INFLUENCE OF MAIZE (*Zea mays* L.) AND BEAN (*Phaseolus vulgaris* L.) ROW ARRANGEMENT, MAIZE INTRA-ROW SPACING AND BEAN SOWING DATE ON COMBINED YIELD WHEN INTERCROPPED

by

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INTRODUCTION

Recently, interest in intercropping studies as a potentially beneficial system of food production in the tropics has increased. It arises from the realization that monocropping, which involves high capital requirements for machinery and inputs, is too expensive for small scale subsistence farmers, who use diverse mixed crop production strategies and simple technology. As a result of low crop management levels in the production of cultivars with low yield potential, crop yields are generally low.

Subsistence farmers make up large proportions of the population in less developed countries of the tropics (World Almanac and Book of Facts, 1986). Furthermore, human populations in the tropics are increasing at such high rates that food deficits are becoming ever more threatening (Food and Agricultural Organiqation of the United Nations, 1984). Therefore, an urgent need exists for research to identify the best ways of exploiting the diverse crop species occurring in tropical environments. Improving the locally popular polycultures by modifying crop canopies, and subsequently the size and shape of land area available for growth to individual plants, are some of the practical possibilities to increase yields.

In this study, intercropping is defined as the production of more than one crop in separate rows on a unit of land area, either sown simultaneously or growing together during the major part of their growing periods. It fits the widespread polyculture food production strategy of resource-poor farmers in the tropics, especially where arable land and capital are limiting, but where labor is abundant and cheap (Dalrymple, 1971). It is likely to continue being important in the foreseeable future, because of the possibility that it can provide yield advantages compared to sole cropping (Dalrymple, 1971; Norman, 1974; Okigbo and Greenland, 1975). A major cause of yield advantages, and the only one for which there is much evidence to date, is better use of growth resources in intercropping (Kasanaga and Monsi, 1954; Osiru, 1974; International Rice Research Institute, 1975; Crookston and Kent, 1976; Lakhani, 1976).

One form of advantage provided by intercropping is higher yields in a given season. Fisher (1976b) reported a clear case of substantial yield advantage in a maize/bean (_Zea mays_ L.) trial at three locations in East Africa. Another alternative advantage is greater stability of yield over different seasons. This is particularly important to subsistence farmers with limited production resources. However, there is limited research evidence to document this form of advantage in practice. It is for this reason that, from evidence of other experiments in different seasons, Fisher (1977) questioned whether greater stability occured if moisture was limiting. Nonetheless, the basis for greater stability of yield over different seasons is that if one crop fails of grows poorly, the other component crop, or crops, can compensate.

In addition, there is the possibility of better control of weeds, other pests and diseases. Where a more competitive community of crop plants is provided by intercropping, either in space or time, better weed control is possible than in sole cropping (Litsinger and Moody, 1975; Rao and Shetty, 1977). Indeed, many instances of better pest and disease control have been reported (Aiyer, 1949; Batra, 1962; International Rice Research Institute, 1972, 1975; Nickel, 1973; Finlay, 1974; Pinchinat et al, 1975; Baker and Norman, 1975; Crookston and Kent, 1976; Raheja, 1977). Other possible causes of yield advantages in intercropping have also received some research attention. A more continuous leaf cover may give better protection against erosion (Dennison, 1956; Siddoway and Bonnett, 1975). One crop may provide physical support for another (Aiyer, 1949), and also one crop may provide shelter for another (Rathke and Hegstrom, 1975).

Nonetheless, more needs to be known about the response of crops in intercropping situations if optimum polycultures for the tropics can be fully developed and high crop yields sustained. Factors needing research attention are many and complex. They include compatibility of different component crops and crop genotypes under different plant populations and spatial arrangements, relative sowing dates, and requirements for light, moisture, nutrients, herbicides, pesticides etc. Whereas local preferences for specific intercrops vary with location and dietary needs, yield improvements can be made by replacing traditional cultivars with properly adapted and genetically higher yielding types. In each case optimum plant populations and spatial arrangements have to be carefully determined, so that excessive competition for light, moisture and soil nutrients, which would tend to reduce yields, does not occur. Where canopies of component crops differ, relay sowing may minimize competition for light. Plant population, spatial arrangement and relative sowing times are fundamental to all considerations of crop competition for growth resources. They deserve a detailed study.

The main objective of the study was to investigate the effects of the dominant crop (maize) and the dominated crop (bean) row arrangements, maize intra-row spacing and bean planting dates on combined grain yield in intercroppping. In addition to measuring main effects, a secondary objective was to measure effects of factor interactions between treatments. It was deliberately intended to compare the effects of these factors on combined grain yield, with equal precision, to enable ranking of their relative importance.

It was the experimenter's wish to estimate the magnitude of the responses and in what direction they indicated. Specifically, it was to determine if there exist any significant differences in crop responses to cropping systems, to crop row arrangements, to maize intra-row spacings and to bean planting dates. If so, are the responses positive or negative, and of what magnitude?

LITERATURE REVIEW

Abundant historical evidence consistently indicates the failure by a majority of subsistence farmers with critically limited resources, to make a complete shift from mixed cropping to sole cropping (Dalrymple, 1971; Norman, 1974; Francis et al., 1975; Guttierrez et al., 1975; Okigbo and Greenland, 1975; Jodha, 1976). However, attempts at co-ordinated, multidisciplinary studies to identify appropriate approaches required to increase crop yields in the subsistence mixed cropping sector are of more recent origin (Ogunfowora and Norman, 1973; Willey, 1979; Francis, 1986). Indeed, only in recent years has an increasing body of knowledge about beneficial aspects of intercropping (contributing to higher crop yields and compatible with soil fertility maintenance) started to be considered seriously.

Recently, attention has been given to the fact that all the optimum conditions responsible for higher yields in sole crops may not necessarily be identical with those required in intercrop situations. Harper (1963) emphasized that the behavior of mixed crop stands is not predictable from the behavior of pure stands. Genotypes which are eventually to be used in a given intercropping situation must, at some stage, be evaluated in that situation. Some important crop production factors thought to be responsible for and considerations pertinent to yield advantages in intercropping, are:

A. Genotype Identification .

Recognizing the differential ability of crops to tolerate other crops grown in association with them, Willey (1979) pointed out that identification of compatible crop genotypes should receive more emphasis in intercropping studies. In most cases, important crop mixtures to local subsistence farmers are closely tied to their dietary needs and/or cash revenues obtained from crop surpluses (Norman, 1972; Jodha, 1976).

Mwaipaya (1984) in maize/soybean (*Glycine max* L. Merrill) and maize/bean intercropping studies reported a 55% and 18% combined yield advantage, respectively, over monocropping. These results document the observation that some crops show better compatibility than others under specific environmental conditions.

B. Planting Patterns.

Various and inconsistent yield responses to planting patterns have been reported in the past. In maize/soybean combinations, Snider (1950) reported that alternating two rows of maize with soybean increased maize yields by 5-27% over monocropping. Illinois farmers (Farm Quarterly, 1951) reported a similar 15-20% maize yield increase in the same maize/soybean row arrangement. Alexander and Genter (1962) obtained 30% higher maize yield in paired alternate intercropped rows of maize/soybean over monoculture. Singh and Rathore (1978) reported highest yields with three alternate rows in maize/soybean. Later, Mohta and De (1980) suggested that single maize rows 120 cm apart (65,000 pl/ha) intercropped with two rows of soybean (400,000 pl/ha), or sorghum [Sorghum bicolor (L.) Moench] and soybean were very good combinations.

Dalal (1975) noted that maize grown alone produced the maximum grain yield/ha/week. When maize and pigeon peas [Cajanus cajan (L) Millsp] were grown in alternate rows they produced maximum protein/ha/week and absorbed the maximum amounts of potassium, calcium and magnesium.

Under strip intercropping, Pendleton and Seif (1962), Beecham (1983) and Reagan (1983) concurred in a 20% yield advantage for maize, when each maize row was bordered by soybean, over monocropping. However, the latter two workers associated this increase with a corresponding 20% decrease in soybean yield. Although the reports of Evans (1960) and Osiru and Kariba (1979) did not establish any significant response differences between spatial arrangements of plants, it would appear that the effect of component crop geometry will depend on the nature of crops and their relative competition for light, moisture, and plant nutrients.

C. Relative Sowing Times

The importance of relative sowing dates in intercropping can be related to the length of the growth cycles of intercrops. Sowing dates influence competition between component crop species for growth resources, at different stages of their growth, in two closely related ways. Ultimately, intercrop yields are affected.

First, sowing times of intercrops affect temporal differences between crops. These are differences between intercrops, in their requirements for growth resources, at different stages of their respective growth. Osiru and Willey (1976) reported that a 20% yield advantage occured in an 85-day bean intercropped with a 120-day maize, sown simultaneously; this advantage completely disappeared if sowing of the bean was delayed by 28 days. Where temporal differences are increased, there may be a potential for greater yield advantages. Of practical importance, however, is the observation that when temporal differences are increased by relay intercropping, the total growing period may be increased. Hasselbach and Ndegwa (1980) observed that up to a 43% reduction in bean yield could be attributed to intercropped maize over a wide range of intercropping trials. However, planting beans one month before maize resulted not only in the highest total yield returns per unit area, but also the highest bean yields in most cases. The lengthened growth period of this crop combination would tend to restrict its use to areas with a high well-distributed rainfall. Working in a similar tropical area, Mwaipaya (1984) demonstrated that two successive bean crops with 85-day maturity period could be relay intercropped with the same maize crop of 170-day maturity.

Second, an earlier sown crop becomes more competitive and the later planted one less competitive than when they are sown simultaneously. Francis et al. (1975) found that sowing bush beans two weeks before maize gave the best balance of competition and the highest yield advantage. Nnko and Doto (1980) reported that variations in cropping systems and planting schedules significantly affected soybean grain yield in maize/soybean and African finger millet (Eleusine coracana Gaerth.)/soybean intercropping studies; without a significant effect on grain weight per plant or seed size of both maize and millet. Lowest soybean yields were obtained when soybean was sown after cereal; more so after millet. Although cereal grain yields were increased, they were lower than the monocrop yields. Planting soybean one week earlier than cereal gave significantly higher soybean yields than when both crops were planted simultaneously. Although there was no significant effect of variations in both cropping system and planting schedule on soybean seed size, the interaction term (cropping systems x planting schedule) effect was highly significant for both seed size and yield of soybean. Mwaipaya (1984) reported significantly higher groundnut (Arachis hypogaea L.) grain yield, compared to simultaneous planting, when groundnut was planted two weeks earlier than maize in a maize/groundnut intercropping study. The two-week delay in planting maize did not significantly reduce maize yield.

Ojehomon (1970) indicated flowering in common beans begins at the basal buds on the terminal node, progresses acropetally through the triad (an arrangement of three flowering units) and then proceeds over the plant at random. Even if flower production is at random, spatially, plant growth and development is sequential. Therefore, pod retention (seed yield) should not be expected to be random. Distinct temporal patterns of flower production and pod retention should exist, although they may differ among cultivars. Ojehomon and Morgan (1969) observed that in both indeterminate and determinate cultivars, the greatest portion of main stem yield was from pods retained during the first 11 days of the reproductive period, particularly in the nodes 5 to 6 region.

D. Light, Moisture and Nutrient Use

By examining the actual growth pattern in intercropped combinations in some detail, it can be determined how component crops compete with each other, and whether they are able to complement each other in space or time.

Pendleton and peters (1967) indicated that light appeared to be the primary ecological factor limiting grain yield of corn (maize) when grown under low light conditions. Loomis et al. (1971), Trenbath (1974), and Gardiner and Craker (1981) reported increased light interception and decreased reflection in maize/bean intercropping because of the layered nature of the crops. As the maize population increased, the amount of light available to the bean crop was less, which led to reduced growht and yield of bean. There was a decrease in Leaf Area Index (LAI), pod number and seed development. Edje (1980) observed a 50% reduction in groundnut LAI when grown in association with maize. Sivakumar and Virmani (1980) noted, however, that a maize/ pigeonpea intercropping took advantage of the changing growth habit of pigeonpea as it makes very little use of Photosynthetic Active Radiation (PAR) during the first 80 days after planting, thus minimizing competition for sunlight at that early stage.

It is to the advantage of a farmer that maximum use be made of all the soil moisture available, since the growing season is usually too short for a double crop. Kutz et al. (1951) observed that lack of soil moisture during the dry season reduced yields of intercropped maize. It was later reported that dry matter production of intercropped maize was also reduced due to moisture stress (Allen and Obura, 1983). Willey (1979) and Natarajan and Willey (1980) concluded that intercropping gave relative advantages under conditions of moisture stress, but little or none under no stress conditions. In addition to the findings of these earlier workers, it is becoming clearer now that intercropping can reduce the negative effect of moisture stress on crop yields, and the magnitude of intercropping advantage will depend upon the stage of growth of intercrop species at which moisture stress, and its degree of severity, occur.

In some intercrop species, improved efficiency of light use can be important if yield advantage is to be realized.

It has been reported that improved efficiency of light use can occur in intercropped millet and groundnut, for example. Under conditions of soil moisture stress, improved efficiency of light use is of less importance. However, it may still be an important determinant of yield advantage under conditions of N-stress (Reddy and Willey, 1979).

Predominance of yield advantages occuring only in low fertility situations has been demonstrated by Ogunfowora and Norman (1973) and Jodha (1976). These workers also reported that intercropping was more frequent in areas where the level of technology was lower and indicated that as more farming inputs become available, farmers tend to move out of intercropping. Nonetheless, it is important to emphasize that farming practices may well reflect a desire for yield stability rather than possible yield advantages in any given season.

