influenced much by intercrop with soybean compared to monocrop. Sorghum

Table 22. Mean sorghum seed weights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Sorghum Genotypes*	Mean Thousand-seed Weight (g)**		
	All Treatments	Inter-cropping Only	Mono-cropping Only
Sorghum 1	24.50 B	24.39 B	24.83 B
Sorghum 2	26.45 A	26.41 A	26.58 A
Sorghum 3	25.25 B	25.70 A	23.91 B

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

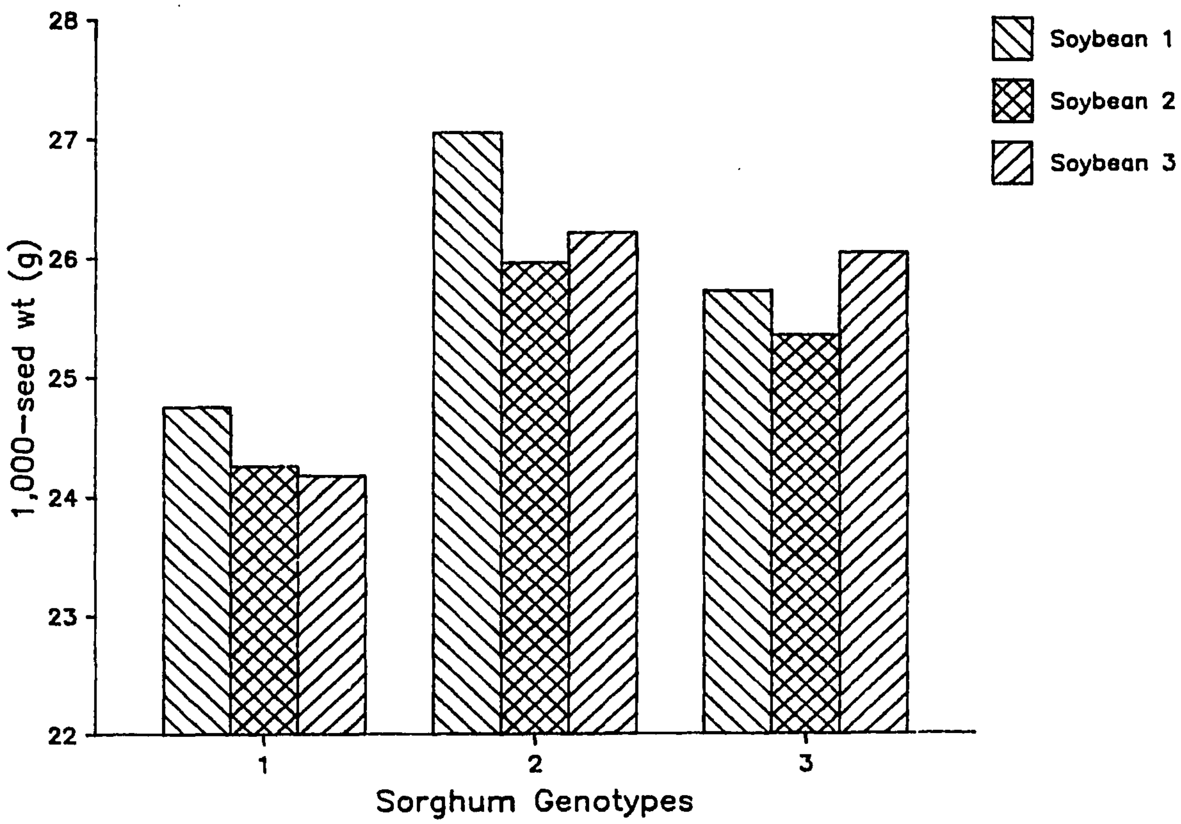

Figure 4. Sorghum thousand-seed weights (g) when intercropped with three soybean genotypes at the University of Arizona Marana Agricultural Center in 1986.

Table 23. Sorghum head weights and number of seeds/head in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Treatment*	Head wt. (g)	% diff. from monocrop	No. of seeds per head	% diff. from monocrop
Sorghum 1-monocrop	51.7		2082	
Sorghum1/soybean1	41.6	-19.5	1681	-19.3
Sorghum1/soybean2	38.1	-26.4	1571	-24.5
Sorghum1/soybean3	39.7	-23.2	1642	-21.1
Sorghum 2-monocrop	51.3		1930	
Sorghum2/soybean1	43.6	-15.1	1612	-16.5
Sorghum2/soybean2	45.6	-11.2	1757	- 9.0
Sorghum2/soybean3	39.9	-22.3	1522	-21.1
Sorghum 3-monocrop	44.7		1870	
Sorghum3/soybean1	41.0	- 8.3	1594	-14.8
Sorghum3/soybean2	44.8	+ 0.1	1768	- 5.5
Sorghum3/soybean3	46.5	+ 3.8	1786	- 4.5

* For identification of sorghum and soybean genotypes refer to Table 7.

1 had the largest decrease, among the sorghums, in head weights of 19.5, 26.4 and 23.2% when in intercrop with soybean 1, soybean 2, and soybean 3, respectively. Sorghum 2 had decreases in head weights of 15.1, 11.2, and 22.3% when in intercrop with soybean 1, soybean 2, and soybean 3, respectively. Sorghum 3 had the lowest decrease, among the sorghums, in head weight of 8.3% when in intercrop with soybean 1, but the smallest increases of 0.1 and 3.8% when in intercrop with soybean 2 and soybean 3, respectively. The soybean genotypes had a stronger influence on head weights of sorghum 1 and sorghum 2 genotypes, perhaps due to the shorter statures of these two sorghum genotypes as compared to sorghum 3. Sorghum 3 was considerably taller than sorghums 1 and 2 so perhaps it (sorghum 3) did not have as much interplot competition shading effect from the soybeans in the intercrop situations.

Waghmare et al. (1982) found that length and girth of sorghum panicles were not changed significantly by the different legume intercrops, but the panicle weight (total and grain weight) increased because of association with different intercrops. Similar trends were also observed in 1,000-grain weight (grain size).

Sorghum head weights were statistically analyzed for all treatments in monocropping, intercropping, and monocropping and intercropping combined (Table 24). In all three

Table 24. Mean sorghum individual head weights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Sorghum Genotypes*	Mean Head Weights (g)**		
	All Treatments	Inter-cropping Only	Mono-cropping Only
Sorghum	42.77 A	39.79 A	51.70 A
Sorghum 2	45.06 A	42.98 A	51.30 A
Sorghum 3	44.25 A	44.09 A	44.74 A

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

analyses, there were no significant statistical differences among all three sorghum genotypes.

Figure 5 shows graphically the mean sorghum head weights when in intercrop with the three soybean genotypes. The three individual sorghum genotypes had different and variable responses for head weight, compared to monocrop, in intercrop with soybean.

