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Planting patterns and densities of intercropped corn-soybean for silage.

Daniel Harold Putnam
University of Massachusetts Amherst

PLANTING PATTERNS AND DENSITIES
OF INTERCROPPED CORN-SOYBEAN FOR SILAGE

A Thesis Presented

By

DANIEL HAROLD PUTNAM

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DANIEL H. PUTNAM

Approved as to style and content by:

Stephen J. Herbert, Chairperson of Committee

Mary I. Poos, Member

Lyle E. Craker, Member

Allen V. Barker, Department Head
Department of Plant and Soil Sciences

DEDICATION

This thesis is dedicated to my wife, Panna, for her love, support and patience.

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CHAPTER I

INTRODUCTION

Intercropping is a practice which dates from antiquity (Stelly,1976). The idea that a mere mixing of crops could lead to a yield increase has always been attractive, as evidenced by work on intercropping at experiment stations in the early part of this century (Slate & Brown, 1925). Intercropping is defined as a type of multiple cropping in which two crop species are simultaneous for most of the growing season (Andrews & Kassam, 1976). This is distinct from sequential cropping (more than one crop in a season) or rattoon cropping (regrowth of a crop) and other forms of multiple cropping.

The mixture of species, which is widely practiced in the developing and developed areas of Asia, Latin America and Africa, could be applicable to the mechanized systems of North America if specific yield goals are met. The yield goals addressed in this study relate to dairy operations, where in the Northeast, the on-farm production of protein is often severely deficient (Smith,1981).

The value of increasing the quality of forages fed to ruminants cannot be overemphasized (Church,1977). Fourteen percent crude protein in the ration is considered adequate for a high producing dairy cow during the first 23 weeks of lactation (Holter et al,1982). If most of this protein is made up from on-farm forage sources, the amount of grain concentrates required could be reduced, which would both be more economical and a better feed source for the animal. A lactating dairy cow consuming a high fiber diet is less likely to develop metabolic or digestive problems (Miller & O'Dell,1969), and fiber is often considered an "essential nutrient" for this reason. Consequently a high quality forage diet with few concentrates is considered better than a low quality forage diet with high concentrates (Miller,1979). Furthermore, higher quality forage would enable the farmer to cut costs by cutting back on concentrates as less concentrates would be required (Church,1977, Miller,1979). With high poduction costs and a currently depressed milk market situation (often with penalties for over-production), cost-cutting is becoming more attractive than raising production as a means of remaining viable for many farmers.

The need, therefore, is for increased forage protein production on the farm, without seriously reducing energy yields. A cropping system to fit these yield goals would be worth considering if a) increased yields were found or b) yields were maintained at an "acceptable" level and an increase in yield quality was obtained. "Acceptable" here depends upon each microeconomic situation: some farmers would accept slight reductions in yield if they could reduce grain costs, others would not. The purpose of this study was to evaluate corn-soybean intercropping as affected by planting patterns and corn densities for forage yield and protein content.

The yield possibilities in intercropping, density and planting pattern effects are reviewed in the first section of the literature review. Tropical and other species intercropping are included, as the principles involved are often quite relevant.

In multiple cropping systems, the assesment of yield becomes more complex, because a number of yield-goal possibilities exist. The problems related to assesment of yield in intercropping are discussed at length in the second part of the Literature Review (Criteria for Yield Advantage in Intercropping).

The growth and yield data reported in chapters IV and V are from an intercropping trial conducted in 1981 at the South Deerfield, Massachusetts Experiment Station Farm of the University of Massachusetts, Amherst.

CHAPTER II

LITERATURE REVIEW

Agronomic Characteristics

Yields.