Although some experiments have supported these traditional beliefs by showing lower LER's at higher levels of nitrogen input for maize/soybean (International Rice Research Institute, 1975) recent work on sorghum/pigeonpea at ICRISAT achieved higher LER values. Similar effects have been reported by Oelsligle et al. (1975). However, Fisher (1977) reported maized/bean experiments, which showed advantages in a wet season, but not in a dry one. To date, there is abundant evidence to show that intercropping advantages do occur at a high fertility level (Kassam and Stockinger, 1972; Willey and Osiru, 1972; Osiru and Willey, 1972; Baker, 1974; Lakhani, 1976).

E. Fertilizer Economy

Since van den Bergh (1968) reported failure by subsistence farmers in semi-arid tropics to maintain soil fertility in traditional mixed cropping systems, intercropping nitrogen fixing crops with cereals has drawn serious consideration. A farmer can save the equivalent in fertilizer N-units of what biological N_2-fixation makes available in the soil. This is an important consideration for any farmer facing critical limitations of fertilizers, needed for higher crop yields. Such a cropping system does not only cut down N-fertilizer requirements, but also is more likely to be adopted by farmers. However, it should be noted that temperature extremes limit both nodulation and N_2-fixation in beans. Temperatures below 17°c reduce nodulation or inhibit nodulation altogether. It is for this reason that the need to select combinations of *Rhizobium phaseoli* (Sangeard) and *Phaseolus vulgaris* L. that form highly effective N_2-fixing symbiosis at higher tempratures than 17°c, was emphasized by Rennie and Kemp (1982).

In soybeans, most *B. japonicum* strains have, for N_2-fixation, an upper soil temperature limit of 33°c. *Bradyrhizobium japonicum* strain 587 isolated from soybean plants growing in Brasil showed the upper limit of 34°c for N_2-fixation. Munevar and Wollum (1981) related the response of different *Bradyrhizobium* strains in symbiosis with soybean plants to increasing temperature. These workers suggested that a pure culture screening of _B. japonicum_ may be a useful tool to aid in selection of strains better suited for soil environments where high temperature is a limiting factor for the symbiosis.

F. Yield Stability

The basis for the frequent statement that

> "a major reason for the predominance of intercropping in poorly developed agriculture is that it can give greater stability of yield over different seasons"

is that where one intercrop fails or grows poorly, the other component species can compensate. Such compensation is not possible if the crops are grown separately. It is an additional and quite separate effect from that of spreading risk by growing several crops. The latter is achieved whether the crops are intercropped or not.

Fisher (1976b) reported a clear case of substantial compensation in a maize/bean trial at three locations in East Africa. At one site, although maize suffered from hail damage and disease, greater bean growth produced a LER value of 1.87, whereas at the other two sites LER values were only 1.08 and 1.24. Although Harwood and Price (1975) have even questioned the whole concept of greater stability, surveys in the semi-arid areas of India by Jodha (1976) and in northern Nigeria by Norman (1972), established that incomes were less variable where intercropping was practiced. This evidence leaves little doubt about farmers' attitude to the possibilities of improving stability. There is a need for research to determine exactly how much stability intercropping actually provides in practice. Assuming it is of significance, it would seem desirable to ensure that any practice recommended to farmers should not provide less stability than what local traditional systems offer.

G. Experimental Designs

Since Willey and Osiru (1972) introduced the use of replacement series treatments at different populations to separate genuine intercropping effects from those due to changes in population pressure, a serious problem has been recognized. This approach fails to give a completely independent assessment of the population response to each component. It was thus suggested that this problem can at least be partly solved by keeping the population and the spatial arrangement of one crop fixed while varying the population of the other (International Rice Research Institute, 1972, 1973; Francis et al., 1975; Shelke, 1977; Freyman and Venkateswarlu, 1977).

It is evident that if many population and spatial arrangement effects are to be examined using traditional methods, the experiments required are very large. Nelder (1962) and Bleasdale (1967) tried to overcome this problem by using systematic arrangements based on designs suggested for sole crops. A more comprehensive design was being tried in which, at a given row arrangement (or a series of row arrangements) the population of each crop was varied independently simply by changing within-row spacing [International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), 1977].

In a review article, Willey (1979) emphasized the importance of proper controls (i.e. sole crop treatments) and designs for intercropping experiments, as follows:

> "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. Without jeopardizing the aims of the experiment controls should be kept to a minimum so that the maximum possible proportion of the experiment is allocated to intercrop treatments. The best guide is that designs should reflect the need to examine objectives efficiently rather than the need to conform to conventional designs which may be easier to lay out and analyse. One of the main problems is that although the intercropping treatments themselves often form a balanced factorial arrangement, The control treatments are usually additional."

MATERIALS AND METHODS

This experiment was planted during both the 1985 and 1986 growing seasons. However, crow birds (*Corvus branchyrhynchos*) caused so much damage to emerging maize seedlings in 1986 that no experimental data was collected. For this reason, only data for 1985 is reported.

Site Description

The study was conducted at the Horticultural Research Center, Southern Illinois University at Carbondale, on an Alford silt loam (fine silty, mixed, mesic, Typic Hapludalf). It is a moderately to well-drained soil of pH 6.7 in the top 15 cm and pH 6.5 in the lower 15-30 cm.

The soil has a moderate clay content, with moderate amounts of cations, particularly calcium and magnesium, giving it good aggregate stability. However, due to appreciable amounts of silt content the soil is readily compacted under heavy loads, especially when wet. The surface soil shrinks and cracks in the dry seasons and swells, becoming plastic in wet seasons.

A 2430 M^2 area (90 x 27 m) of uniform topography (1 to 3% slope) was selected as the experimental site. The choice was made because the original site at the Agronomy Research Center was still too wet for preparation by the first week of May. The area was previously cropped with maize (1984) after clearing a peach orchard.

Factors

A. Crop row arrangements.

1. 1 maize row bordered by 2 bean rows (1M:2B).
2. 2 maize rows bordered by 3 bean rows (2M:3B).

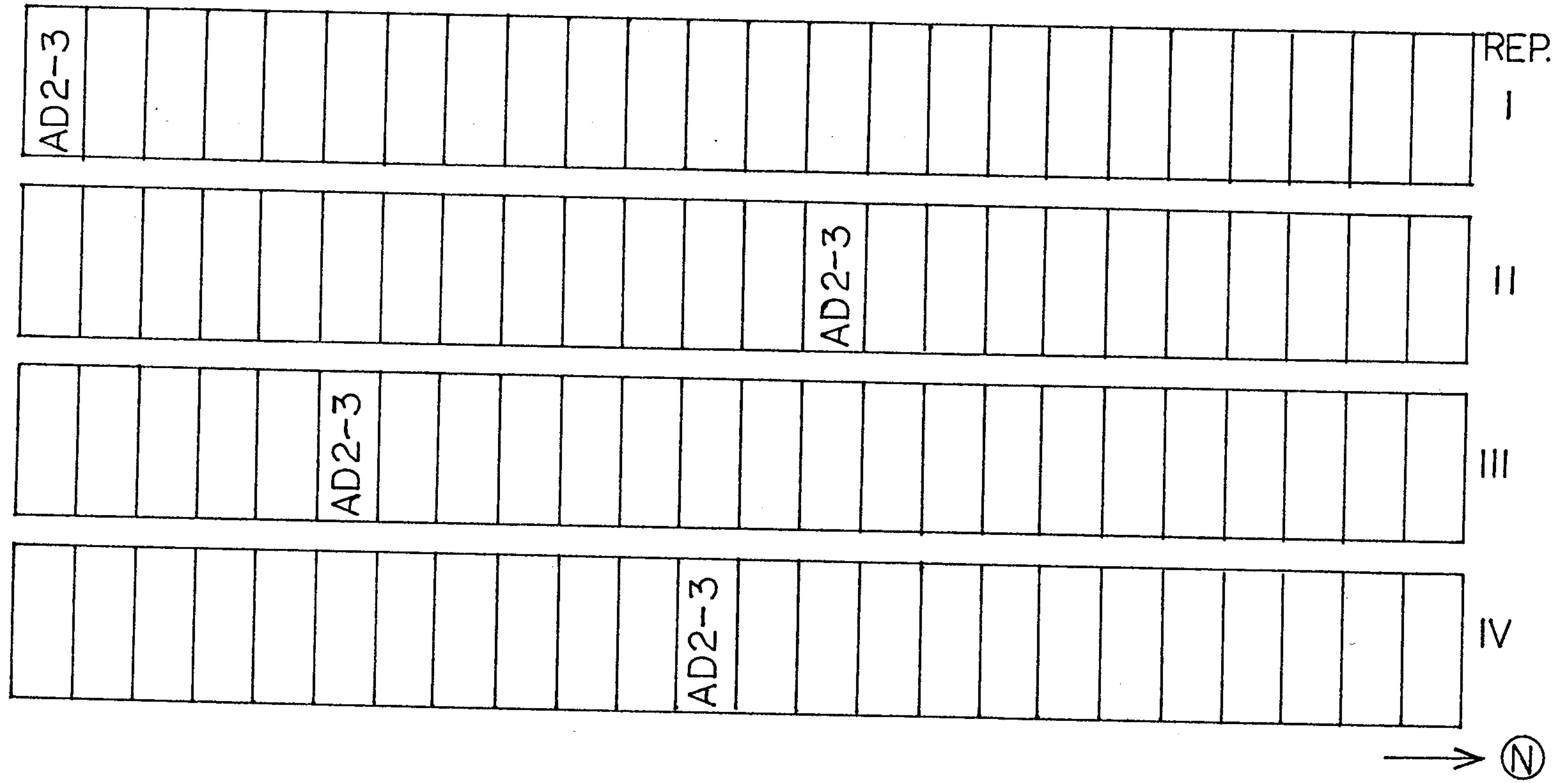
B. Maize within row (intra-row) spacing.

1. 50 cm between plants, 1 plant per hill (50 x 1).
2. 30 cm between plants, 1 plant per hill (30 x 1).
3. 50 cm between plants, 2 plants per hill (50 x 2).

C. Bean planting dates.

1. May 15th, 1985 (two weeks before maize, i.e. B2<M).
2. May 23rd, 1985 (one week before maize, i.e. B1<M).
3. May 31st, 1985 (simultaneous with maize, i.e. BPS).

In total there were 18 factor combinations (intercropping treatments). However, because of the need to have a monoculture treatment for each of the maize and bean factors, six monoculture treatments (three each for maize intra-row spacing and bean planting date) were also included. These additional monoculture treatments enabled calculation of LER values, so as to evaluate intercropping treatments objectively. In order to keep the total number of treatments withing practically manageable limits, it was dicided to plant all the three maize monoculture treatments simultaneously with bean only. Therefore, a total of 24 treatments were involved in this study (see plot plan, Fig.1).



Note: The 24 treatments were randomized in each replicate independently as shown. See page 30 for treatment code.

Figure 1. Field Plot Layout.

Experimental Design

The 24 treatments were tested in a Randomized Complete Block Design, replicated four times.

Field Operations

On May 6, 1985, 157.5 Kg/ha potassium phosphate (0-10-30) was broadcast evenly over the entire experimental area and later ploughed under. On May 10, 1985, 4.67 liters/ha of 45.1% Lasso herbicide (0.23 Kg/liter ai) was sprayed preplant, mainly against grasses. Experimental treatments were then randomly assigned their relative positions using a table of random numbers. Accordingly, treatment plots were laid out and pegged on the experimental area.

Maize and beans were sown according to treatments. In addition to chosen treatments, two monoculture plots for each of the three maize intra-row spacings were also sown during the first and second bean planting dates as observation plots. All other maize plantings were done simultaneously with the third and last bean planting date. Both bean and maize were oversown to allow for thinning, after emergence and establishment, in order to obtain the intended crop densities of each species according to treatment. At three weeks after emergence, establishment and thinning in maize, ammonium nitrate (33.5-0-0) was sidedressed to maize at the rate of 200 Kg/ha. Liquid sevin (80%) was sprayed to bean plants against bean beetles (Epilachna varivestis Mulsant) from flowering to pod setting. Subsequent weeding in all plots was carried out using a hoe, to achieve weed-free conditions as much as practically possible.

Although planting of all the experimental treatments was finished on May 31, 1985. thinning of the first bean planting was done on June2, 1985 when all bean plants had emerged and were establishing. Two subsequent thinnings (in the second bean planting and the simultaneous plantings of beans with maize) were one week apart, starting one week after the first thinning of beans. Bean stand was very satisfactory. Maize thinning for all treatment plots was done one day after the third bean thinning (i.e. 15 days after emergence). In maize also, plant stand was very statisfactory.

Records taken prior to harvest in the sampling area, included number of plants in both crops, ear height, number of ears in maize, plant height, total number of pods, and number of mature pods in beans. After harvest, cob weight in maize and grain weight in both crops were determined.

Sampling Technique for Height Measurements

Maize ear height was measured as the distance from ground level to the stalk node bearing the first ear. Bean plant height was the distance from ground to end of growing point. In both crops, mean values were based on randomly selected 8 plants in each plot.