Number of Seeds per Head. All three sorghum genotypes had decreases, some quite large, in number of seeds per head when intercropped with soybean, regardless of the legume genotype, as compared to their number of seeds per head in monocropping (Table 23). Sorghum 1 showed the strongest influence of soybean intercropping on the number of seeds per head, with the largest decreases. These decreases could be attributed to its height, since it was the shortest sorghum genotype. The shorter sorghum would have the least photosynthetic leaf area above the soybean in intercrop. This results in the highest amount of shaded area caused by adjacent soybean entries, resulting in more reduced photosynthetic activity and less plant growth. Sorghum 3 was the tallest among the three sorghum genotypes and had the least interplot competition influence of soybean intercropping, regarding number of seeds per head.

Statistical analyses were run for sorghum number of seeds per head, one including the intercropping and mono-

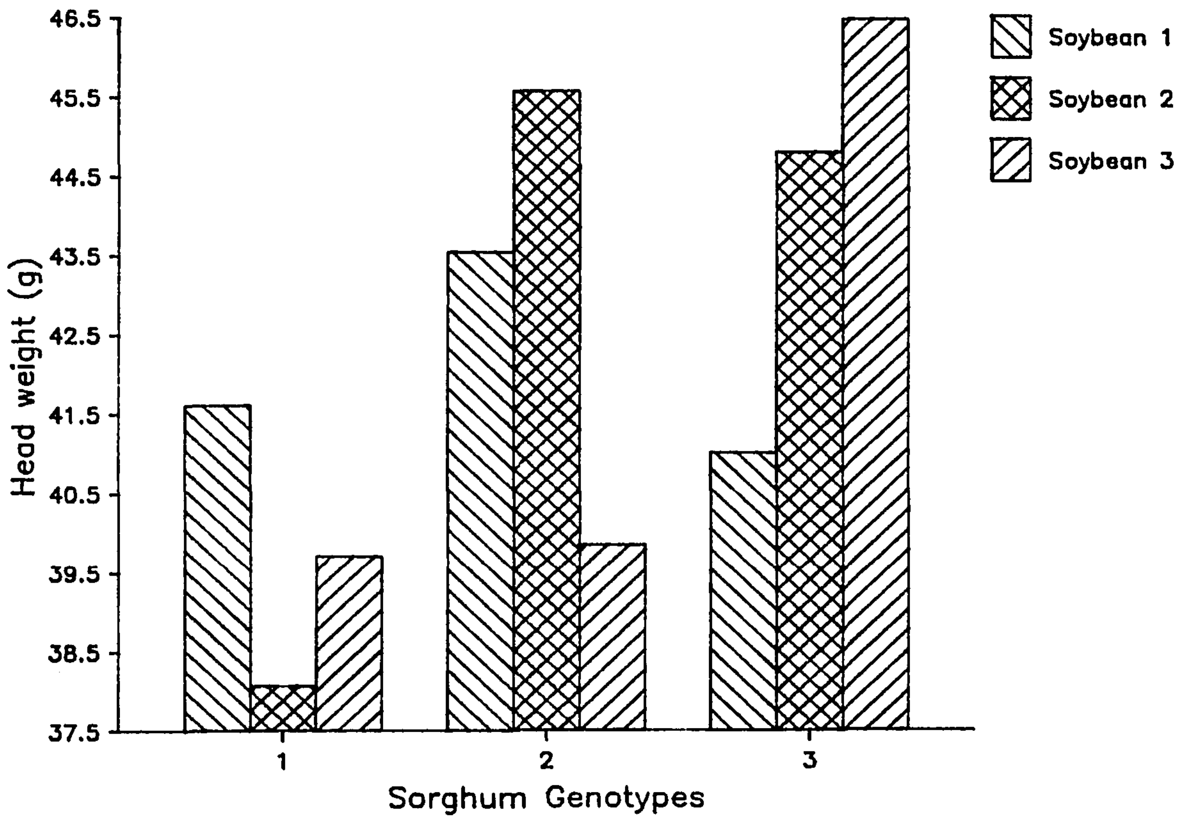

Figure 5. Sorghum head weights (g) when intercropped with three soybean genotypes at the University of Arizona Marana Agricultural Center in 1986.

cropping treatments, one including only the intercropping treatments, and another one including only the monocropping treatments, and are shown in Table 25. In all three analyses, there were no statistical significant differences among the three sorghum genotypes regarding number of seeds per head.

Figure 6 shows graphically the mean sorghum seeds per head when in intercrop with the three soybean genotypes.

Number of Heads per Hectare. The mean sorghum number of heads per hectare in two of the three sorghums was influenced from intercropping of this cereal with soybean genotypes (Table 26). Sorghum 2 and sorghum 3 had increases in number of heads per hectare when intercropped with soybean. The magnitude of these increases were different between sorghum genotypes but similar within sorghum genotypes. Higher increases were observed in sorghum 3, which was the tallest among the three cereal genotypes. Sorghum 2 was intermediate in plant height and also showed intermediate values for the influence of soybean intercropping on the number of heads per hectare. Sorghum 1 had a small decrease in number of heads per hectare when in intercropping with soybean 1 and small increases in number of heads per hectare when intercropped with soybean 2 and soybean 3. Sorghum 1 was the shortest sorghum genotype and therefore had the greatest proportion of its plant shaded by the adjacent

Table 25. Mean sorghum number of seeds per head in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Sorghum Genotypes*	Mean No. of Seeds/head**		
	All Treatments	Inter-cropping Only	Mono-cropping Only
Sorghum 1	1748 A	1635 A	2084 A
Sorghum 2	1703 A	1628 A	1927 A
Sorghum 3	1748 A	1709 A	1866 A