Introduction. When soybeans were introduced into the United States in the early part of this century, intercropping was already a common agronomic practice, tracing back to the Native American methods of planting corn, beans and squash in varying combinations. Several experiment stations at this time reported increased yields when corn was planted with soybean for silage including Conneticut (Slate & Brown, 1925), Ohio (Park et al, 1922), Minnesota (Boss, 1917), Virginia (Stemple,1917), Missouri (Etheridge & Helm, 1924), although other experiment stations reported mixed results such as Pennsylvania (Noll & Lewis, 1921) and Rhode Island (Hartwell, 1920). It was often considered desireable to plant soybean in corn for "hogging down", or grazing of cornfields after harvest (Hughes & Wilkins, Iowa,1925). When corn and soybean were grown together in the thirties for silage, it was found that the losses in total dry matter production in the corn were more than made up for by the addititonal soybean in the mixture. Actual increases of 5.3 to 9.2 percent were recorded. The losses in dry matter production of corn were not made up by the yield of associated pole beans, however, with losses of 18.7 to 19.8 percent

(Wiggans,1935). As rapidly increasing yields of hybrid corn and soybean in monoculture became attractive and readily attainable, interest in legume-corn mixtures waned.

More recently, interest in intercropping for countries with a higher degree of mechanization has been spurred by the possibility of increased yields, use as windbreaks, more efficient use of prime land and increased quality of silage (Faix et al,1976, Pendleton et al,1963, Cordero & McCollum,1979). Intercropping in North America received a wider scrutiny with the "Multiple Cropping Seminar" in 1975 held in Knoxville, Tenn., sponsored jointly by the American Society of Agronomy, Crop Science Society of America, and the Soil Science Society of America (Stelly,1976).

Temperate Regions. The yield goals in the studies cited here are often widely variant as have been the types of planting patterns, row spacings, densities, cultivars and environments studied. It is not surprising, therefore that the results of the intercropping trials reviewed are mixed.

In Georgia, it was found that corn or sorghum intercropped in the same row with beans did not significantly effect the yield or protein levels of the silage (as compared to corn monoculture), but a trend for increases in protein in the mixtures was always present. Little change was observed in in vitro digestibility (Cummins,1973). Studies in Mississippi showed that the average silage production over three years was higher for corn and soybeans interplanted in the row than for corn alone or alternate-row intercropping, but the alternate-row intercropping produced 11.27% protein as compared to 10.47% for the within-row treatment and 8.34% for straight corn (Pogue & Arnold,1979). Results from South Dakota showed silage yield for corn to be similar to corn-soybean silage under eastern South Dakota conditions. With 17-21% soybean in the mixture, protein content was raised from 10.1 % for corn alone to 13.0% by adding the soybean (Bartle & Voelker,1968). In Illinois when corn and different legumes were seeded in killed standing fescue sod for silage, it was found that only soybean can improved protein content when intercropped with corn, but a decrease in digestibility can be expected. Light was considered the key factor in the suppression of legumes, yet soybean was more tolerant of shade for flowering and setting pods than were cowpeas (Faix et al,1976). "Succotash silage" (corn intercropped with various varieties of pole beans) was tested in Nebraska without any yield improvement; crop establishment and insect pests were cited as problems encountered (Anderson & Daigger,1975). In Massachusetts, when corn and soybean were interplanted within the row, in narrow alternate rows, and in a replacement series where 3 rows of soybean replaced every other (50% corn/50% soybean), every third (67% corn/33% soybean) and the third and fourth rows (50% corn/50% soybean) of corn, it was found that all but the latter produced yields similar to corn monoculture silage. The within-row and narrow row intercrop patterns produced high yields yet the percent soy in the mixture was not adequate to raise the protein content of the silage. However, the two

50/50 intercrops produced a significant soybean percentage in the silage to raise the protein content of the feed (Herbert & Putnam,1981).

Corn and soybean have also been planted in varying arrangements for grain. Although corn yields were increased 75% over solid corn in a narrow row 2 corn/4 soybean pattern in Alabama, soybean was reduced 25-30%, and the economic value of the intercrop was seen to be the same as monoculture (King et al,1978). Minnesota land use efficiency (Land Equivalent Ratio) was not improved by intercropping corn and soybean for grain in narrow alternating corn and soybean patterns (with varying intimacy), or under various densities and planting dates (Crookston & Hill,1979). This was similar to the results of Von Heemstra (1982), who found LERs to be less than 1 in most cases for corn and soybean mixtures, but differed from the results of Beste (1979), Alexander & Genter (1962), and Cordero & McCullum (1979), who found Land Equivalent Ratios to be greater than 1.0 in most treatments.