Yield Preparation And Determination

Harvesting in both crops was carried out separately on a treatment plot basis. Beans were harvested first, after plant maturity, but before the pods started shattering. For the maize crop, physiological maturity was indicated by appearance of a black layer in the grain. The harvested grain for each crop, was allowed to air-dry. Maize was shelled using a powered sheller while beans were shelled by hand. Moisture content of shelled grains in both crops was determined by a digital moisture meter with each grain lot being carefully sealed in plastic bags and weighed immediately. Only good, clean marketable grains were included in each lot.

Evaluation

No intercropping situation can be fully evaluated without combining the crops in some way. Willey (1979) considered that when component populations are directly related to proportional sown areas, it is valid to analyze yield per plant (or yield per row), with the direct merit of competitive effects. Some common denominator such as yield of protein, dry matter, digestible nutrients or monetary market value have been used by various researchers in the past. However, because of differences in the competitive abilities of component crops between monoculture and intercropping, the combined mixture yield in such a comparison contains a larger proportion of the dominant species than does the combined pure stand yield. Thus, if the dominant species is higher yielding, such a comparison is biased in favor of intercropping. Conversely, if the dominant species is the lower yielding, the comparison is biased in favor of sole crops.

Willey and Osiru (1972) avoided this possible bias by calculating the proportions of sole cropping which would give the same final yield proportions as in intercropping. This was the basis for what is now known as Land Equivalent Ratio (LER), which is defined as the relative land area under sole crops that is required to produce the yields achieved in intercropping. LER has the great merit that it gives an accurate assessment of the greater biological efficiency of the intercropping situation.

LER was used in this study to evaluate combined grain yield response to treatment factors and their combinations. When maize intercrop LER values were calculated, respective treatment grain yields were divided by the monoculture maize yield from the intra-row spacing of 50 cm between single plants (50 cm x 1). This monoculture treatment was chosen as the denominator, because the experimenter considered that intra-specific competition for growth resources within maize rows was balanced by that between rows. Bean intercrop LER values were calculated in a similar way with component bean treatment grain yields being divided by the monoculture bean yield from the treatment planted simultaneously with maize. In this way, an unbiased evaluation of crop responses to all treatments and their interactions was possible.

Statistical Analyses

Treatment data for ear height, number of ears per plant, shelling percentage and grain yield per plant in maize; as well as number of pods per plant and grain yield per plant in beans was separately subjected to analyses of variance. Plot grain weight for maize was corrected to 13.5% moisture content and to 12% moisture for beans. Calculated absolute grain yields per hectare and LER values, for each crop in each treatment, were also analyzed. Further, in those analyses of variance where treatment responses showed significant differences, single degree of freedom orthogonal comparisons were made. These detailed comparisons were made in order to derive quantitative answers to specific important questions formulated at the planning stage of the experiment, relating to specific crop responses to the chosen treatments and their interactions.

All statistical analyses were conducted using the MSTAT statistical software program (version 3.0) developed by Michigan State University in 1985, on an apple IIe microcomputer.

RESULTS AND DISCUSSION

Precipitation

Precipitation during the 1985 growing season (April-September) at Carbondale, Illinois, was greater than long term (1914-1984) means. In spite of this, precipitation distribution at the site during the growing period was not ideal for plant growth. Low precipitation during the later part of June through July resulted in plant stress. This long dry and hot period coincided with the early reproductive stage of the bean intercrop (Fig. 2).

Intercrop Plant Density Effects

It is recognized that plant population is directly related to planting pattern (Trenbath, 1975). Various plant densities can be achieved by changing both inter-row and intra-row spacing in monoculture as well as in polyculture. Also with each inter-row and/or intra-row spacing in polyculture (as in intercropping), a wide range of component crop density combinations can be achieved by replacing given proportions of one crop species with equivalent proportions of another species. Therefore, choice of planting pattern, will not only be influenced by convenience for sowing, pest control and harvesting but also that the yields of components (including weeds) may depend on planting pattern (Harper, 1961; International Rice Research Institute, 1975).

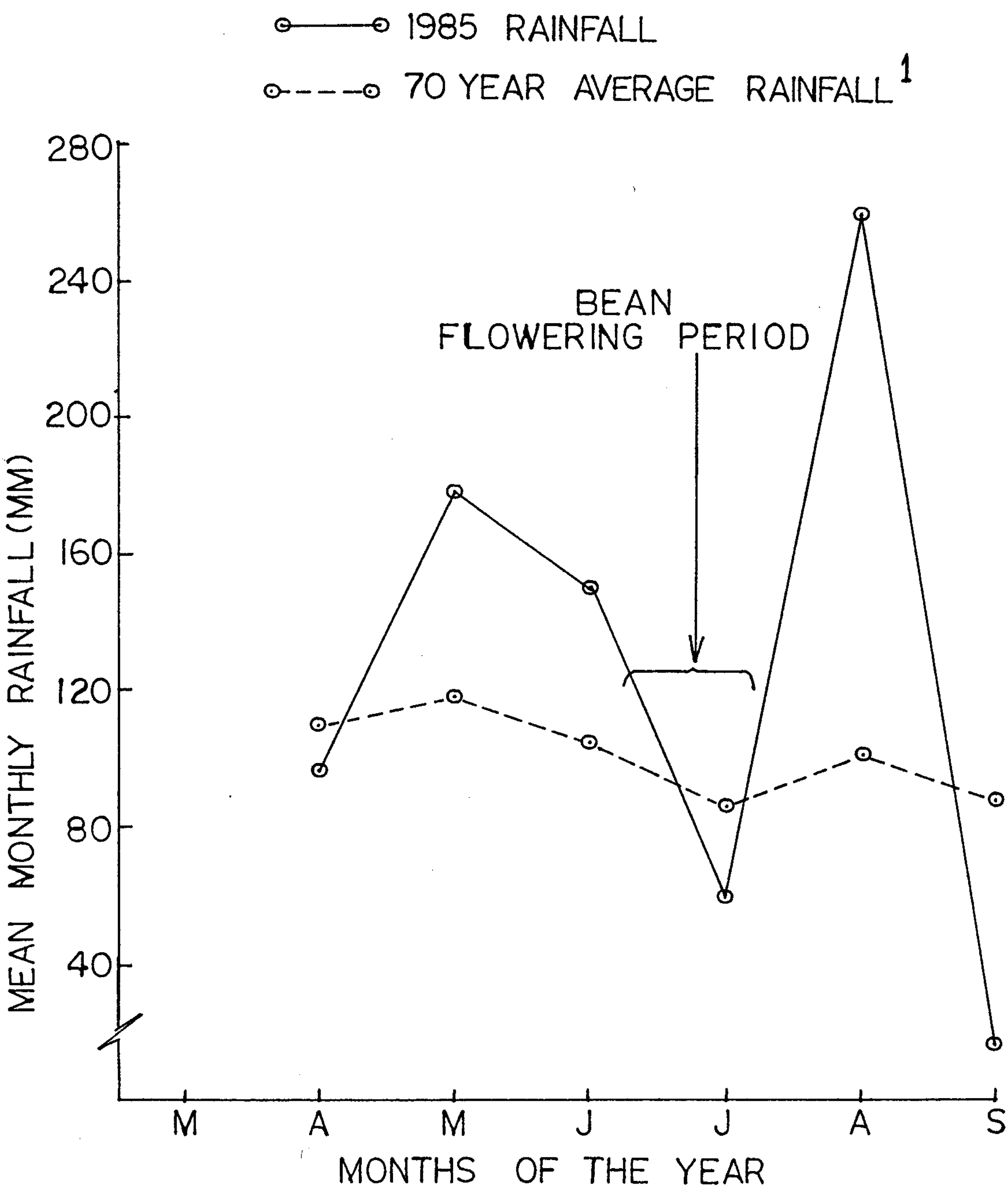


Figure 2. Rainfall at the Horticultural Research Center, Carbondale, Illinois

[1]1914-1984 Spring-Summer average rainfall at Horticultural Research Center, Carbondale, IL
Source: School of Agriculture, SIU.-Carcondale, Illinois.

In this study, significantly different intercrop densities were achieved by varying intra-row spacing in maize and crop row arrangement (replacement series) in intercropping with beans (Table 1). Inter-row spacing was kept constant in both intercrops. It was important to recognize these changes in component crop desities so that the portion of yield advantage or disadvantage due to plant density could be separated from that resulting from other treatment effects.

1. MAIZE

1.A Ear Height

There were significant differences in maize ear height between treatments at the 1% probability level (Table 2). Maize ear height responses to the respective factors and/or factor interactions (Fig. 3) were due to, in large part, changes in interspecific and intraspecific competitive pressures resulting from total plant densities of intercrops. Lower total plant densities were associated with decrease in maize ear height while higher plant densities led to increased maize ear height.

Independent (orthogonal) comparisons indicated that a significant net decrease of 1.28 cm in maize ear height was due to intercropping as compared to planting in monoculture ($P<0.01$). Within intercropping, a similar but less significant decrease in ear height resulted from the interaction B2<M x 2m:3B x (50 x 2) as compared to the interaction B1<M x 1M:2B x (30 x 1) at the 5% probability level.

Table 1. Maize and Beans Plant Densities at Harvest (Carbondale, Illinois, 1985)

Treatment Code[1]	Cropping System	MAIZE Intra-row Spacing (cm x pl/hill)	MAIZE (000 pl/ha)	BEAN (Planting Date)	BEAN (000 pl/ha)
A*	Monoculture	50 x 1	40.00c	-	-
B*	"	30 x 1	66.25b	-	-
C*	"	50 x 2	80.00a	-	-
D	"	-	-	BPS	200.001
E	"	-	-	B1<M	200.001
F	"	-	-	B2<M	200.001
AD1-2	Intercropping	50 x 1	13.33g	BPS	133.33m
AE1-2	"	50 x 1	13.33g	B1<M	133.33m
AF1-2	"	50 x 1	13.33g	B2<M	133.33m
BD1-2	"	30 x 1	21.67f	BPS	133.33m
BE1-2	"	30 x 1	21.67f	B1<M	133.33m
BF1-2	"	30 x 1	21.67f	B2<M	133.33m

Table 1. Continued

Treatment Code[1]	Cropping System	MAIZE Intra-row Spacing (cm x pl/hill)	MAIZE (000 pl/ha)	BEAN (Planting Date)	BEAN (000 pl/ha)
CD1-2	Intercropping	50 x 2	26.67e	BPS	133.33m
CE1-2	"	50 x 2	26.67e	B1<M	133.33m
CF1-2	"	50 x 2	26.67e	B2<M	133.33m
AD2-3	"	50 x 1	16.00g	BPS	120.00mn
AE2-3	"	50 x 1	16.00g	B1<M	120.00mn
AF2-3	"	50 x 1	16.00g	B2<M	120.00mn
BD2-3	"	30 x 1	26.00e	BPS	120.00mn
BE2-3	"	30 x 1	26.00e	B1<M	120.00mn
BF2-3	"	30 x 1	26.00e	B2<M	120.00mn
CD2-3	"	50 x 2	32.00d	BPS	120.00mn
CE2-3	"	50 x 2	32.00d	B1<M	120.00mn
CF2-3	"	50 x 2	32.00d	B2<M	120.00mn

Table 1. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

* Monoculture maize was planted during the third planting date of beans.

[1] A total of 24 treatment combinations were evaluated in this study.

A = Maize, intra-row spacing 50 cm with 1 plant/hill (50 x 1).

B = Maize, intra-row spacing 30 cm with 1 plant/hill (30 x 1).

C = Maize, intra-row spacing 50 cm with 2 plant/hill (50 x 2).

D = Beans planted simultaneously with maize (BPS).

E = Beans planted one week before maize (B1<M).

F = Beans planted two weeks before maize (B2<M).

1-2 = Replacement series in which one row of maize alternates with two rows of beans (1M:2B).

2-3 = Replacement series in which two rows of maize alternate with three rows of beans (2M:3B).

Table 2. Maize Ear Height Response to Intercrop plant densities (Carbondale, Illinois, 1985)

Treatment Code[1]	Cropping System	PLANT DENSITY Maize (000 pl/ha)	Beans (000 pl/ha)	Maize Ear Height (cm)
A*	Monoculture	40.00c	-	64.45wx
B*	"	66.25b	-	66.88vw
C*	"	80.00a	-	73.58v
D	"	-	200.001	-
E	"	-	200.001	-
F	"	-	200.001	-
AD1-2	Intercropping	13.33g	133.33m	58.20wxyz
AE1-2	"	13.33g	133.33m	56.38xyz
AF1-2	"	13.33g	133.33m	60.95wxyz
BD1-2	"	21.67f	133.33m	62.58wxy
BE1-2	"	21.67f	133.33m	63.28wxy
BF1-2	"	21.67f	133.33m	54.10yz

Table 2. Continued

Treatment Code[1]	Cropping System	PLANT DENSITY Maize (000 pl/ha)	Beans (000 pl/ha)	Maize Ear Height (cm)
CD1-2	Intercropping	26.67e	133.33m	62.58wxy
CE1-2	"	26.67e	133.33m	52.15z
CF1-2	"	26.67e	133.33m	59.48wxyz
AD2-3	"	16.00g	120.00mn	58.03wxyz
AE2-3	"	16.00g	120.00mn	57.60xyz
AF2-3	"	16.00g	120.00mn	55.85xyz
BD2-3	"	26.00e	120.00mn	60.93wxyz
BE2-3	"	26.00e	120.00mn	60.60wxyz
BF2-3	"	26.00e	120.00mn	61.90wxy

Table 2. Continued

Treatment Code[1]	Cropping System	PLANT DENSITY Maize (000 pl/ha)	Beans (000 pl/ha)	Maize Ear Height (cm)
CD2-3	Intercropping	32.00d	120.00mn	62.88wxy
CE2-3	"	32.00d	120.00mn	60.90wxyz
CF2-3	"	32.00d	120.00mn	59.80wxyz
CF	-	7.24%	10.56%	8.89%

Table 2. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

* Monoculture maize was planted during the third planting date of beans.