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

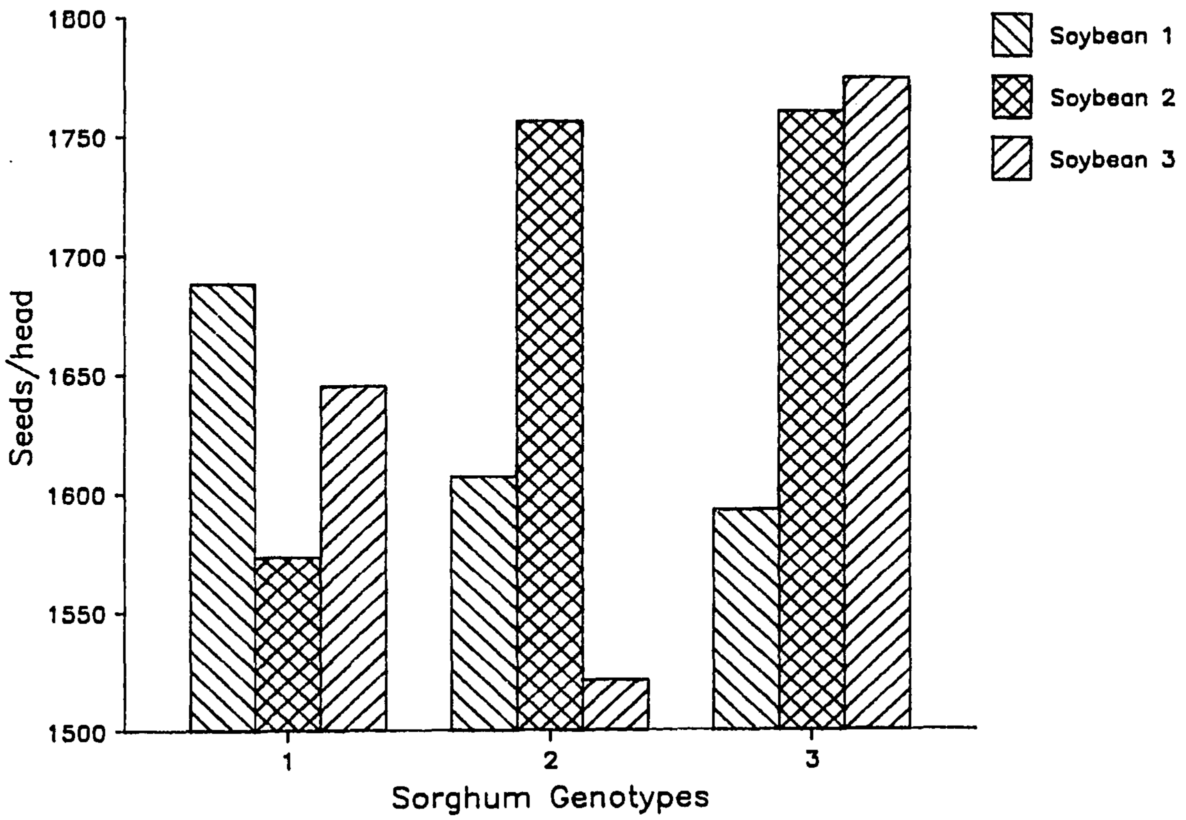

Figure 6. Sorghum seeds per head when intercropped with three soybean genotypes at the University of Arizona Marana Agricultural Center in 1986.

Table 26. Sorghum number of heads per acre and grain yields in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Treatment*	Yield (kg/ha) **	% Diff. from Monocrop	No. of Heads/ ha	% Diff. from Monocrop
Sorghum 1 - monocrop	9434		182,200	
Sorghum 1/soybean 1	7493	-20.6	180,800	-0.8
Sorghum 1/soybean 2	7214	-23.5	189,300	+3.9
Sorghum 1/soybean 3	7443	-21.1	187,300	+2.8
Sorghum 2 - monocrop	7901		154,600	
Sorghum 2/soybean 1	7544	-4.5	172,400	+11.5
Sorghum 2/soybean 2	8043	+1.8	176,600	+14.2
Sorghum 2/soybean 3	6921	-12.4	174,000	+12.5
Sorghum 3 - monocrop	7378		154,600	
Sorghum 3/soybean 1	7922	+7.4	192,700	+18.3
Sorghum 3/soybean 2	8349	+13.2	186,300	+14.4
Sorghum 3/soybean 3	8944	+21.2	191,100	+17.3

* For identification of sorghum and soybean genotypes refer to Table 7.

** Yields related to equal areas of land as in monocropping (1 ha).

soybean plants. This greater shaded are reduced its total photosynthetic output more than for sorghums 2 and 3 in intercrop.

Statistical analyses were run for sorghum number of heads per hectare, one including the intercropping and monocropping treatments, one including only the intercropping treatments, and another one including only the monocropping treatments, and are shown in Table 27.

Figure 7 shows graphically the sorghum mean heads per hectare when in intercropping with the three soybean genotypes.

Grain Yields. Grain yields of each of the three sorghums differed similarly in their responses to the three legumes in intercrop, as compared to monocrop (Table 26). Sorghum 1 showed an average grain yield decrease of 21.7% when in intercrop with the three soybean genotypes; sorghum 2 showed an average grain yield decrease of 5.0% when in intercrop with the three soybean genotypes, whereas sorghum 3 showed an average grain yield increase of 13.9% when in intercrop with the three soybean genotypes. The highest increase in grain yield was shown by sorghum 1 when in intercrop with soybean 2 (23.5%). The sorghum species appears to have a very high intraspecific variability for grain yield when intercropped with soybean. Sorghum 1 in monocrop was the significantly highest yielding genotype but

Table 27. Mean sorghum number of heads per hectare in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Sorghum Genotypes*	Mean No. of Heads/ha** All Treatments	Intercropping Only	Monocropping Only
Sorghum 1	184,900 A	185,800 A	182,200 A
Sorghum 2	169,400 B	174,300 B	154,600 B
Sorghum 3	183,300 A	190,100 A	162,900 B

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

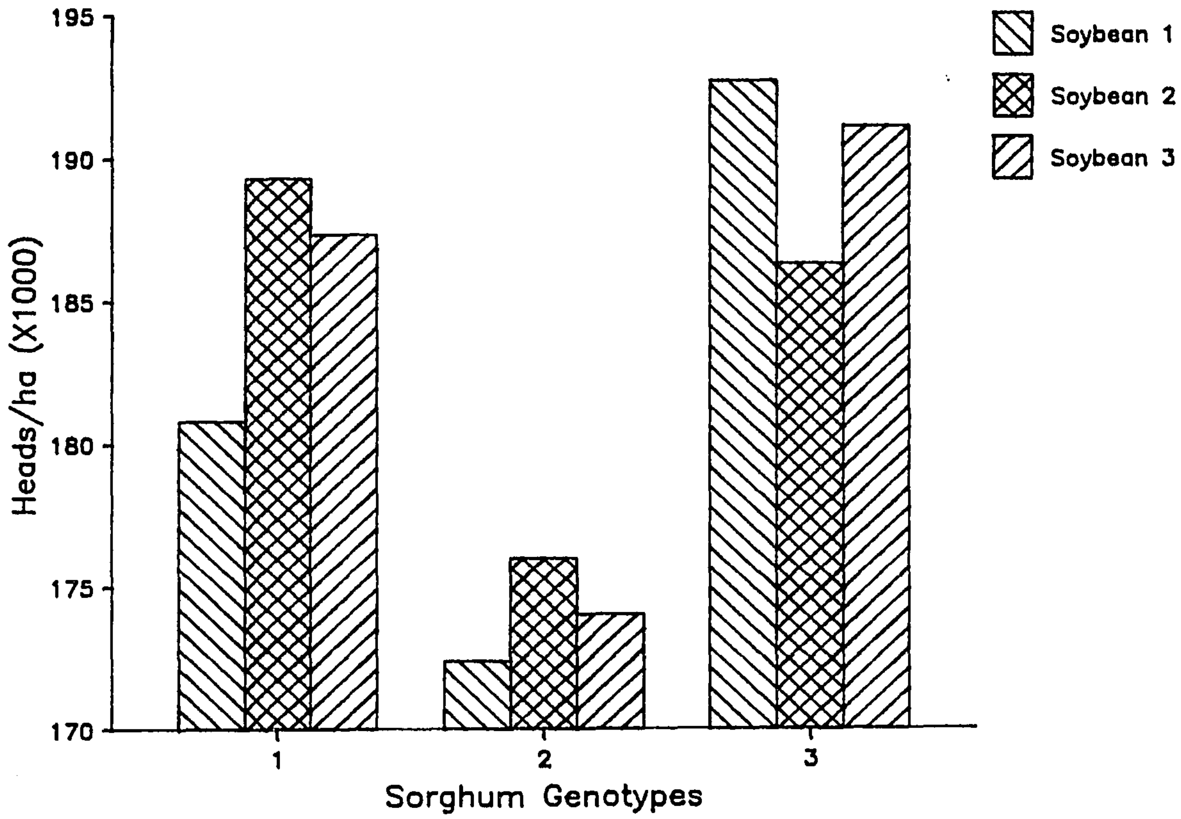

Figure 7. Sorghum heads per hectare when intercropped with three soybean genotypes at the University of Arizona Marana Agricultural Center in 1986.

in intercrop was the lowest at a 21.7% decrease. Sorghum 3 in monocrop was the lowest in grain yield but was significantly the highest in intercrop with a 13.9% gain.