When monoculture corn was planted in a double row pattern, yields were reduced by 8-12 percent relative to normal row check, and a further yield reduction of 5 to 10 percent resulted when soybean or snapbean was planted in the 147 cm space between paired rows of corn. The yields of the soybean in the mixture were reduced to about 25% of soybean monoculture treatment (Cordero & McCollum,1979). Similarly, Zekeng (1980) found that intercropped combinations of alternating 2, 4, and 8 rows of corn and soybean was did not significantly effect the yields of maize in North Dakota, but reduced significantly the yield of strips of intercropped soybean and dry edible bean. Biological and grain yields for both legumes increased as the number of rows in the strip increased (Zekeng,1980). Intercropping yields per unit area were also higher than sole crop yields when bean, cowpea and velvet-bean were intercropped with corn in West Virginia (Materu,1980).

Sweet corn grown with soybean has been shown in some experiments to be an advantageous system to harvest two crops in a season. When sweet corn and soybean were planted together in the row, acceptable sweet corn yields were obtained and soybean yields of about 1400 kg/ha were realized (Beste,1976). However, soybean was considered to be the least adapted to relay-intercropping systems with corn in Florida, where three crops are often planted. Maize yield was not significantly affected by intercropping and a maximum soybean yield of 970 kg/ha was obtained at a low corn population of 24 plants/m2 in a study in Florida. At high corn populations, the soybean plants died before maturity (Akhanda et al, 1977).

Tropical Regions. Farmers in tropical countries have practiced mixed cropping and intercropping to a wide extent to reduce weed and pest problems, spread out labor peaks, utilize available rainfall, satisfy dietary requirements, increase production, and stabilize yields (Andrews & Kassam,1976, Dalrymple,1971, Monyo et al,1976, Willey,1979). There has been an increased emphasis on mixed cropping in research work in the tropics, with the recognition not only that subsistence farmers will continue to intercrop, but there may be sound economic and cultural reasons that they should (Harwood & Price,1976, Francis et al,1975, Bradfield,1972, Willey & Rao,1981, Reddy et al,1980, Schroder & Warnken,1981).

Most of the work done on corn-bean and other mixtures in the tropics is not for silage but for grain, and not always directly applicable to the northeastern United States, yet the principles involved are often relevant. Mixtures of maize and bean (Phaseolus vulgaris) in Uganda were reported to be up to 38% higher and mixtures of sorghum and beans to be up to 55% higher than could be acheived by growing the respective crops separately (Willey & Osiru,1972, Osiru & Willey, 1972). While intercropping maize with either bean or cowpea decreased total yield of the grain (cereal and legume) per hectare in Tanzania, intercropping sorghum with pigeonpea increased total grain yield per hectare (Enyi,1973). In western Nigeria, calopo, cowpea and greengram had little effect on intercropped maize yield and seemed to tolerate the shade in intercrops whereas popondo and mucuma lowered maize yield considerably (Agboola & Fayemi,1971).

In Kenya, mixtures of maize and bean produced an apparent yield advantage over pure stands, but this could be explained by the authors soley by a more optimum population pressure in the mixtures (Fisher,1976b). Maize yields were not affected when grown in association with beans (Phaseolus vulgaris) in Columbia, but the intercropped bean yields were significantly reduced when sown under maize. However, the mixed stand was judged to yield 62% more than sole crops (as compared to growing equal planted areas to sole crops) (Edje et al, 1976). It was found that protein yield/ha, income, LERs, and total yields were greater than monoculture bean or corn for the association of the two crops in an intercrop in Columbia (Francis,1978). LERs above 1.50 indicate a potential for intercropping to produce 50% more under the conditions studied in Columbia (Francis et al,1982). The LERs of the three best bean cultivars were 1.25 when the seed yields of 8 bean cultivars in pure stands and intercropped with corn were compared. The yields of all cultivars were reduced by the association with maize, whereas the maize was not affected by the bean intercrop (Fisher,1974).