[1] A total of 24 treatment combinations were evaluated in this study.

A = Maize, intra-row spacing 50 cm with 1 pl/hill (50 x 1).

B = Maize, intra-row spacing 30 cm with 1 pl/hill (30 x 1).

C = Maize, intra-row spacing 50 cm with 2 pl/hill (50 x 2).

D = Beans planted simultaneously with maize (BPS).

E = Beans planted one week before maize ($B1<M$).

F = Beans planted two weeks before maize ($B2<M$).

1-2 = Replacement series in which one row of maize alternates with two rows of beans (1M:2B)

2-3 = Replacement series in which two rows of maize alternate with three rows of beans (2M:3B).

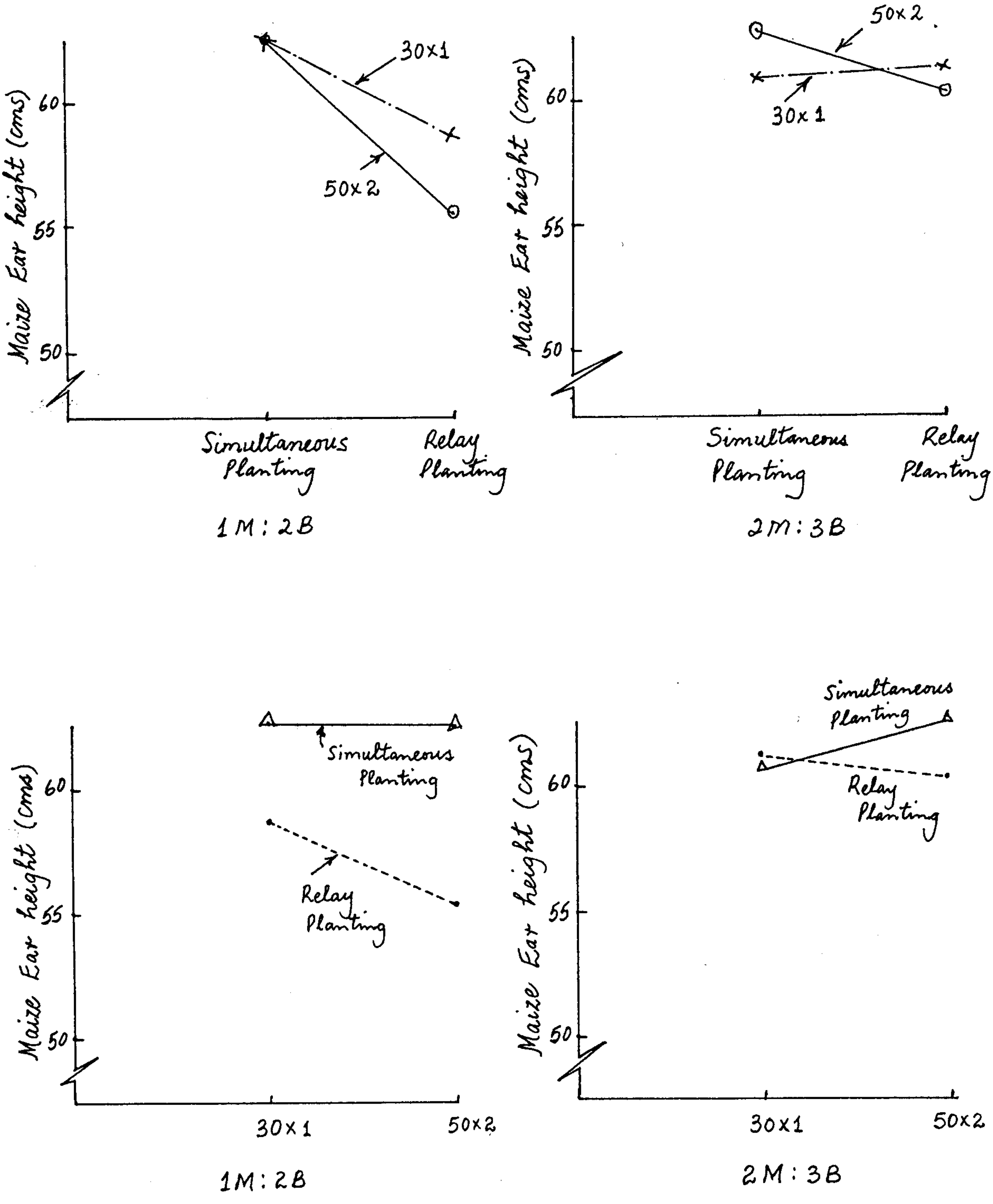


Figure 3. Types of three-factor Interactions in Maize Ear Height Response to Combinations of Maize and Bean Plant Densities

By contrast, a significant increase in maize ear height was due to the interaction: Relay Planting Maize x 2M:3B x (50 x 2) as compared to BPS x 1M:2B x (30 x 1) at the 1% probability level. Increasing maize plant density (i.e.using 30 x 1 and 50 x 2 compared to the 50 x 1 intra-row spacing) resulted in a significant 0.92 cm increase in maize ear height ($P<0.05$). The practical significance of these ear height responses will depend on possible correlations with maize grain yield components (see grain yield/ear, Appendix).

1.B Ears/Plant

Significant differences in ears/pl were observed between treatments (Table 3). Intercropping maize with beans had a significant main net effect of increasing the number of ears/pl ($P<0.05$). This response was mainly due to the reduced maize intercrop plant density which most probably led to reduced intraspecific competition for growth resources. Within intercropping, there was a significant reduction in ears/pl due to increasing maize plant density ($P<0.01$). Another significant decrease in ears/pl was due to relay planting of maize in beans as compared to simultaneous planting ($P<0.05$). However, the interaction effect of Relay Planting Maize x 2M:3B as compared to BPS x 1M:2B resulted in a significant increase in ears/pl ($P<0.05$). Similarly, the interaction effect of Relay Planting Maize x 2M:3B x (50 x 2) as compared to BPS x 1M:2B x (30 x 1) was significantly positive ($P<0.05$).

Table 3. Maize Ears/Plant Response to Intercrop Plant Densities (Carbondale, Illinois, 1985)

Treatment Code[1]	Cropping System	PLANT DENSITY Maize (000 pl/ha)	Bean (000 pl/ha)	Maize (Ears/Pl)
A*	Monoculture	40.00c	-	1.07yz
B*	"	66.25b	-	1.01z
C*	"	80.00a	-	0.99z
D	"	-	200.001	-
E	"	-	200.001	-
F	"	-	200.001	-
AD1-2	Intercropping	13.33g	133.33m	1.51w
AE1-2	"	13.33g	133.33m	1.22xyz
AF1-2	"	13.33g	133.33m	1.22xyz
BD1-2	"	21.67f	133.33m	1.00z
BE1-2	"	21.67F	133.33m	1.12xyz
BF1-2	"	21.67f	133.33m	1.07yz

Table 3. Continued

Treatment Code[1]	Cropping System	PLANT DENSITY Maize (000 pl/ha)	Bean (000 pl/ha)	Maize (Ears/Pl)
CD1-2	"	26.67e	133.33m	1.30wxy
CE1-2	"	26.67e	133.33m	1.00z
CF1-2	"	26.67e	133.33m	1.02z
AD2-3	"	16.00g	120.00mn	1.23xyz
AE2-3	"	16.00g	120.00mn	1.25xyz
AF2-3	"	16.00g	120.00mn	1.35wx
BD2-3	"	26.00e	120.00mn	1.03z
BE2-3	"	26.00e	120.00mn	1.00z
BF2-3	"	26.00e	120.00mn	0.99z
CD2-3	"	32.00d	120.00mn	1.03z
CE2-3	"	32.00d	120.00mn	1.00z
CF2-3	"	32.00d	120.00mn	1.01z
CV		7.24%	10.56%	14.04%

Table 3. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[*] Monoculture maize was planted during the third planting date of beans.

[1] A total of 24 treatment combinations were evaluated in this study.

A = Maize, intra-row spacing 50 cm with 1 pl/hill (50 x 1).

B = Maize, intra-row spacing 30 cm with 1 pl/hill (30 x 1).

C = Maize, intra-row spacing 50 cm with 2 pl/hill (50 x 2).

D = Beans planted simultaneously with maize (BPS).

E = Beans planted one week before maize (B1$<$M).

F = Beans planted two weeks before maize (B2$<$M).

1-2 = Replacement series in which one row of maize alternates with two rows of beans (1M:2B).

2-3 = Replacement series in which two rows of maize alternate with three rows of beans (2M:3B).

Fig. 4a and 4b illustrate the different factor interactions on maize ears/pl.

1.C Maize Shelling Percentage

No significant differences in shelling percentage were detected between treatments in this study.

1.D Maize Grain Yield

There were significant differences in maize grain yield between treatments (Table 4). Maize grain yield response to plant density was observed to be consistent in both monoculture and intercropping (Table 5). In monoculture, as maize plant density increased from 40,000 pl/ha to 80,000 pl/ha, grain production/pl progressively decreased. This was due to the anticipated increased intraspecific competition for growth resources (especially soil moisture and nutrients) by maize plants. Maize grain yield/ha increased to a maximum at the plant density of 66,250 pl/ha, thereafter assumed a diminishing characteristic.

Overall, shifting from monoculture to intercropping led to a significant 5g/pl maize grain yield increase ($P<0.01$). Planting maize using the 50 x 2 instead of the 30 x 1 intra-row spacing resulted in a significant 10g/pl (257 Kg/ha) decrease in maize grain yield ($P<0.01$).

In intercropping also, as the maize intercrop plant density increased from 13,333 pl/ha to 32,000 pl/ha, grain production/pl progressively declined. Adopting the 2M:3B,

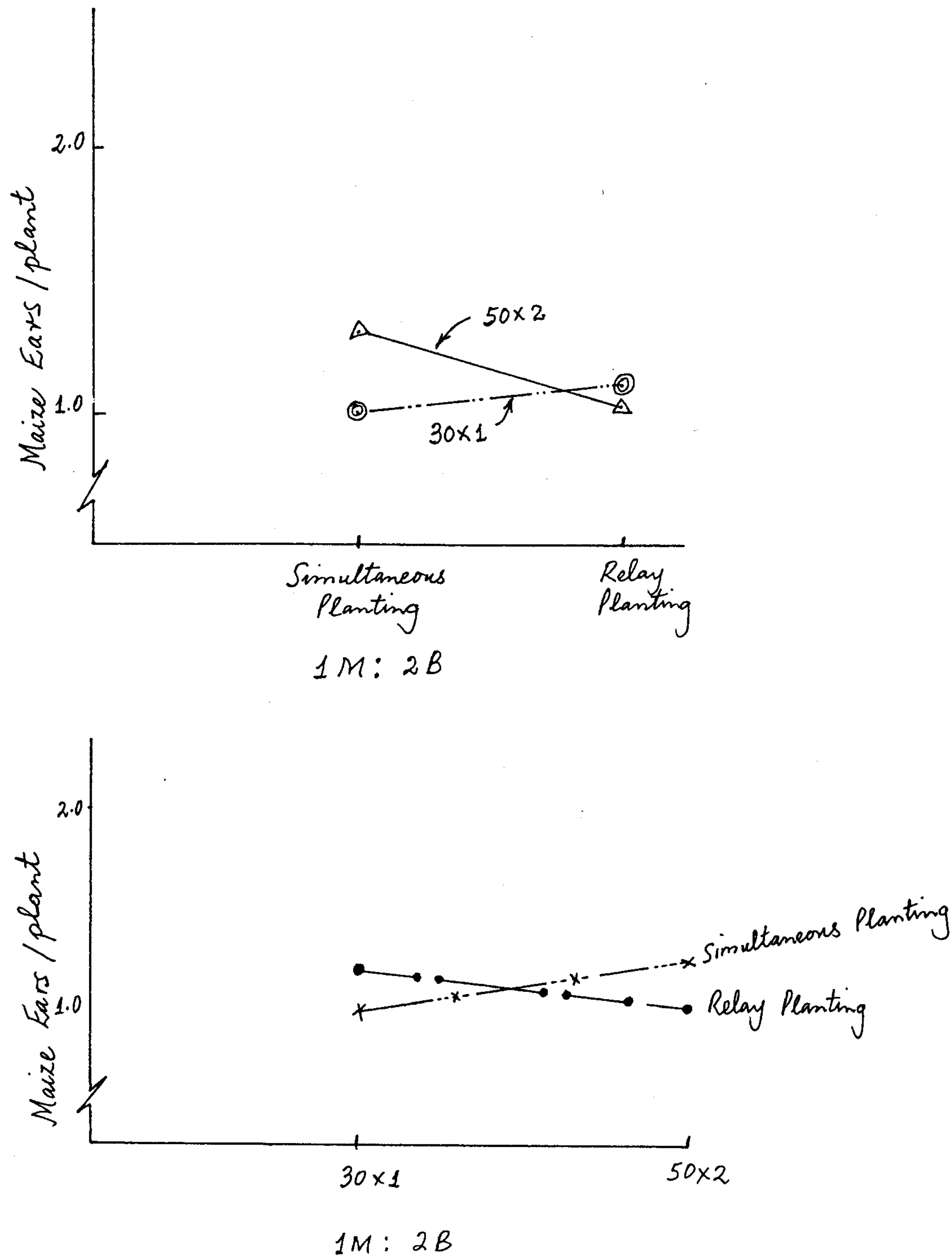
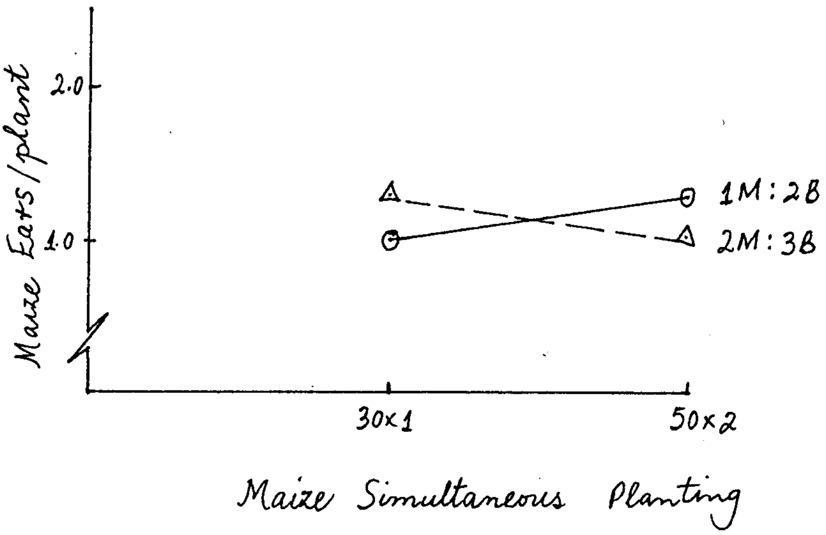