Grain yield in sorghum is determined primarily by head numbers, seed numbers per head and size of seed. These three characteristics may vary in different ways in intercrop for each sorghum genotype, resulting in variable intercrop yields. Each of these three components of yield plant characteristics also varied for each of the three sorghum genotypes but each genotype did not vary much when intercropped with all three soybeans (Tables 19, 23 and 26). This indicates that sorghum genotypes may be evaluated in single interspecies intercrop test for these yield components.

According to Waghmare and Singh (1984), in grain legumes, much of the fixed nitrogen is translocated to the grain so that only nitrogen excreted by the nodules during the growing period or left in the soil after harvesting would be available to the sorghum, and this would explain why sorghum yields were not increased as a result of association with peanut or soybean. Distinct differences in the maturity periods of the component crops usually results in quite large yield advantages. This type of combination clearly allows for better use of resources over time (Willey and Osiru, 1972; Osiru and Willey, 1972). The results emphasize that there is a great deal yet to be learned about compatibility of different crops in intercropping and the kind of combinations, which may confer yield advantages (Rao and Willey, 1980). According to work by Mohta and De (1980), the yield of sorghum was higher in the sole cropping system and could be due to the keen competition from soybean for solar radiation. Sorghum has a slow growth rate initially, whereas soybean grows relatively fast and hence the closeness of soybean rows to the sorghum in various planting patterns reduced the growth and grain yield of sorghum.

Sorghum grain yields were statistically analyzed for all treatments in monocropping, intercropping, and monocropping and intercropping combined (Table 28). When monocropping and intercropping were combined in one overall statistical analysis, there were no significant differences among the three sorghum genotypes, although sorghum 3 showed the highest grain yield. The statistical analyses of the intercropping treatments alone showed sorghum 3 differing statistically from sorghum 1 and sorghum 2. No significant difference was observed between sorghum 1 and sorghum 2 in intercrop, regarding mean grain yields. The statistical analyses of the monocropping treatments showed sorghum 1 to be significantly higher in grain yield than sorghums 2 and 3, which were significantly different from each other in grain yield.

Table 28. Mean sorghum grain yields in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Sorghum Genotypes*	Mean Grain Yields (kg/ha)** All Treatments	Inter-cropping Only	Mono-cropping Only
Sorghum 1	7896 A	7383 B	9434 A
Sorghum 2	7602 A	7502 B	7901 B
Sorghum 3	8148 A	8405 A	7378 B

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

Figure 8 shows graphically the mean sorghum grain yields when in intercrop with the three soybean genotypes. All three sorghum genotypes showed different patterns of response to intercrop within and among genotypes. Sorghum 3 had the highest grain yields.

The Effects on the Agronomic Characteristics of Cereals from Intercropping with Legumes

Days to 50% Bloom. Each of the three soybean genotypes when intercropped with all three sorghum genotypes reached 50% bloom in almost the same number of days under intercropping as under monocropping (Table 17). The few differences of one or two days were small, indicating that maturity of the three soybean genotypes, as indicated by their days to 50% bloom, was generally affected very little by intercropping influences of the three sorghum genotypes.

Widths and Heights. Progressive measurements of soybean widths and heights were taken during five consecutive weeks and are presented in Tables 29 and 30. None of the soybean genotypes showed a tendency for any great increase or decrease in width between monocropping and intercropping.The variations were small for both increases and decreases in width changes from monocrop. It could be expected that a decrease in soybean width could occur due to sorghum competition, especially from an interplot shading effect, but it did not seem to occur.

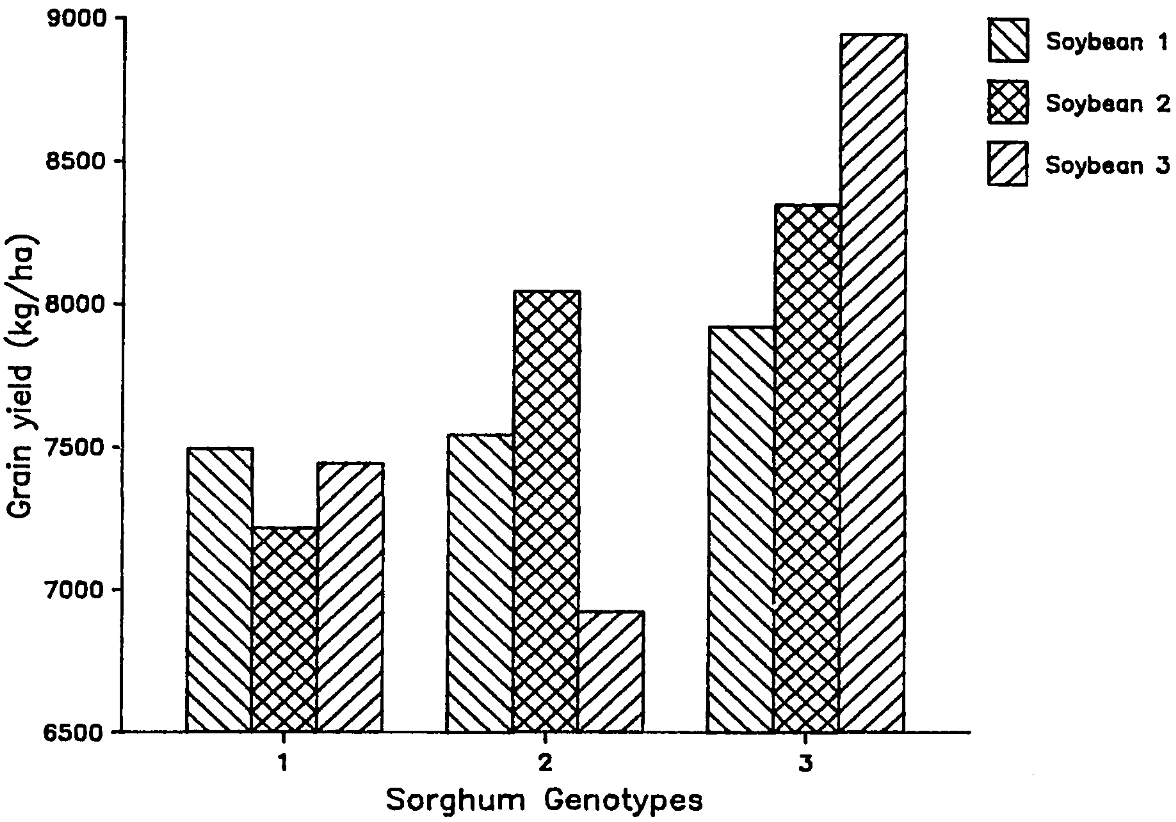

Figure 8. Sorghum grain yield (kg/ha) when intercropped with three soybean genotypes at the University of Arizona Marana Agricultural Center in 1986.