In an experiment conducted at 14 locations in seven Asian countries from 1976-1979, it was found that intercropping maize and soybean generally gave greater combined yields and monetary returns than obtained from either crop grown alone. On the basis of LERs, yield advantage from intercropping varied from 64% at zero N to 42% at 100% of the recommended rate of N application to maize (Ahmed & Rao,1982). Total land productivity was increased to the maximum of 31 and 48 percent by intercropping sorghum and maize (respectively) with soybean in India over 5 years. The grain yield of maize was not affected significantly by intercropping, while sorghum and bean yields were reduced by intercropping (Mohta & De,1980). In Trinidad, the yield of maize was significantly reduced only when associated bean was planted in the same row as corn, but soybeans were reduced under both alternate and within-row planting patterns (Dalal, 1977).

Other Mixtures. There have been numerous other mixtures of crops grown together, primarily but not exclusively in the tropics, which have shown promise. The slow-establishing and late-maturing pigeonpea mixes well with shorter-seasoned cereals and legumes, often giving yield advantages in semi-arid regions. Intercropping with sorghum has been popular in both the subcontinent of India and in parts of Africa where water is limiting. Intercropping sorghum with pigeonpea increased total grain yield per hectare in Tanzania (Enyi,1973), yet pigeonpea and cowpea had a greater adverse effect on the grain yields of sorghum than did bean. Yields of sorghum grown alone at high populations generally surpassed yields of sorghum intercropped with pigeonpea in an experiment in India, yet monetary, nutritional, and risk considerations favored the intercrop (Freyman & Venkateswarlu,1977). Yield advantages (based on LERs) of 20 and 57% for a sorghum-pigeonpea intercrop were recorded for Alfisols and Vertisols respectively when several combinations were tested in India (Rao & Willey,1980b). When the early-maturing cereal setaria was intercropped with pigeonpea, there was little competition between the crops, with the combined intercrop yield about equal to the additive sole crop yields. Yield advantages (LERs) for alfisols were 83% and for vertisols 104% (Rao & Willey,1980b). Positive LERs were also shown for pigeonpea/pearl millet (33-86%), and soybean/pigeonpea and cowpea/ pigeonpea mixtures, where yield advantages were not consistant with soil type (Rao & Willey,1980a). Efficiencies of dry matter production calculated from the relationship between dry matter production and cummulative intercepted PAR was highest for a maize/pigeonpea intercrop (as compared to sole maize or pigeonpea) in India (Sivakumar & Virmani,1980). Yield advantages of up to 67% and monetary returns of up to 45% were acheived in a sorghum-pigeonpea intercrop in 1977 (Natarajan & Willey,1980a).

In Nigeria, relay cropping and intercropping with maize, millet or cowpeas gave 59 and 80% more gross return per acre respectively than did a sole crop of sorghum, with increases coming mainly from higher cereal yields (compared on an equivalent area basis)(Andrews,1972). Maize and millet are early maturing crops (80-90 days), and are often harvested before floral initiation of the longer-seasoned sorghum. Cowpea can be planted midseason, even after the removal of the early cereal crop, for harvest at the same time or shortly after the sorghum. Dwarf sorghum has been shown to be superior in such a system, with increases in yield per plant due mainly to more grains per head. The dwarf sorghum advantage over tall was of the same magnitude as sole crops; the dwarf varieties offer less competition to the other crop and are also able to maintain higher plant yields themselves (Andrews,1974).

The climbing habit of the cowpea (Vigna unguiculata L.) has made this crop an attractive one for intercropping systems, using a tall crop such as maize for support. Relative Yield Totals (analogous to LERs) were significantly higher for mixtures of maize and cowpeas than for the mean monoculture yields in Nigeria (Remison,1978). However, the highest stand yield in several experiments was in the monoculture maize. Other researchers in Africa found that the maize cultivar greatly affected the cowpea characteristics of the associated cowpea, with the shorter, more erect-leaved plants allowing more light to reach the cowpea, enhancing its growth and yield (Wahua et al,1981).