Figure 4a. Two-factor and three-factor Interactions in Maize Ears/Plant Response to Combinations of Maize and Bean Plant Densities



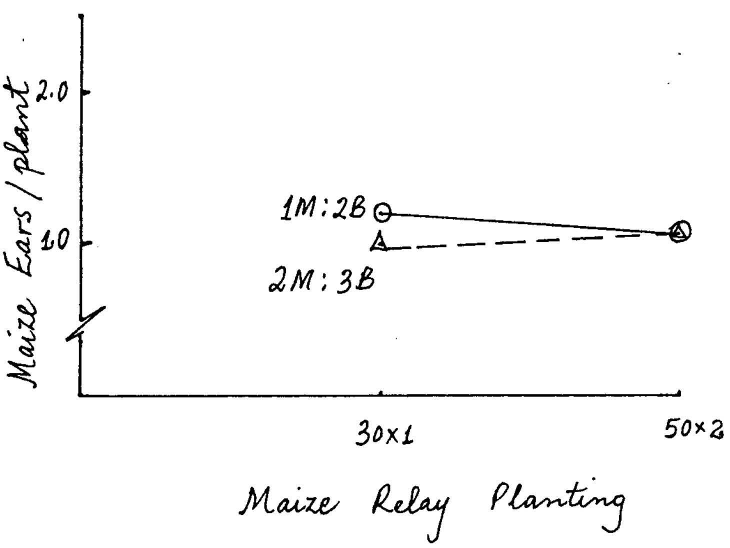


Figure 4b. Two-factor and three-factor Interactions in Maize Ears/Plant Response to Combinations of Maize and Bean Plant Densities

Table 4. Maize grain yield Response to Cropping Systems, Intercrop Plant Densities and Bean Planting Dates (Carbondale, Illinois, 1985)

Treatment Code[1]	Cropping System	Maize (000 pl/ha)	BEAN (000 pl/ha)	BEAN (Planting date)	Maize Grain Yield (g/pl)	Maize Grain Yield (Kg/ha)
A*	Monoculture	40.00c	-	-	129.50mnpqr	5188v
B*	"	66.25b	-	-	91.50st	6718u
C*	"	80.00a	-	-	75.25t	5834v
D	"	-	200.00h	BPS	-	-
E	"	-	200.00h	B1<M	-	-
F	"	-	200.00h	B2<M	-	-
AD1-2	Intercropping	13.33g	133.33i	BPS	163.00kl	2381yz
AE1-2	"	13.33g	133.33i	B1<M	166.25kl	2224z
AF1-2	"	13.33g	133.33i	B2≤M	183.25k	2173z
BD1-2	"	21.67f	133.33i	BPS	116.25pqrs	3431wx
BE1-2	"	21.67f	133.33i	B1≤M	157.25klm	3674w
BF1-2	"	21.67f	133.33i	B2≤M	142.001mnp	2904wxyz

Table 4. Continued

Treatment Code[1]	Cropping System	Maize (000 pl/ha)	BEAN (000 pl/ha)	BEAN (Planting date)	Maize Grain Yield (g/pl)	Maize Grain Yield (Kg/ha)
CD1-2	Intercropping	26.67e	133.33i	BPS	109.50pqrs	3087wxy
CE1-2	"	26.67e	133.33i	B1<M	103.25qrst	2688xyz
CF1-2	"	26.67e	133.33i	B2<M	139.75lmnp	2869wxyz
AD2-3	"	16.00g	120.00ij	BPS	153.50klmn	2330yz
AE2-3	"	16.00g	120.00ij	B1<M	153.75klmn	2256z
AF2-3	"	16.00g	120.00ij	B2<M	136.00lmnpq	2455yz
BD2-3	"	26.00e	120.00ij	BPS	121.75npqrs	3658w
BE2-3	"	26.00e	120.00ij	B1<M	119.50pqrs	3429wx
BF2-3	"	26.00e	120.00ij	B2<M	122.00npqrs	3621w
CD2-3	"	32.00d	120.00ij	BPS	99.50rst	3118wxy
CE2-3	"	32.00d	120.00ij	B1<M	104.75qrst	3155wxy
CF2-3	"	32.00d	120.00ij	B2<M	101.75rst	3085wxy
CV	-	7.24%	10.56%	-	15.56%	14.95%

Table 4. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[*] Monoculture maize was planted during the third planting date of beans.

[1] A total of 24 treatment combinations were evaluated in this study.

A = Maize, intra-row spacing 50 cm with 1 pl/hill (50 x 1).

B = Maize, intra-row spacing 30 cm with 1 pl/hill (30 x 1).

C = Maize, intra-row spacing 50 cm with 2 pl/hill (50 x 2).

D = Beans planted simultaneously with maize (BPS).

E = Beans planted one week before maize (B1<M).

F = Beans planted two weeks before maize (B2<M).

1-2 = Replacement series in which one row of maize alternates with two rows of beans (1M:2B).

2-3 = Replacement series in which two rows of maize alternate with three rows of beans (2M:3B).

Table 5. Mean Maize Grain Yield Response to Cropping System And Plant Density (Carbondale, Illinois,1985)

Cropping System	Maize Intra-row Spacing[1]	Plant Density in thousands/ha (Maize)	(Beans)	Maize Grain Yield (g/pl)	(Kg/ha)
Monoculture:	50 x 1	40.00c	-	129.50jk	5188x
	30 x 1	66.25b	-	91.501m	6718w
	50 x 2	80.00a	-	75.25m	5834x
Intercropping[2]:					
1M:2B	50 x 1	13.33g	133.33h	170.83j	2259z
	30 x 1	21.67f	133.33h	138.50jk	3336y
	50 x 2	26.67e	133.33h	117.50jkl	2881yz
2M:3B	50 x 1	16.00g	120.00hi	147.75jk	2347z
	30 x 1	26.00e	120.00hi	121.08jkl	3569y
	50 x 2	32.00d	120.00hi	102.00klm	3119y
CV	-	7.24%	10.56%	15.56%	14.95%

Table 5. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[1] 50 x 1 = Maize intra-row spacing 50 cm between single plant hills.

30 x 1 = Maize intra-row spacing 30 cm between single plant hills.

50 x 2 = Maize intra-row spacing 50 cm between pair plant hills.

[2] 1M:2B = Replacement series in which one row of maize alternates with two rows of beans.

2M:3B = Replacement series in which two rows of maize alternate with three rows of beans.

as compared to the 1M:2B, replacement series resulted in a significant decrease of about 9g/pl in maize grain production (P<0.01). Nonetheless, due to the increased maize plant density, a non-significant 93 Kg/ha increase in grain yield was achieved. There resulted also a significant 4g/pl increase in maize grain production due to the interaction of Relay Planting Maize x 2M:3B, as compared to BPS x 1M:2B, at the 5% probability level. However, due to the relatively more effective and negative combined impact of delayed planting of higher maize plant densities, the 29Kg/ha increase in maize grain yield was non-significant. This response demonstrated the principle that the loss in maize grain yield due to delayed planting can not be compensated for by using higher maize plant density.

Furthermore, maize grain yields from the 50 x 2 intra-row spacing, in both the 1M:2B and the 2M:3B replacement series, were lower than those obtained from the 30 x 1 intra-row spacing. Although these yield differences were not statistically significant, they amounted to 450 Kg/ha (5 x 90 Kg bags/ha). Such a quantity of maize grain/ha can be a significant food source to a subsistence farm-family.

It is evident in Table 5 that in intercropping, maize grain yield/ha declined progressively with decrease in maize plant density. This evidence underlines the important point that below 26,000 maize pl/ha, increase in maize grain yield/pl may not compensate sufficiently for potential yield lost due to suboptimal plant density. Therefore, proper maintenance of favorable intercrop densities in intercropping requires to be given priority attention.

1.E <u>Maize Intercrop LER</u>

Table 6 illustrates the significant maize intercrop LER differences between treatments.

Overall, there was a 20% net increase in maize intercrop LER as cropping system was changed from intercropping to monoculture. This means that 20% more land area was required in monoculture to obtain the same yield as that obtained in intercropping. This advantage of intercropping was apportioned into contributions from the 1M:2B and the 2M:3B replacement series. In the 1M:2B series where maize occupied 0.33 of land area, the mean maize intercrop LER value of 0.55 meant that there was a 22% maize grain yield advantage as compared to monoculture. In contrast, maize in the 2M:3B replacement series occupied 0.40 of land area. Here the mean maize intercrop LER value of 0.58 indicated 18% maize grain yield advantage as compared to monoculture.

Irrespective of replacement series, intercropping maize using the 30 x 1 intra-row spacing resulted in 9% maize grain yield advantage over the 50 x 2 intra-row spacing. Intercropping 26,000 maize pl/ha using the 30 x 1 intra-row spacing with 120,000 bean pl/ha in the 2M:3B replacement series indicated to have been optimum under the conditions of this study. This combination of intercrop plant densities gave the highest maize grain LER (Table 7).

Table 6. Maize Intercrop LER Response to Intercrop Plant Densities (Carbondale, Illinois, 1985)

		PLANT DENSITY		
Treatment Code[1]	Cropping System	Maize (000 pl/ha)	Beans (000 pl/ha)	Maize Intercrop LER
A*	Monoculture	40.00c	-	1.00u
B*	"	66.25b	-	1.30t
C*	"	80.00a	-	1.13u
D	"	-	200.001	-
E	"	-	200.001	-
F	"	-	200.001	-
AD1-2	Intercropping	13.33g	133.33m	0.46xyz
AE1-2	"	13.33g	133.33m	0.43z
AF1-2	"	13.33g	133.33m	0.42z
BD1-2	"	21.67f	133.33m	0.66vw
BE1-2	"	21.67f	133.33m	0.71v
BF1-2	"	21.67f	133.33m	0.56vwxyz

Table 6. Continued

		PLANT DENSITY		
Treatment Code[1]	Cropping System	Maize (000 pl/ha)	Beans (000 pl/ha)	Maize Intercrop LER
CD1-2	Intercropping	26.67e	133.33m	0.60vwxy
CE1-2	"	26.67e	133.33m	0.52wxyz
CF1-2	"	26.67e	133.33m	0.56vwxyz
AD2-3	"	16.00g	120.00mn	0.45yz
AE2-3	"	16.00g	120.00mn	0.44z
AF2-3	"	16.00g	120.00mn	0.48xyz
BD2-3	"	26.00e	120.00mn	0.71v
BE2-3	"	26.00e	120.00mn	0.66vw
BF2-3	"	26.00e	120.00mn	0.70v
CD2-3	"	32.00d	120.00mn	0.60vwxy
CE2-3	"	32.00d	120.00mn	0.61vwx
CF2-3	"	32.00d	120.00mn	0.60vwxy
CV		7.24%	10.56%	14.96%

Table 6. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

* Monoculture maize was planted during the third planting date of beans.

1 A total of 24 treatment combinations were evaluated in this study.

A = Maize, intra-row spacing 50 cm with 1 pl/hill (50 x 1).

B = Maize, intra-row spacing 30 cm with 1 pl/hill (30 x 1).

C = Maize, intra-row spacing 50 cm with 2 pl/hill (50 x 2).

D = Beans planted simultaneously with maize (BPS)

E = Beans planted one week before maize (B1<M).

F = Beans planted two weeks before maize (B2<M).

1-2 = Replacement series in which one row of maize alternates with two rows of beans (1M:2B).

2-3 = Replacement series in which two rows of maize alternate with three rows of beans (2M:3B).