Table 29. Progressive weekly width measurements in soybean in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

	Width per plot row (cm)				
Soybean Genotype*	Jul 14	Jul 21	Jul 28	Aug 4	Aug 11
Soybean 1 - monocrop	64	82	93	105	112
Soybean 1 x Sorghum 1	59	77	89	100	115
Soybean 1 x Sorghum 2	65	78	85	97	107
Soybean 1 x Sorghum 3	58	75	85	97	111
Soybean 1 - monocrop	53	71	80	97	112
Soybean 2 x Sorghum 1	59	77	91	101	112
Soybean 2 x Sorghum 2	55	73	84	97	110
Soybean 2 x Sorghum 3	59	76	92	101	110
Soybean 3 - monocrop	54	75	89	103	114
Soybean 3 x Sorghum 1	61	77	95	102	114
Soybean 3 x Sorghum 2	59	76	92	101	110
Soybean 3 x Sorghum 3	56	73	88	99	108

* For identification of sorghum and soybean genotypes, refer to Table 7.

Table 30. Progressive weekly height measurements in soybean in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

	Width per plot row (cm)				
Soybean Genotype*	Jul 14	Jul 21	Jul 28	Aug 4	Aug 11
Soybean 1 - monocrop	67	82	93	89	102
Soybean 1 x Sorghum 1	68	76	91	101	102
Soybean 1 x Sorghum 2	73	82	87	100	101
Soybean 1 x Sorghum 3	76	89	103	108	111
Soybean 2 - monocrop	60	70	84	95	94
Soybean 2 x Sorghum 1	62	76	86	97	103
Soybean 2 x Sorghum 2	61	74	85	92	96
Soybean 2 x Sorghum 3	58	79	86	91	101
Soybean 3 - monocrop	59	77	89	97	102
Soybean 3 x Sorghum 1	62	81	81	100	103
Soybean 3 x Sorghum 2	64	79	90	99	101
Soybean 3 x Sorghum 3	59	77	86	94	100

* For identification of sorghum and soybean genotypes, refer to Table 7.

Soybean heights in intercrop had both increase and decrease variations from monocropping during the five periodical measurements. These responses of height of soybean in intercrop with sorghum were similar in variability to the width. Sorghum 3, being the tallest of the three sorghums, might be expected to have the greatest interplot competitive influence on the soybean growth habit. However, all three sorghums had small and offsetting influences on the intercrop heights of the soybeans, indicating the stability of soybean heights to changes from intercrop interplot competition influences.

Test Weights. As shown in Table 31, none of the three soybean genotypes showed the effect of intercropping with sorghum, regarding test weights. Higher test weight values were shown by soybean 2. This was also the only soybean genotype which showed any decrease in test weight values when in intercrop with sorghum, although the decreases were very small. Soybean 1 and soybean 3 showed small increases in test weight values when in intercrop with sorghum. Soybean test weight seems to be a relatively stable characteristic in intercrop with sorghum, with little interspecies or intraspecies variation. There is a slight indication of intraspecies variation for uniform response to sorghum intercrop for test weight.

Table 31. Soybean test weights and thousand-seed weights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Treatment*	Test weight (kg/m^3)	% diff. from monocrop	1,000-seed wt (g)	% diff. from monocrop
Soybean1-monocrop	716.0		168.9	
Soybean1/sorghum1	718.8	+0.4	180.6	+6.9
Soybean1/sorghum2	721.7	+0.8	183.4	+8.6
Soybean1/sorghum3	718.9	+0.4	178.8	+5.9
Soybean2-monocrop	728.3		175.2	
Soybean2/sorghum1	728.3	0.0	174.3	-0.5
Soybean2/sorghum2	724.5	-0.5	176.8	+0.9
Soybean2/sorghum3	721.1	-1.0	179.4	+2.4
Soybean3-monocrop	707.8		182.9	
Soybean3/sorghum1	708.3	+0.1	185.5	+1.4
Soybean3/sorghum2	714.3	+0.9	172.4	-5.7
Soybean3/sorghum3	709.2	+0.2	176.9	-3.3

* For identification of sorghum and soybean genotypes refer to Table 7.

Statistical analyses were run for soybean test weights, one including the intercropping and monocropping treatments, one including only the intercropping treatments, and another one including only the monocropping treatments, and are shown in Table 32. The statistical analysis of both intercropping and monocropping treatments combined showed all three soybean genotypes to be significantly different, regarding test weights. Soybean 2 (Asgrow 6520) had the highest test weight (725.6 kg/m^3) and soybean 3 (Rillito) had the lowest test weight (709.9 kg/m^3). The statistical analysis of only the intercropping treatments showed no significant difference between soybean 1 (Asgrow 6242) and soybean 2, but there was a statistically significant difference between these two genotypes and soybean 3. The statistical analysis of the monocropping treatments indicated no significant difference between soybean 1 and soybean 2, as well as between soybean 1 and soybean 3. There was a significant difference between soybean 2 and soybean 3.

Very small test weight differences by intercrop treatments from monocrop as indicated by percentages of mostly less than 1% (Table 31) indicates a strong intraspecific stability for test weight of soybean in intercrop with sorghum. The uniformity of test weights for each of the three soybeans in intercrop indicates an intraspecific variability for test weight differences.

Table 32. Mean soybean test weights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Sorghum Genotypes*	Mean Test Weights (kg/m^3)**		
	All Treatments	Inter-cropping Only	Mono-cropping Only
Soybean 1	718.8 B	719.8 A	716.0 AB
Soybean 2	725.6 A	724.6 A	728.3 A
Soybean 3	709.9 C	710.6 B	707.8 B

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

Figure 9 shows graphically the mean test weights of the three soybean genotypes in intercropping with sorghum. All three soybean genotypes showed the same pattern regarding test weights, when in intercrop with sorghum genotypes.

Seed Weights. There was some influence of sorghum on soybean seed weights when in intercropping (Table 31). Soybean 1 was the only soybean genotype which showed increase in seed weight when intercropped with sorghum (7.1% average). Soybean 2 and soybean 3 were somewhat variable in their responses with both increases and decreases in seed weights when intercropped with sorghum. Decreases in soybean seed weights might be expected from intercropping with sorghum, especially from the taller sorghum 3 genotype, which caused more shading, thereby decreasing the photosynthetic rates of the soybean genotypes, but there was not a uniform influence by sorghum 3.

Soybean thousand-seed weight data were statistically analyzed for all treatments in monocropping, intercropping, and monocropping and intercropping combined (Table 33). In all three analyses, there were no statistically significant differences among the three soybean genotypes, regarding seed weights.