The economic benefits of sorghum/greengram and sorghum/pigeonpea are evident from several studies. Sorghum/pigeonpea gave an increase of 1,120 to 2,620 Rupees/ha while sorghum/greengram gave a benefit of 590 to 700 Rupees/ha over the cultivation of a sole crop of sorghum in two locations in India (ICRISAT,1976, and 1981). Data from Illinois indicates that a "judicious combination" of dwarf sorghum cultivars at appropriate plant populations intercropped with soybeans may result in profitable total yields per unit land area (Wahua & Miller,1978a).

Maize and groundnut is also considered to be a promising mixture in some situations. When maize and groundnut (peanut) were intercropped in Cameroon, mixtures were found to be advantageous with an average of 6% and 16% more land needed in pure stands to attain the same yields as the mixtures in two consecutive years (Mutsaers,1978). In Florida, relay intercropped corn and peanut produced a full corn crop plus 20% of the peanut sole crop yield. The authors recommend successive double cropping instead of relay-intercropping where there is a longer warm season (Akhanda et al,1978).

Mixtures of field peas and several cereals in Prince Edward Island, Canada produced equalled or increased total seed and protein yields as compared to pure stands of the respective cultivar, and thereby the mixtures were offered as an alternate method of protein production for on-farm use. (Johnston et al, 1978). Small grain species mixtures have produced yield and protein improvements compared with pure stand means but not better than the higher yielding component (Fejer et al, 1982). Such mixtures often offer other benefits, however, such as insurance against disease and pest risk (Fejer et al, 1982).

Density Relations.

Overall Density. Plant density is often considered to consist of two components (Willey & Heath,1969). One is the absolute number of plants per unit area, ie. plants/ha or plants/m2, and the other component is the arrangement of these plants into rows, hills, or planting patterns, which will determine the degree of "recangularity" of the crop or "on-the-square" planting ("uniformity"--Duncan,1969). Both the absolute number of plants per unit area and the planting pattern of the crop should be seen within the context of how these effect the intra-crop competition, and, when considering intercrops, both the inter- and intra-crop competition and the interrelationship between them.

The problem of density in intercrops is often complicated with the method used to transfer density assumptions from monoculture to intercrops. Some have mentioned the difficulties of confounding density and planting patterns (Freyman & Venkateswarlu,1977). In several of the experiments reviewed, intercrops are acheived by adding together the densities used in pure stands, making the overall population roughly twice that of the average of the pure stand densities (Pogue & Arnold,1979, Agboola & Fayemi,1971, Fisher,1977b, Cummins,1973, Ahmed & Rao,1982). Thus, if the monoculture densities are not optimally high, yield advantages might be apparent merely because a more optimum population pressure was acheived in mixture (Fisher,1977b). This bias is alleviated by the use of a replacement series (Willey & Osiru,1972) where part of one crop is replaced with a "row equivalent" of another. An advantage of this is that one plant of one species is not considered to be equal to one of the other, but may be replaced in correspondence with the optimum sole crop density for that species. For instance, one maize plant is replaced by four soybean plants; these are considered equal in terms of population pressure, and thereby one "plant unit" (de Wit,1960). Plant component densities can then be manipulated in a similar fashion in both monoculture and intercrops, making comparisons between rows in monoculture and intercropping possible. Replacement series have been widely used (Osiru & Willey,1972, Willey & Osiru,1972, Herbert & Putnam,1982).

There is evidence that higher overall densities are required in intercropping than in sole cropping (Willey,1979, Willey & Osiru,1972, Osiru & Willey,1972, Natarajan & Willey,1980a, ICRISAT,1977). Some have stated that yield advantages can be attributed soley to the increased densities which result in mixtures. When additive population pressures in intercropping are in effect (as opposed to replacement series "equivalent" pressures), apparent yield advantages (LERs) of up to 52% were found in one study. However, when pure-stand yields were estimated from calculated "equivalent" densities, considering yield per plant to be a function of plant density over the relevant range, this apparent yield advantage dissappeared, and the LERs (termed equivalent areas) were close to unity (Fisher,1977b). It is important to emphasize the value of growing pure stand crops at sufficient ranges in order to adequately describe the optimal sole crop density for comparison. For example, the estimated yield of corn based upon a calcuated population pressure was out of the experimental range in one study, and might not represent the actual response of corn at that density (Fisher,1977b).