Table 7. Mean Maize Intercrop LER Response To Cropping Systems And Intercrop Plant Densities (Carbondale, Illinois, 1985)

Cropping System	Maize Intra-row Spacing[1]	Plant Density in thousands/ha (Maize)	(Beans)	Maize Intercrop Grain LER
Monoculture	50 x 1	40.00c	-	1.00x
	30 x 1	66.25b	-	1.30v
	50 x 2	80.00a	-	1.13w
Intercropping[2]				
1M:2B	50 x 1	13.33g	133.33h	0.44z
	30 x 1	21.67f	133.33h	0.64y
	50 x 2	26.67e	133.33h	0.56yz
2M:3B	50 x 1	16.00g	120.00hi	0.46z
	30 x 1	26.00e	120.00hi	0.69y
	50 x 2	32.00d	120.00hi	0.60y
CV		7.24%	10.56%	14.96%

Table 7. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[1] 50 x 1 = 50 cm between single plant hills.

30 x 1 = 30 cm between single plant hills.

50 x 2 = 50 cm between pair plant hills.

[2] 1M:2B = Replacement series in which one maize row alternates with two bean rows.

2M:3B = Replacement series in which two maize rows alternate with three bean rows.

2. BEANS

2.A Plant Height

No significant differences in bean plant height were detected between treatments in this study.

2.B Pods/Plant

Although the number of pods/pl were generally low in all treatments, significant differences were detected between treatments at the 1% probability level (Table 8). The bean plant density of 133,333 pl/ha, planted two weeks before maize, and intercropped with maize plant density of 13,333 pl/ha (in 50 x 1 intra-row spacing) in the 1M:2B replacement series gave the highest number of pods/pl.

Orthogonal comparisons indicated that the net effect of intercropping beans with maize was a significant increase in pods/pl, as compared to planting beans in monoculture ($P = 0.05$). In intercropping, significant increases in bean pods/pl resulted from relay planting the maize in beans, as compared to simultaneous planting of the intercrops ($P<0.01$). Planting beans two weeks before maize resulted in significantly higher number of bean pods/pl than planting beans one week before maize ($P<0.01$). In contrast, use of the 2M:3B replacement series resulted in a significant reduction of bean pods/pl, as compared to the 1M:2B replacement series. This response may have been due to wider strips of land area with bean plants exposed to higher evapotranspiration demands in the 2M:3B than in the 1M:2B series.

Tabel 8. Number of bean pods/plant response to Cropping System, intercrop plant density and planting date (Carbondale, Illinois, 1985)

Treatment Code[1]	Cropping System	BEAN (000 pl/ha)	BEAN (Planting date)	Maize (000 pl/ha)	Bean (Pods/pl)
A*	Monoculture	-	-	40.00n	-
B*	"	-	-	66.25m	-
C*	"	-	-	80.001	-
D	"	200.00a	BPS	-	3.63tuv
E	"	200.00a	B1<M	-	2.38yz
F	"	200.00a	B2<M	-	2.43xyz
AD1-2	Intercropping	133.33b	BPS	13.33s	3.28tuvwxy
AE1-2	"	133.33b	B1<M	13.33s	2.88uvwxyz
AF1-2	"	133.33b	B2<M	13.33s	4.18t
BD1-2	"	133.33b	BPS	21.67r	3.25tuvwxy
BE1-2	"	133.33b	B1<M	21.67r	3.48tuvwx
BF1-2	"	133.33b	B2<M	21.67r	3.35tuvwxy
CD1-2	"	133.33b	BPS		

Table 8. Continued

Treatment Code[1]	Cropping System	BEAN (000 pl/ha)	BEAN (Planting date)	Maize (000 pl/ha)	Bean (Pods/pl)
CE1-2	Intercropping	133.33b	B1<M	26.67q	3.30tuvwxy
CF1-2	"	133.33b	B2<M	26.67q	3.90tu
AD2-3	"	120.00bc	BPS	16.00s	2.55wxyz
AE2-3	"	120.00bc	B1<M	16.00s	3.18tuvwxyz
AF2-3	"	120.00bc	B2<M	16.00s	3.53tuvw
BD2-3	"	120.00bc	BPS	26.00q	2.18z
BE2-3	"	120.00bc	B1<M	26.00q	2.70vwxyz
BF2-3	"	120.00bc	B2<M	26.00q	3.58tuvw
CD2-3	"	120.00bc	BPS	32.00p	2.63vwxyz
CE2-3	"	120.00bc	B1<M	32.00p	2.75vwxyz
CF2-3	"	120.00bc	B2<M	32.00p	3.10uvwxyz
CV		10.56%		7.24%	19.94%

Table 8. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[*] Monoculture maize was planted during the third planting date of beans.

[1] A total of 24 treatment combinations were evaluated in this study.

A = Maize, intra-row spacing 50 cm with 1 plant/hill (50 x 1).

B = Maize, intra-row spacing 30 cm with 1 plant/hill (30 x 1).

C = Maize, intra-row spacing 50 cm with 2 plants/hill (50 x 2).

D = Beans planted simultaneously with maize (BPS).

E = Beans planted one week before maize (B1<M).

F = Beans planted two weeks before maize (B2<M).

1-2 = Replacement series in which one row of maize alternates with two rows of beans (1M:2B).

2-3 = Replacement series in which two rows of maize alternate with three rows of beans (2M:3B).

2.C Bean Grain Yield

There were significantly different bean grain yields between treatments ($P<0.05$). Significant differences were observed also between planting dates, and between intercrop density combinations (Table 9).

As the maize intercrop plant density increased in intercropping, there was increased light interception by maize due to the layered nature of the intercrops. Consequently, the amount of light available to the bean crop was less. Two opposing effects of this phenomenon on bean grain yield may have occurred. On the one hand, reduced light on the beans may have significantly reduced the rate of photosynthesis (growth) and yield of beans. Bean pod number and seed development have been reported in the past to get affected by maize shading beans (Loomis et al., 1971: Trenbath, 1974: Gardiner and Craker, 1981). On the other hand, reduced light on beans may have significantly reduced the rate of soil moisture loss by evaporation; thereby sustaining a more equitable soil moisture regime. The immediate effect of maize shading beans on soil moisture evaporation would occur before canopy closure, especially in low maize plant density intercropped plots. The net effect, therefore would depend on the relative impact of the two apparently opposing effects on bean growth and development.

It is highly probable that the long dry and hot period (not quantified fully) that occurred during bean flowering,

Table 9. Bean Grain Yield Response ToCropping System, Planting Time And Intercrop Plant Density (Carbondale, Illinois, 1985)

Cropping System	Planting Time[1]	Plant Density in thousands/ha (Bean)	Plant Density in thousands/ha (Maize)	Bean Grain Yield (g/pl)	Bean Grain Yield (Kg/ha)
Monoculture:	BPS	200.00a	-	2.90mn	536vw
	B1<M	200.00a	-	2.30n	468vwxyz
	B2<M	200.00a	-	3.05mn	516vwx
Intercropping[2]:					
1M:2B	BPS	133.33b	13.33j	3.53mn	481vwxyz
	B1<M	133.33b	13.33j	3.13mn	312xyz
	B2<M	133.33b	13.33j	4.40m	588v
	BPS	133.33b	26.67i	3.28mn	414vwxyz
	B1<M	133.33b	26.67i	3.40mn	458vwxyz
	B2<M	133.33b	21.67i	2.98mn	393vwxyz

Table 9. Continued

Cropping System	Planting Time[1]	Plant Density in thousands/ha (Bean)	Plant Density in thousands/ha (Maize)	Bean Grain Yield (g/pl)	Bean Grain Yield (Kg/ha)
Intercropping[2]:					
1M:2B	BPS	133.33b	26.67h	3.75mn	512vwxy
	B1<M	133.33b	26.67h	3.05mn	416vwxyz
	B2<M	133.33b	26.67h	3.50mn	448vwxyz
2M:3B	BPS	120.00bc	16.00j	2.55mn	295yz
	B1<M	120.00bc	16.00j	3.35mn	398vwxyz
	B2<M	120.00bc	16.00j	3.48mn	428vwxyz
	BPS	120.00bc	26.00h	2.48n	264z
	B1<M	120.00bc	26.00h	2.68mn	324vwxyz
	B2<M	120.00bc	26.00h	3.33mn	380vwxyz

Table 9. Continued

Cropping System	Planting Time[1]	Plant Density in thousands/ha (Bean)	(Maize)	Bean Grain Yield (g/pl)	(Kg/ha)
Intercropping[2]:					
2M:3B	BPS	120.00bc	32.00g	2.50n	289z
	B1<M	120.00bc	32.00g	2.53n	310xyz
	B2<M	120.00bc	32.00g	2.40n	267z
CV	-	10.56%	7.24%	35.33%	31.87%

Table 9. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[1] BPS = Beans planted simultaneously with maize.

B1<M = Beans planted one week before maize.

B2<M = Beans planted two weeks before maize.

[2] 1M:2B = Replacement series involving one row of maize alternating with two rows of beans.

2M:3B = Replacement series involving two rows of maize alternating with three rows of beans.

pod setting and pod filling may have critically reduced bean grain yields differentially among treatments. This observation was suppprted by high CV in bean grain yields (Table 9). As a result, true treatment effects may have been significantly affected.

Indeed, mean 100-bean grain test weights ranged only 15-25g among all the treatments and factor combinations, as compared to 45-53g when the bean cultivar is grown under normal environmental conditions. Even where significantly different maize plant densities were intercropped with the same bean plant density, in each replacement series, bean grain yield/pl was essentially the same (Table 10).

More field studies would have to be conducted in order to ascertain that significant differences in bean grain yield between spatial arrangements of maize and beans do not occur, even under more favorable growing conditions.

Orthogonal comparisons indicated a significant 17 Kg/ha decrease in bean grain yield was due to intercropping, as compared to planting beans in monoculture ($P<0.01$). Another significant 59 Kg/ha decrease was due to planting the intercrops in the 2M:3B as compared to the 1M:2B replacement series ($P<0.01$). In both cases, decreased bean grain yields were the result of reduced bean plant density. The increase in number of pods/pl was not able to compensate enough.

Table 10. Mean bean grain yield response to cropping system and intercrop plant density combination (Carbondale, Illinois, 1985)

Cropping System	Plant Density in thousands/ha (Bean)	(Maize)	Bean Grain Yield (g/pl)	(Kg/ha)
Monoculture	200.00a	-	2.75m	507x
Intercropping[1]:				
1M:2B	133.33b	13.33j	3.69m	460xy
	133.33b	21.67i	3.22m	422xy
	133.33b	26.67h	3.43m	459xy
2M:3B	120.00bc	16.00j	3.13m	374xy
	120.00bc	26.00h	2.83m	323xy
	120.00bc	32.00g	2.48m	289y
CV	10.56%	7.24%	35.33%	31.87%

Table 10. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[1] 1M:2B = Replacement series in which one row of maize alternates with two rows of beans.

2M:2B = Replacement series in which two rows of maize alternate with three rows of beans.

There was also a significant 26 Kg/ha decrease in bean yield due to the interaction B2<M x (30 x 1 and 50 x 1) as compared to B1<M x (50 x 1), at the 5% probability level. This response suggested that the beneficial effect of planting beans earlier than maize was of less importance to bean grain yield than bean plant density.

2.D <u>Bean Intercrop LER</u>

LER responses of beans to factors and their interactions closely folloed the bean yield/ha responses (Tables 11 and 12).

In intercropping, beans occupied 0.67 of land area in the 1M:2B replacement series but only 0.60 of land area in the 2M:3B series. Bean intercrop LER advantages or disadvantages were calculated in a similar way used when considering maize intercrop LER values.

Intercropping beans with maize resulted in 12% bean intercrop LER advantage over monoculture beans. This meant that 12% more land area in bean monoculture was required to obtain the mean bean intercrop LER value obtainted in intercropping, overall (i.e. irrespective of bean planting date, replacement series and maize intra-row spacing). In intercropping, the relative influences of bean planting date, maize intra-row spacing and replacement series on bean intercrop LER were also estimated.

The replacement series effect indicated to be of greatest influence to bean intercrop LER response, resulting in a 25% intercrop LER advantage due to 1M:2B, compared to bean monoculture (Table 11). This was a mean response

Table 11. Bean Intercrop LER Response to Cropping System, Planting Time And Intercrop Plant Density (Carbondale, Illinoise, 1985)

Cropping System	Planting Time[1]	Plant Density in thousands/ha (Bean)	Plant Density in thousands/ha (Maize)	Bean Grain Yield (Kg/ha)	Bean Grain Yield (Component LER)
Monoculture:	BPS	200.00a	-	536pq	1.00vwx
	B1<M	200.00a	-	468pqrst	0.91vwxyz
	B2<M	200.00a	-	616pqr	1.04vw
Intercropping[2]:					
1M:2B	BPS	133.33b	13.33i	481pqrst	0.93vwxy
	B1<M	133.33b	13.33i	312rst	0.61xyz
	B2<M	133.33b	13.33i	588p	1.14v
	BPS	133.33b	21.67h	414pqrst	0.80vwxyz
	B1<M	133.33b	21.67h	458pqrst	0.89vwxyz
	B2<M	133.33b	21.67h	393pqrst	0.76vwxyz

Table 11. Continued

Cropping System	Planting Time[1]	Plant Density in thousands/ha (Bean)	(Maize)	Bean Grain Yield (Kg/ha)	(Component LER)
Intercropping[2]:					
1M:2B	BPS	133.33b	26.67g	512pqrs	0.99vwx
	B1<M	133.33b	26.67g	416pqrst	0.81vwxyz
	B2<M	133.33b	26.67g	448pqrst	0.87vwxyz
2M:3B	BPS	120.00bc	16.00i	295st	0.57yz
	B1<M	120.00bc	16.00i	398pqrst	0.77vwxyz
	B2<M	120.00bc	16.00i	428pqrst	0.83vwxyz
	BPS	120.00bc	26.00g	264t	0.51z
	B1<M	120.00bc	26.00g	324pqrst	0.63wxyz
	B2<M	120.00bc	26.00g	380pqrst	0.74vwxyz

Table 11. Continued

Cropping System	Planting Time[1]	Plant Density in thousands/ha (Bean)	(Maize)	Bean Grain Yield (Kg/ha)	(Component LER)
Intercropping[2]:					
2M:3B	BPS	120.00bc	32.00f	289t	0.56yz
	B1<M	120.00bc	32.00f	310rst	0.60xyz
	B2<M	120.00bc	32.00f	267t	0.52yz
CV	-	10.56%	7.24%	31.87%	31.86%

Table 11. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[1] BPS = Beans planted simultaneously with maize.