Figure 10 shows graphically the mean seed weights of the three soybean genotypes, when intercropped with the three sorghum genotypes. Soybean 1 appeared to have a uniform

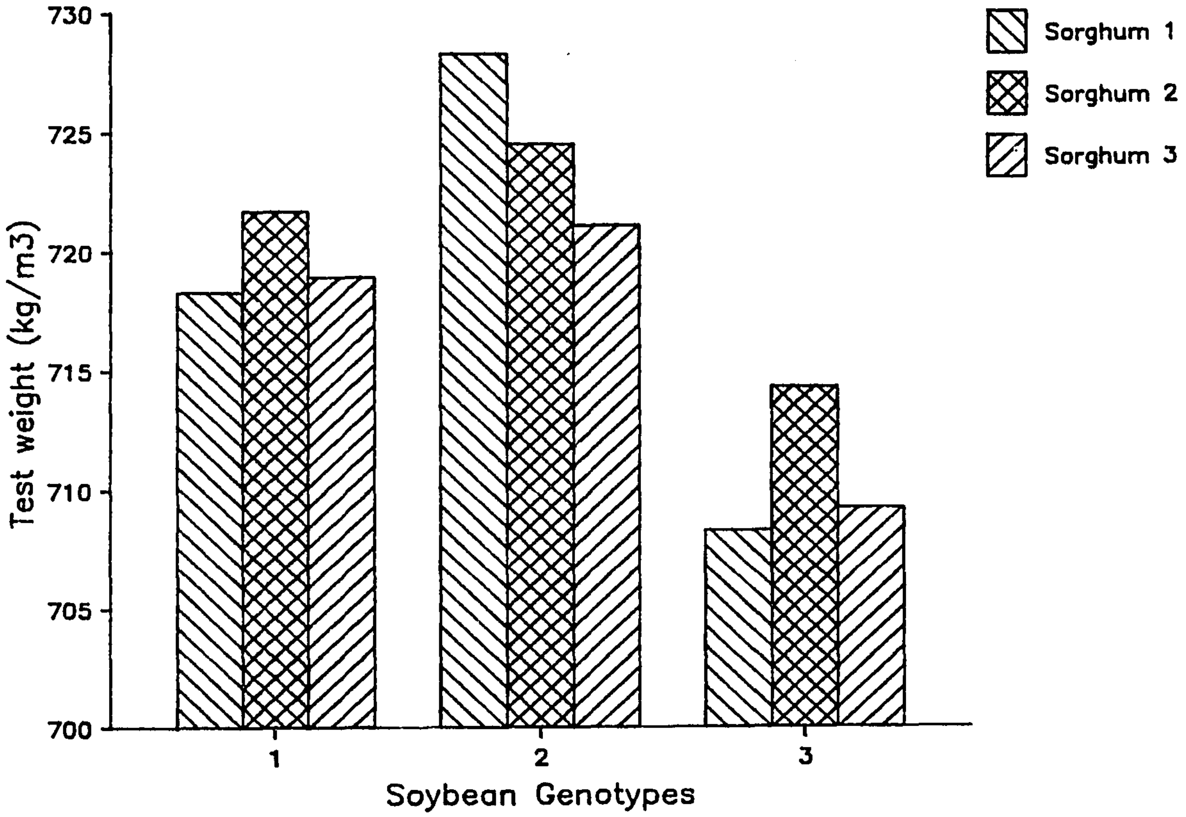

Figure 9. Soybean test weights (kg/m^3) when intercropped with three sorghum genotypes at the University of Arizona Marana Agricultural Center in 1986.

Table 33. Mean soybean thousand-seed weights in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

	Mean Thousand-seed Weight (g)**		
Sorghum Genotypes*	All Treatments	Inter-cropping Only	Mono-cropping Only
Soybean 1	177.9 A	180.9 A	168.9 A
Soybean 2	176.4 A	176.8 A	175.2 A
Soybean 3	179.4 A	178.3 A	182.9 A

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

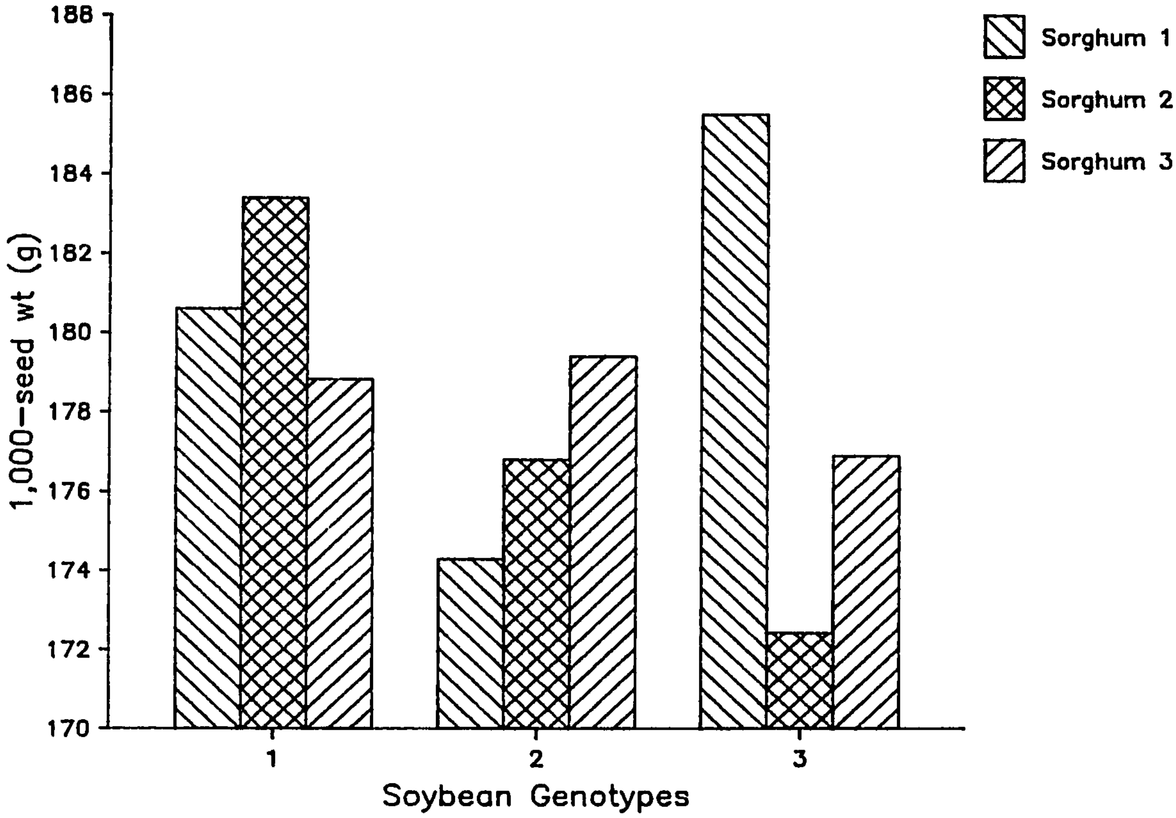

Figure 10. Soybean thousand-seed weights (g) when intercropped with three sorghum genotypes at the University of Arizona Marana Agricultural Center in 1986.

small increase in seed weight in intercrop with all three sorghums. Soybeans 2 and 3 had small, non-uniform responses to all three sorghums for seed weight. The seed weight characteristic in soybean appears to be a fairly stable character in intercrop with sorghum.