This problem aside, Willey (1979) has emphasized that increased total populations might be most important when large temporal differences in growth patterns of the components are evident, ie. in the mixtures of 80-90 day cereals and 150-180 day pigeonpea cited by Freyman & Venkateswarlu (1977) and ICRISAT (1977).

As a general rule, most of the literature indicates that as the population of the dominant component intercrop is increased, that component becomes more competitive, and the dominated crop becomes less competitive (in relation to the amount of competition normally present in sole crops at corresponding densities). Simply speaking, this tends to lead to yield increases for the dominant crop and yield decreases for the dominated crop. These are not necessarily equal, though, a fact which often leads to a yield advantage. A difficulty is that often insufficient data is obtained in order to identify and quantify the more competitive crop in any given environmental condition. The competitive relationship is not necessarily a "given" under particular genotypic and environmental conditions. Competitive ability is not a constant and quantifiable function for a crop, but dependent upon density and other factors (Willey,1979). Francis et al (1982) found a diminishing per-plant competitive effect which occurs as growth factors become more limiting at higher densities. There was a greater maize yield reduction per plant from the first 10 beans/m2 added to an intercrop than from the second 10 beans/m2 added, suggesting self-competition in the beans becoming more important at higher densities.

A more competitive species may utilize a greater proportion of the environment than allocated at planting time, exploitation which will not necessarily subtract growth factors from the less competitive crop. It could be that a yield advantage is not at its maximum until there is enough intensity of competition between species (promoted by high densities) to make them fully utilize their respective sections of the environment (Willey & Osiru,1972).

When sorghum and soybean were intercropped under a wide range of sorghum densities for grain in Illinois using a fan-type systematic design (Nelder,1962), the highest Relative Yield Total (RYT) of the mixture occurred at the lowest sorghum population (5 plants/m2) at a spacing of 74 x 74 cm. intercropped with soybean between the rows spaced 5 cm. apart. This indicates the inability of soybean to tolerate even medium range densities of the more competitive crop under the conditions studied (Wahua & Miller,1978a).

While with similar maize-bean experiments (Willey & Osiru,1972), maize was always the more competitive crop, and became more so with higher corn densities, but the competitive abilities of sorghum and bean were not affected by changes in population under similar conditions (Osiru & Willey,1972). Higher populations were important to maintain yields in a 67% sorghum, 33% bean pattern and optimum populations were higher than for monoculture, yet neither of these trends were apparent when mixtures consisted of 33% sorghum and 67% bean (Osiru & Willey,1972).

Increasing the maize population in a maize-pigeonpea intercrop in India showed that the yield advantage increased with populations much higher than sole crop optimums, similar effects were found for a sorghum-pigeonpea mixture (ICRISAT,1978). Cummins (1973) found that soybean tended to depress the yields of corn when grown in the same row at high corn densities when not irrigated. Percent ears decreased and leaves and stalks increased as sole crop corn populations increased and the interplanting of soybean did not influence this trend. Protein content was increased (though not significantly) at the lower corn populations more than at the high populations by intercropping.

There was no reduction in maize yield caused by intercropped bean when bean densities varied and the climbing bean response to density was relatively unaffected by cropping system in Columbia (Francis, Planting Patterns. The spacial arrangement of the plants within the crop community is another component of population pressure, and is distinct from, but related to the overall density of the crop. In monoculture, the pattern of planting is manipulated by changing the degree of rectangularity (longest distance between plants divided by the shortest distance between plants), in order to adjust the between-plant competition within the monoculture crop community. Some studies have shown benefits from decreased rectangularity (more on-the-square planting) in monoculture especially at high overall densities (Weber et al,1966).