B1<M = Beans planted one week before maize.

B2<M = Beans planted two weeks before maize.

[2] 1M:2B = Replacement series in which one row of maize alternates with two rows of beans.

2M:3B = Replacement series in which two rows of maize alternate with three rows of beans.

Table 12. Mean Bean Intercrop LER Response To Cropping System And Intercrop Plant Density Combination (Carbondale, Illinois, 1985).

Cropping System	Plant Density in thousands/ha (Bean)	(Maize)	Bean Grain Yield (Kg/ha)	(Component LER)
Monoculture:	200.00a	-	507k	0.98x
Intercropping[1]:				
1M:2B	133.33b	13.33i	460kl	0.89xy
	133.33b	21.67h	422kl	0.82xy
	133.33b	26.67g	459kl	0.89xy
2M:3B	120.00bc	16.00i	374kl	0.72xy
	120.00bc	26.00g	323kl	0.63y
	120.00bc	32.00f	289l	0.56y
CV	10.56%	7.24%	31.87%	31.86%

Table 12. Continued

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[1] 1M:2B = Replacement series in which one row of maize alternates with two rows of beans.

2M:3B = Replacement series in which two rows of maize alternate with three of benas.

irrespective of bean planting date and maize intra-row spacing. Intercropping beans with maize in the 2M:3B replacement series gave the lowest (2%) bean intercrop LER advantage over monoculture beans.

Of next greatest influence to bean intercrop LER response was maize intra-row spacing. There resulted a 19% bean intercrop LER advantage due to intercropping beans with maize (50 x 1), compared to monoculture beans, irrespective of planting date and replacement series. Planting intercropped maize at 30 cm x 1 or 50 cm x 2 gave bean intercrop LER advantage of about 10% each, over monoculture beans.

The planting date effect on bean intercrop LER response was a mean 14% advantage in intercropping as compared with monoculture beans. Planting beans two weeks before maize in intercropping led to a 16% bean intercrop LER advantage. Bean planting at one week before maize achieved 15% advantage while 10% advantage was due to intercropping the two species and planting them simultaneously, compared to bean monoculture.

3. COMBINED MAIZE/BEAN LER

There were significant differences in combined Maize/ Bean LER between factor combinations, as shown in Table 13 ($P<0.01$). Intercropping resulted in a significant 25% combined yield advantage over monoculture ($P<0.01$). This means that when the intercrops were grown separately in monoculture, 25% more land area was required to get the same combined yield as that obtained when they were intercropped, overall.

The relative main factor effects on combined maize/bean LER indicated the following order, overall: Maize Intra-row Spacing > Row Arrangement > Bean Planting Date. The indication of this one year study were that planting beans two weeks before maize resulted in 24% combined maize/bean LER advantage over the overall maize and B2<M bean monoculture LER mean. Simultaneous planting or planting beans one week before maize achieved about 20% combined maize/bean LER advantage, each, over the overall maize and B1<M or BPS bean monoculture LER mean.

The effect of crop row arrangement on combined maize/ bean LER was a 25% advantage as compared to the combined maize and bean monoculture LER mean. The 1M:2B crop row arrangement gave the highest 35% combined maize/bean LER advantage while the 2M:3B series gave only 16% combined maize/bean LER advantage, over the combined monoculture LER mean.

The overall maize intra-row spacing effect on combined

Table 13. Combined Maize/Bean LER Response to Cropping System, Maize intra-row spacing, bean planting date and intercrop plant density (Carbondale, Illinois, 1985)

Cropping System	MAIZE Intra-row Spacing (cm x pl/hill)	MAIZE (000 pl/ha)	BEAN (Planting Date)	BEAN (000 pl/ha)	Combined LER
Monoculture	50 x 1*	40.00c	-	-	1.00yz
"	30 x 1*	66.25b	-	-	1.30vwxyz
"	50 x 2*	80.00a	-	-	1.13wxyz
"	-	-	BPS	200.001	1.00yz
"	-	-	B1<M	200.001	0.91z
"	-	-	B2<M	200.001	1.04xyz
Intercropping[1]:					
1M:2B	50 x 1	13.33g	BPS	133.33m	1.39vwxy
"	50 x 1	13.33g	B1<M	133.33m	1.04xyz
"	50 x 1	13.33g	B2<M	133.33m	1.56vw
"	30 x 1	21.67f	BPS	133.33m	1.46vwx

Table 13. Continued

Cropping	M A I Z E		B E A N		Combined
System	Intra-row Spacing (cm x pl/hill)	(000 pl/ha)	(Planting Date)	(000 pl/ha)	LER
1M:2B	30 x 1	21.67f	B1<M	133.33m	1.59v
"	30 x 1	21.67f	B2<M	133.33m	1.32vwxyz
"	50 x 2	26.67e	BPS	133.33m	1.59v
"	50 x 2	26.67e	B1<M	133.33m	1.32vwxyz
"	50 x 2	26.67e	B2<M	133.33m	1.42vwxy
2M:3B	50 x 1	16.00g	BPS	120.00mn	1.02xyz
"	50 x 1	16.00g	B1<M	120.00mn	1.21vwxyz
"	50 x 1	16.00g	B2<M	120.00mn	1.30vwxyz
"	30 x 1	26.00e	BPS	120.00mn	1.22vwxyz
"	30 x 1	26.00e	B1<M	120.00mn	1.29vwxyz
"	30 x 1	26.00e	B2<M	120.00mn	1.44vwxy

Table 13. Continued

Cropping System	MAIZE Intra-row Spacing (cm x pl/hill)	(000 pl/ha)	BEAN (Planting Date)	(000 pl/ha)	Combined LER
2M:3B	50 x 2	32.00d	BPS	120.00mn	1.16vwxyz
"	50 x 2	32.00d	B1<M	120.00mn	1.21vwxyz
"	50 x 2	32.00d	B2<M	120.00mn	1.11xyz
CV	-	7.24%	-	10.56%	20.53%

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

* Monoculture maize was planted during the third planting date of beans.

[1] 1M:2B = Replacement series in which one row of maize alternates with two rows of beans.

2M:3B = Replacement series in which two rows of maize alternate with three rows of beans.

maize/bean LER was a 29% advantage as compared to the combined maize and bean monoculture LER mean. Intercropping, with maize planted at 30 x 1 intra-row spacing, achieved a 33% combined maize/bean LER advantage over the overall bean and 30 x 1 maize monoculture LER mean. The 50 x 2 maize intra-row spacing gave a 28% combined maize/bean LER advantage over the overall bean and 50 x 2 maize monoculture mean LER. Planting maize at 50 x 1 intra-row spacing gave 26% combined maize/bean LER advantage compared with the overall bean and 50 x 1 maize monoculture LER mean.

All the interaction effects of the different factor levels on combined maize/bean LER were not significant.

Combined Maize/Bean LER values in Table 14 indicate ne factor level responses. It is therefore possible to rank these means in terms of relative importance to the specific study.

Table 14. Combined maize/Bean LER Response to Factor Levels (Carbondale, Illinois, 1985)

Factor Level		Combined Maize/Bean LER
Row Arrangement[1]:		
	1M:2B	1.41x
	2M:3B	1.22z
Maize Intra-row Spacing[2]:		
	50 x 1	1.25yz
	30 x 1	1.39xy
	50 x 2	1.30xyz
Bean Planting Date[3]:		
	BPS	1.31xyz
	B1<M	1.28xyz
	B2<M	1.36xyz
	CV	20.53%

Numbers in the same column followed by the same letter are not significantly different at the 5% probability level.

[1] 1M:2B = Alternating one maize row with two bean rows.

2M:3B = Alternating two maize rows with three bean rows.

[2] 50 x 1 = Maize intra-row spacing 50 cm with 1 pl/hill.

30 x 1 = Maize intra-row spacing 30 cm with 1 pl/hill.

50 x 2 = Maize intra-row spacing 50 cm with 2 pl/hill.

[3] BPS = Beans planted simultaneously with maize.

B1<M = Beans planted one week before maize.

B2<M = Beans planted two weeks before maize.

SUMMARY AND CONCLUSIONS

Based on the one year's data and the inestimable magnitude of the effects of prevailing weather conditions, the results of this study can only be considered as indications. More research in more locations would have to be carried out to provide results upon which recommendations could be based. Nonetheless, the following indications were observed:

1. Intercropping maize and beans significantly increased the number of maize ears/plant and the number of bean pods/plant than monoculture.
2. Maize intercrop grain yield/plant grain yield/ha and LER also increased in intercropping as compared to monoculture. In contrast, bean intercrop grain yield/plant, grain yield/ha and LER were essentially the same in both monoculture and intercropping between all factor levels. It is highly probable that the long, dry and hot period during bean flowering, pod setting and pod filling may have critically influenced true bean grain yield responses.
3. Overall, intercropping maize and beans increased combined maize/bean LER compared to monoculture.
4. Increasing maize plant density from 13,000 plants/ha to 80,000 plants/ha indicated a reduction in maize ears/plant, at higher stalk nodes, in both monoculture and intercropping. Maize grain yield/plant also decreased.

5. Intercropping maize and beans in the 2M:3B replacement series reduced bean pods/plant. This response was most likely due to the wider beans strips which were subjected to high evapotranspiration demands, especially prior to full canopy cover.
6. Relay planting maize in beans did not significantly influence the number of maize ears/plant, maize shelling percentage, or combined maize/bean LER.
7. The relative influence of the experimental factors tested on combined maize/bean grain yield indicated the order Maize Intra-row Spacing > Row Arrangement > Bean Planting Date.

REFERENCES

Aiyer, A.K.Y.N. 1949. Mixed Cropping in India. Indian J. Agric. Sci. 19:439-543.

Alexander, M.W., and C.F. Genter. 1962. Production of Corn and Soybeans in alternate pairs of rows. Agron. J. 54:233-234.

Allen, J.R., and R.K. Obura. 1983. Yield of Corn and Soybeans under different intercropping systems. Agron. J. 75:1005-1009.

Baker, E.F.I. 1974. Research on mixed cropping with cereals in Nigerian farming systems - a system for improvement. [In] International Workshop on Farming Systems (Proc.) ICRISAT, Hyderabad, India, Nov. 18-21. 287-301.

Baker, E.F.I., and D.W. Norman. 1975. Cropping Systems in Northen Nigeria. [In] Proc. Cropping Systems Workshop, I.R.R.I., Los Banos, Philippines, 334-361.

Batra, H.N. 1962. Mixed Cropping and Pest Attack. Indian Farming 11(11) 25, 11(12) 23-40.

Beecham, T. 1983. Use of corn-bean strips to harvest more outside corn rows. Prairie Farmer. 6:31.

Bergh, J.P. van den. 1968. An analysis of yields of grasses in mixed and pure stands. Verslag Landbouwkundige Onderzoek 714, 1-71.

Bleasdale, J.K.A. 1967. Systematic designs for spacing experiments. Expl. Agric. 3, 73-85.

Crookston, R.K., and R. Kent. 1976. Intercropping - a new version of an old idea. Crops and Soils, Aug.-Sept., 28(9), 7-9.

Dalal, R.C. 1975. Effects of intercropping maize and soybeans on grain yield. Trop. Agric. 54:189-191.

Dalrymple, D.F. 1971. Survey of Multiple Cropping in less developed nations. Foreign Economic Development Service, U.S. Department of Agriculture co-operating with U.S. Agency for International Development, Washington, D.C. 20250, 108 pp.

Dennison, E.C. 1956. Problems of reclaiming certain infertile areas in the Sudan Zone of Northern Nigeria, World Crops, 8, 131-133.

Edje, O.T. 1980. Comparative development and yield and other agronomic characteristics of maize and groundnuts in monoculture and in association. pp. 17-26. Intercropping. Proc. the second symp. on intercropping in semi-arid areas. Morogoro, Tanzania. 4-7 Aug. Univ. of Dar-es-Salaam.

Evans, A.C. 1960. Studies of intercropping. 1. Maize or Sorghum with groundnuts. E.Afr. Agric. For J. 26:1-10.

Farm Quarterly. 1951. Every row an outside row. 5:58-59.

Finlay, R.C. 1974. Intercropping Soybeans with Cereals. Regional Soybeans Conference (Proc.) Addis Ababa, 14-17th October.

Fisher, N.M. 1976b. A limited objective approach to the design of agronomic experiments with mixed crops. [In] Symp. on Intercropping in Semi-Arid Areas, Morogoro, Tanzania, 10-12th May.

Fisher, N.M. 1977. Studies in mixed cropping. 1. Seasonal differences in relative productivity of crop mixtures and pure stands in the Kenya Highlands. Expl. Agric. 13:177-184.