Grain Yields. There was a high percent decrease in grain yield of all three soybean genotypes from monocropping to intercropping with sorghum (Table 34). Greatest average decreases were observed when soybean genotypes were intercropped with sorghum 3. Soybean 1 had a 17.4% average decrease in grain yield when in intercrop; soybean 2 had a 27.1% average decrease in grain yield when in intercrop, and soybean 3 had a 29.4% average decrease in grain yield when in intercrop.

One reason that would explain why sorghum 3 caused the highest decrease in soybean grain yield is that this sorghum genotype was the tallest, which may have caused more shading on the soybean plants and, consequently, less light interception and less grain yield. Since there was no marked influence of sorghum intercrop on soybean heights, widths, and seed weights, one explanation for the drastic decreases in soybean grain yields would be a possible decrease in either pod number per plant or seed number per pod, parameters which were not investigated in this study. Lower

Table 34. Soybean grain yields in monocropping and in intercropping relative to equal areas of land at the University of Arizona Marana Agricultural Center in 1986.

Treatment*	Yield** (kg/ha)	% diff. from monocrop
Soybean 1-monocrop	4153	
Soybean 1/sorghum 1	3534	-14.9
Soybean 1/sorghum 2	3993	- 3.9
Soybean 1/sorghum 3	2762	-33.5
Soybean 2-monocrop	4436	
Soybean 2/sorghum 1	3102	-30.1
Soybean 2/sorghum 2	3672	-17.2
Soybean 2/sorghum 3	2927	-34.0
Soybean 3-monocrop	4041	
Soybean 3/sorghum 1	3248	-19.6
Soybean 3/sorghum 2	2592	-35.9
Soybean 3/sorghum 3	2720	-32.7

* For identification of sorghum and soybean genotypes refer to Table 7.

** Yields related to equal areas of land as in monocropping (1 ha).

proportional decreases in grain yield were shown by soybean 1.

Soybean grain yield data were statistically analyzed for all treatments in monocropping, intercropping, and monocropping and intercropping combined (Table 35). When monocropping and intercropping were combined, as well as when only intercropping treatments were taken into consideration, soybean 3 differed statistically from soybean 1 and soybean 2 and there was no statistically significant difference between soybeans 1 and 2. When only monocropping treatments were taken into consideration there was no statistically significant difference between soybeans 1 and 3 but a significant difference between these two genotypes and soybean 2.

Figure 11 shows graphically the mean soybean grain yields when in intercrop with the three sorghum genotypes.

Land Equivalent Ratios (LER)

Figure 12 shows graphically the LER values for both sorghum and soybean in all intercropping combinations. All three sorghum genotypes had LER values showing intercropping to be more advantageous than monocropping. However, soybean genotypes did not have the same behavior. On the average, soybeans 1 and 2 showed LER just a little above 0.5, whereas soybean 3 showed LER below 0.5.

Taking only LER values into consideration, treatment 9 was the best yielding intercrop treatment, followed by

Table 35. Mean soybean grain yields in monocropping and in intercropping at the University of Arizona Marana Agricultural Center in 1986.

Sorghum Genotypes*	Mean Grain Yields (kg/ha)** All Treatments	Inter-cropping Only	Mono-cropping Only
Soybean 1	3611 A	3430 A	4153 B
Soybean 2	3534 A	3234 A	4436 A
Soybean 3	3150 B	2853 B	4041 B

* For identification of sorghum genotypes refer to Table 7

** Means followed by the same letter do not differ statistically by both LSD and Newman-Keuls' tests at the 5% level of significance.

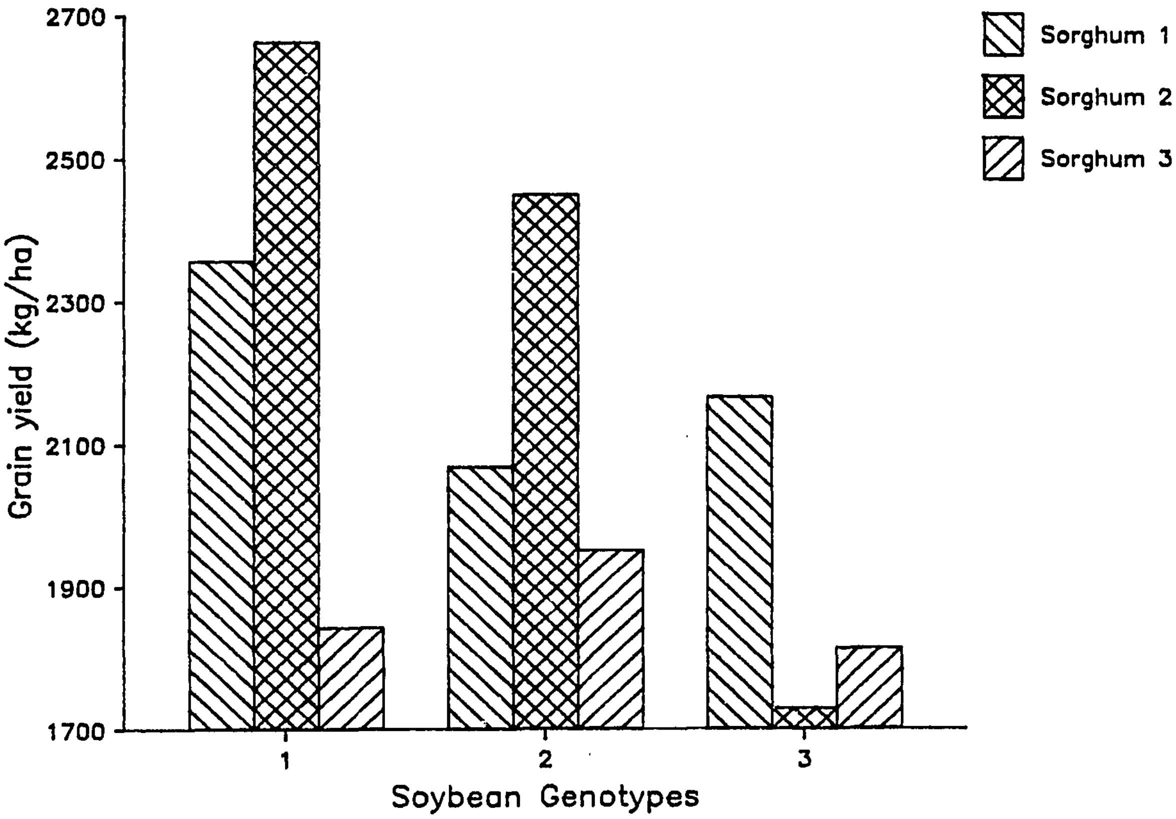

Figure 11. Soybean grain yields (kg/ha) when intercropped with three sorghum genotypes at the University of Arizona Marana Agricultural Center in 1986.