Food and Agricultural Organization of the United Nations, 1984. Year book.

Francis, C.A., C.A. Flor and S.R. Temple. 1975. Adapting varieties for intercropped systems in the tropics. [In] Multiple Cropping Symp. (Proc.) Am. Soc. Agron., Annual Meeting, Knoxville, Tennessee, 24-29th August.

Francis, C.A. 1986. (Editor). Multiple Cropping Systems. Macmillan Publishing Co., New York, U.S.A. 400 pp.

Freyman, S., and J. Venkateswarlu. 1977. Intercropping on rainfed red soils of the Deccan Plateau, India. Canadian J. Plant Sci., 57, 697-705.

Gardiner, T.R., and L.E. Craker. 1981. Bean growth and light interception in a bean-maize intercrop. Field Crop Res. 4:313-320.

Guttierrez, U., M. Infante and A. Pinchinat. 1975. Situacion del cultivo de frijol en America Latina. Boletin Informe Centro International de Agricultura Tropical, Cali, Colombia.

Harper, J.L. 1961. Approaches to the study of plant competition. Symposia of the Society for Experimental Biology. XV. Mechanisms in Biological Competition (Proc.), 1-39.

Harper, J.L. 1963. The individual in the population. Journal of Ecology, 52, 149-58.

Harwood, R.R., and E.C. Price. 1975. Multiple Cropping in Tropical Asia. [In] Multiple Cropping Symp. (Proc.), Am. Soc. Agron. Annual Meeting, Knoxville, Tennessee, 24-29th August.

Hasselbach, O.E., and A.M.M. Ndegwa. 1980. Modifying the competitive relationship in maize-bean mixtures in Kenya. pp. 68. Intercropping. Proc. the second Symp. on intercropping in semi-arid areas. Morogoro, Tanzania. 4-7th August. Univ. of Dar-es-Salaam.

International Crops Research Institute for the Semi-Arid Tropics. 1977. Report on the Cropping Systems research carried out during the Kharif (monsoon) and Rabi (post-monsoon) season of 1976. Hyderabad. India, 44 pp.

International Rice Research Institute. 1972. Multiple Cropping. [In] I.R.R.I. Annual Report for 1972, Los Banos, Philippines, 21-24.

International Rice Research Institute. 1973. Multiple Cropping. [In] I.R.R.I. Annual Report for 1973, Los Banos, Philippines, 15-34.

International Rice Research Institute. 1975. Cropping Systems Program Report for 1975, Los Banos, Philippines, 73 pp.

Jodha, N.S. 1976. Resource base as a determinant of cropping pattern. [In] Symp. on Cropping Systems Research and Development for the Asian rice farmer. I.R.R.I., Los Banos, Philippines, 21-23 September.

Kassam, A.H., and K.R. Stockinger. 1972. Growth and nitrogen uptake of sorghum and millet in mixed cropping. Samaru Agricultural Newsletter, 15, 28-32.

Kasanaga, H., and M. Monsi. 1954. On the light transmission of leaves. Japanese J. Bot., 14, 304-324.

Kurtz, T., S.W. Melstead and R.H. Bray. 1951. The importance of nitrogen and water in reducing competition between intercrops and corn. Agron. J. 44:13-17.

Lakhani, D.A. 1976. A crop physiological study of mixtures of sunflower and fodder radish. Ph.D. Thesis. Reading University, England, 171 pp.

Litsinger, J.A., and K. Moody. 1975. Integrated pest management in multiple cropping systems. [In] Multiple Cropping Symp. (Proc.), Am. Soc. Agron. Annual Meeting Knoxville, Tennessee, 24-29th August.

Loomis, R.S., W.A. Williams and A.E. Hall. 1971. Agricultural Productivity. Ann. Rev. Plt. Phys. 22:431-468.

Mohta, N.K., and R. De. 1980. Intercropping maize and sorghum with soybeans. J. Agric. Sci. 95:117-122.

Munevar, F., and A.G. Wollum II. 1981. Effect of high root temperature and Rhizobium strain on nodulation, nitrogen fixation and growth of soybeans. Soil Sci. Soc. Am. J. 45:1113-1120.

Mwaipaya, A.M.A. 1984. Annual productivity of some maize-dominated cropping systems; effect of association on combined grain yield in maize/groundnuts, maize/ soybeans and maize/field beans when intercropped. Research memorandum, Department of Agric., Zambia.

Natarajan, M., and R.W. Willey. 1980. Effects of moisture availability on intercropping and yield advantages. pp. 71-72. Intercropping. Proc. Second Symp. on Intercropping in Semi-Arid Aras. Morogoro, Tanzania. 4-7th August. Univ. of Dar-es-Salaam.

Nnko, E.N., and A.L. Doto. 1980. Intercropping maize or millet with soybeans, with particular reference to planting schedule. pp. 33-36. Intercropping. Proc. of the Second Symp. on Intercropping in Semi-Arid areas. Morogoro, Tanzania. 4-7th August. University of Dar-es-Salaam.

Norman, D.W. 1972. An economic survey of three villages in Zaria Province. II. Input-output relationships. Ahmadu Bello University, Samaru, Nigeria.

Norman, D.W. 1974. Rationalizing mixed cropping under indigenous conditions. The example of Northern Nigeria. J. Development Studies, 11(1), 3-21. (Samaru Research Bulletin 232).

Nelder, J.A. 1962. New kinds of systematic designs for spacing experiments. Biometrics, 18, 283-307.

Nickel, J.L. 1973. Pest situations in changing agricultural systems - a review. Bulletin of the Entomological Soc. Am., 19(3), 136-142.

Oelsligle, D.D., E.E. McCollum and B.T. Kang. 1975. Soil fertility management in tropical multiple cropping. [In] Multiple Cropping Symp. (Proc.), Am. Soc. Agron. Annual Meeting, Knoxville, Tennessee, 24-29th August.

Ogunfowora, O., and D.W. Norman. 1973. An optimization model for evaluating the stability of sole cropping and mixed cropping systems under changing resource and technology levels. Bulletin of the Rural Economic Society, 8(1), 77-98.

Ojehomon, O.O. 1970. Effects of continuous removal of open flowers on the seed yield of two varieties of cowpea, <u>Vigna unguiculata</u> (L.) Walp. J. Agric. Sci. 74:375-381.

Ojehomon, O.O., and D.F. Morgan. 1969. A quantitative study of inflorescence development in <u>Phaseolus vulgaris</u>. Ann. Bot. (London) 33:325-332.

Okigbo, B.N., and D.J. Greenland. 1975. Intercropping Systems in tropical Africa. [In] Multiple Cropping Symp. (Proc.), Am. Soc. Agron. Annual Meeting, Knoxville, Tennessee, 24-29th August.

Osiru, D.S.O. 1974. Physiological studies of some annual crop mixtures. Ph.D. Thesis, Makerere University, Kampala, Uganda, 260 pp.

Osiru, D.S.O., and G.R. Kariba. 1979. Sorghum/pigeon pea and finger millet/groundnut mixture with special reference to plant population and crop arrangements. pp. 78-85. Proc. International Intercropping Workshop. ICRISAT, Hyderabad, India.

Osiru, D.S.O., and R.W. Willey. 1972. Studies on mixtures of dwarf sorghum and beans with particular reference to plant population. J. Agric. Sci. 79:531-540.

Osiru, D.S.O., and R.W. Willey. 1976. Studies on mixtures of maize and beans with particular emphasis on the time of planting beans. [In] Symp. on Intercropping in Semi-Arid Areas (Proc.), Morogoro, Tanzania, 10-12th May.

Pendleton, J.W., and R.D. Seif. 1962. Role of height in corn competition. Crop Sci., 2(2) 154-156.

Pendleton, J.W., and D.B. Peters. 1967. Response of maize (<u>Zea mays</u> L.) to light rich field environment. Agron. J. 59:395-397.

Pinchinat, A.M., J. Soria and R. Bazan. 1975. Multiple Cropping in tropical America. [In] Multiple Cropping Symp. (Proc.), Am. Soc. Agron. Annual Meeting, Knoxville, Tennessee, 24-29th August.

Raheja, A.K. 1977. Pest and disease relationships within various crop mixtures, Research Program 1977-78. H. Cropping Systems. Institute for Agricultural Research, Samaru, Nigeria 4.

Rathke, J.K., and R.T. Hegstrom. 1975. Strip intercropping for wind protection. [In] Multiple Cropping Symp. (proc.), Am. Soc. Agron. Annual Meeting, Knoxville, Tennessee, 24-29th August.

Rao, M.R., and S.V.R. Shetty. 1977. Some biological aspects of intercropping systems on crop weed balance. [In] Weed Sci. Conference/Workshop in India (Proc.), Andhra Pradesh Agricultural University, Hyderabad, India. 17-20th January.

Reagan, J.J. 1983. Strip intercropping worth a look. The Furrow. 88:18-19.

Reddy, M.S., and R.W. Willey. 1979. A Study of Pearl Millet/Groundnut Intercropping with Particular Emphasis on the Efficiencies of Leaf Canopy and Rooting Pattern. In proc. of the International Workshop on Intercropping. ICRISAT, Hyderabad India.

Rennie, R.J., and G.A. Kemp. 1983. N_2-Fixation in Field Beans Quantified by ^{15}N Isotope Dilution. I. Effect of Strains of Rhizobium phaseoli. II. Effect of Cultivars of Beans. Agron. J. 75:640-649.

Shelke, V.B. 1977. Studies in crop geometry in dryland intercrop systems. Ph.D. Thesis, Marathwada Agricultural University, Parbhani, Maharastra, India.

Siddoway, F.H., and A.P. Bonnett. 1975. Water and wind erosion control aspects of multiple cropping. [In] Multiple Cropping Symp. (proc.), Am. Soc. Agron. Annual Meeting, Knowville, Tennessee, 24-29th August.

Singh, H.G., and A.S. Rathore. 1978. Investigations on stand geometry and intercropping of maize with pulses for increasing production under rainfed conditions. [In] National Symp. on non-monetary inputs in field crop production. Haryana Agricultural University, Hissar, India, 11-12th February.

Sivakumar, M.V.K., and S.m. Virmani. 1980. Growth and resource use of maize, pigeon pea and maize/pigeon pea intercrop in an operational research watershed. Expl. Agric. 16:377-386.

Snider, H.J. 1950. Growing corn and soybeans. Hoard's Dairyman 95-350.

Trenbath, B.R. 1974. Biomass productivity of mixtures. Adv. in Agron. 26:177-210.

Willey, R.W. 1979. Intercropping: Its importance and research needs. 1. Competition and yield advantages. 2. Agronomy and research approaches. FCA. 32 No. 1:1-10. 32 No. 2:73-85.

Willey, R.W., and D.S.O. Osiru. 1972. Studies on mixtures of maize and beans (Phaseolus vulgaris L.) with particular reference to plant population. J. Agric. Sci. 79:519-529.

World Almanac and Book of Facts, 1986.

APPENDIX

Appendix Table 1. Cropping Systems Terminology (derived from Willey, 1979 and modified by the author).

MUTIPLE CROPPING refers to all cropping systems in which total production from an area of land in one farming season or year is achieved through growing more than one crop in any combination of ways or sequences. It includes mixed cropping, intercropping, and intracropping. This term may also include rotation cropping where this practice satisfies the time limit.

STRIP INTERCROPPING involves two or more crops, grown in alternating numbers of rows of each crop, wide enough for independent growth and yet close enough to interact with the rows of the other crop(s).

RELAY CROPPING refers to general staggered planting of more than one crop, in time sequence, on the same land area.

RELAY INTERCROPPING refers specifically to intercropping in which the different crops' growing periods only briefly overlap; planting of the later crop usually preceding the harvesting of earlier crop(s).

INTRACROPPING refers to cases where more than one crop share common rows. In practice, however intracropping is usually limited to only two crops; competition among three or more crops sharing a common row, becomes too complex that interpretation of any such data is often rendered meaningless.

COMPONENT CROP refers to either of the different crops making up the multiple cropping situation.

INTERCROP YIELD is the yield of a component crop when grown in intercropping and expressed over the total intercropped area (i.e., area occupied by both or all crops). A simple addition of both or all intercrop yields thus gives a COMBINED INTERCROP YIELD.

SOLE CROP refers to a component crop being grown alone and unless otherwise indicated is assumed to be grown at optimum population and spacing.

LAND EQUIVALENT RATIO (LER) is the land area required in monocropping to obtain the same yield as that obtained in intercropping. As a ratio, it has no units.

Appendix Table 2. Some maize parameters' responses to cropping system and plant density.

Cropping System	Maize Plant Density (thousands/ha)	Maize Ear height (cm)	Maize Ears/pl	Maize (g/plant)	Grain (g/Ear)	Yield (Kg/ha)
Monoculture	40.00	64.45	1.07	129.50	121	5188
	66.25	66.88	1.01	91.50	91	6718
	80.00	73.58	0.99	75.25	76	5834
Intercropping[1]						
1M:2B	13.33	58.51	1.32	170.83	131	2259
	21.67	59.99	1.06	138.50	130	3336
	26.67	58.07	1.11	117.50	108	2881
2M:3B	16.00	57.16	1.28	147.75	116	2347
	26.00	61.14	1.01	121.08	120	3569
	32.00	61.19	1.01	102.00	101	3119

Appendix Table 2. Continued

[1] 1M:2B = Replacement series in which one row of maize alternates with two rows of beans.

2M:3B = Replacement series in which two rows of maize alternate with three rows of beans.

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