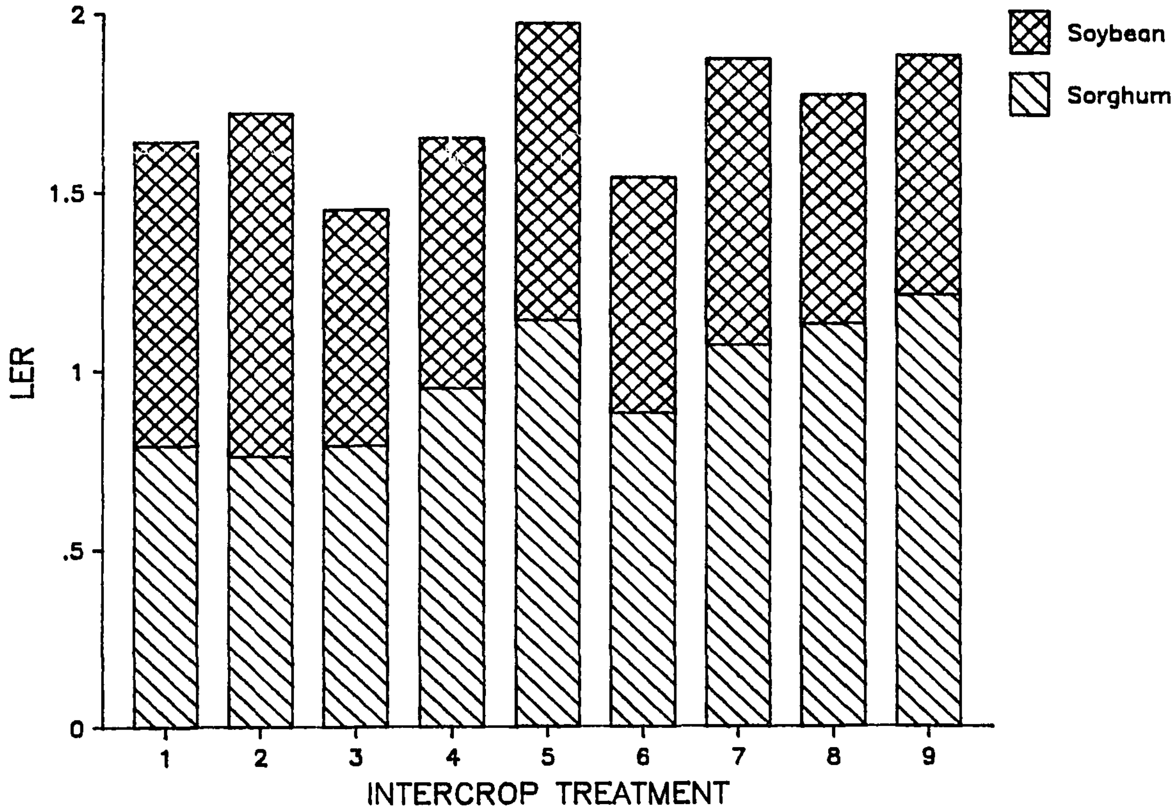

Figure 12. Land Equivalent Ratios (LER) for sorghum and soybean intercropping combinations at the University of Arizona Marana Agricultural Center in 1986. (For identification of intercrop treatments, refer to Table 8.)

treatment 4 and treatments 5 and 8. One of the problems of examining intercropping effects on the basis of single treatments of sole crops and intercrops is that comparisons may be biased if any treatment is not at optimum population and spacing. The most likely bias is that intercropping advantages are underestimated because little is yet known of the optimum population and spatial arrangement requirements for all species or genotypes in intercropping, though there can be an overestimate of intercropping advantages if either sole crop is not at its optimum (Willey, 1979b).

General Comments and Best Intercropping Treatment

Different results on intercropping are obtained by different scientists in all parts of the world. Although some of these results contradict the fact that intercropping is more advantageous than monocropping, most of them support it. Intercropping systems are as old as agriculture, and they will continue to be practiced by small farmers, especially in the semiarid tropics.

However, as mentioned in Chapter 2, several points should be considered when analyzing, interpreting or recommending intercropping.

The results indicate the viability of intercropping sorghum and soybean for higher production over space and time by better utilization of resources.

In deciding to select the best genotypes based on monocropping yields, sorghum 1 and soybean 2 would be selected. But in deciding to select the best genotypes based on intercropping yields, sorghum 3 and soybean 3 would be selected. This confirms the idea that genotypes adapted to intercropping should be selected under actual intercropping conditions.

CHAPTER 5

CONCLUSIONS

The following conclusions were drawn from the results obtained in the experiments carried out in the summers of 1985 and 1986 at the University of Arizona Marana Agricultural Center:

1. All three legumes (field bean, cowpea, and soybean) had higher yields when intercropped with pearl millet, showing that this cereal was not a good competitor against the legumes.
2. Sorghum was a better cereal competitor than maize or pearl millet for grain yield against the three legume species studied. This uniform but variable response of the cereal species indicates interspecies variability for intercropping responses with legumes.
3. Pearl millet was the cereal with the greatest decrease in grain yield when intercropped with the legumes indicating poor interspecific competition potential by pearl millet.
4. Cowpea was the least competitive legume against the cereals.

5. Sorghum x soybean was chosen as the most desirable intercrop combination for the second year study (1986).
6. All three soybean genotypes used in 1986 (see Table 5) showed high (17.4 to 29.4%) decrease in yield from monocrop to intercrop, regardless of the sorghum genotypes. These decreased yields were believed to be primarily from interplot competition shading effects of the taller sorghums in adjacent plots.
7. Asgrow A6520 soybean had the highest grain yield in monocrop and Asgrow A6242 soybean had the highest grain yield in intercrop with sorghum. This indicates intraspecific genetic variability of the soybean species for response to intercropping with sorghum.
8. Only one sorghum genotype (Pioneer 8493) showed higher yield in monocrop while the other two yielded higher in intercropping. This indicates intraspecific genetic variability for the sorghum species for response to intercropping with soybeans.
9. California 1080H40 sorghum showed the highest yields when intercropped with any of the three soybean genotypes.
10. All three sorghum genotypes showed, on the average, intercropping to be advantageous with LER > 0.5, whereas soybean LER's were < 0.5. This indicates a

strong interspecific intercrop competition advantage of sorghum over soybean. This advantage of sorghum is expressed through several sorghum characteristics such as height, head numbers, seed per head, and seed size.

11. Considering both yield and LER, sorghum 3 (California I080H40) x soybean 3 (Rillito) was the best intercrop treatment, followed by sorghum 2 (Funks G-522DR) x soybean 1 (Asgrow A6242).
12. The sorghum species had greater increases in intercrop compared to monocrop with legumes (field bean, cowpea and soybean) than maize or pearl millet for number of seed per head or ear and was equal to or better for increases in seed weight and head numbers. These advantages of the sorghum species make it a very desirable potential choice for intercropping if it is environmentally adapted to the location.
13. The soybean species exhibited genetic intraspecific stability, when in intercropping with sorghum, for the characteristics of days to 50% bloom, soybean row widths and heights and grain test weights.

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