In intercrops, manipulating the planting patterns involves changing the degree of "intimacy" or closeness-of-association of the two (or more) crops. Intimacy could range from broadcast mixtures, and within-row intercrops (which are the most intimate of intercrops) to crops which are "infinitely" separated in space, ie. monoculture, which are the least intimate. Intimacy effects the amount of "border contact" or "border effect" which is affecting each component of the intercrop (Pendleton et al,1963). If the border effect is one in which resources become more available to the plant then intimacy may be beneficial, possibly leading to higher yields for that component. If the border effect is one in which resources become less available to the plant then intimacy is not beneficial and yield decreases for that component may result.

Component density must be seen within the context of the planting pattern and the competitive balance within the intercrop. Willey

(1979) has suggested that the more dominant component, and the more favorable its spacial arrangement, the more likely it is to show a population response similar to monoculture, whereas the dominated crop with the less favorable spacial arrangement will show a density-response curve greatly different from that found in sole crops. This is also supported by some researchers (Osiru & Willey,1972, Francis et al,1975).

The planting pattern effect upon yields is probably quite dependent upon the cultural and weather conditions peculiar to different areas. Cummins (1973) found that planting soybean in the row did not effect the yield of a corn-soy intercrop, nor protein percentage, yet Pogue & Arnold (1979) found that the yields of corn and soy interplanted in the row were higher than corn alone, and corn alone higher than corn and soybean planted in alternate rows. With percent protein, the alternate-row intercrop gave the highest percent protein (Pouge & Arnold,1979).

Several studies have shown a reduction of soybean when planted in the same row as corn (Dalal,1977, Herbert & Putnam,1981). Francis (1978), however, emphasized that considerable flexibility exists when designing planting patterns for bush or climbing beans in maize, although trends for lower yields with paired row patterns were found. Some have found that double rows of the taller crop, with legumes interplanted, has shown some advantage to allow light in. Double rows of corn (15" apart) with legumes in the wide centers (45" between rows) had no significant effect on the yield, but the legumes contributed only 12% under this system (Faix et al,1976). With narrow row (30 cm.) and wider row (45 cm.) and double sorghum row patterns, Freyman & Venkateswarlu (1977) found no significant effects of planting pattern on yields in a sorghum/pigeonpea system.

Criteria for Yield Advantage in Intercropping

Introduction. In monoculture crop studies, the assesment of yield advantage from various treatments is relatively easy, depending only upon the yield goals for that crop. In multiple cropping systems, the assesment of yield becomes more complex. For instance, any treatment of one component of the intercrop is almost necessarily confounded with interactions with the second crop, often in ways not expected (Mead & Riley,1981). Another reason is that the motivations for growing an intercrop (verses monoculture) are often quite varied. For example, the yield criteria for a cassava/ground-nut intercrop grown in Western Nigeria as a staple food crops is apt to be quite different from a corn-soybean mixture grown in North America to increase the protein content of silage fed to ruminants. The yield criteria might vary from farm to farm as well as from crop to crop and from region to region (Andrews & Kassam, 1976).

Criteria for assesssing yield advantage in intercropping might be broken up into two distinct but interrelated components: biological criteria and yield-goal-dependent criteria. The latter criteria for an intercropping advantage may be (and in most cases must be) based upon some sort of biological advantage. However, just because there is a margin of biological superiority in an intercrop doesn't mean that a farmer's yield goals will be satisfied. This depends upon economic, nutritional, labor, cultural, disease, risk, and personal factors.

Complimentarity and Competition. It seems that any yield advantage from intercropping (as measured by yield-goal-dependent criteria) must stem in some measure from a biological complimentarity between the two species (Willey, 1979). That is, there is some factor in nature which is more available, or less competed for, when the intercrop ecosystem is taken as a whole. Andrews and Kassam (1976) point out that in a successful crop mixture of both similar and dissimilar maturities, the sum of the inter-crop competition should be less than the sum of the intra-crop competition when each component is grown alone.

The nature of this biological efficiency may be simply a matter of time. An example of this is "relay intercropping", where one crop is maturing as another is germinating. There have been a number of crop mixtures which have been cited as being more efficient in the utilization of time (Okigbo & Greenland,1976, Trenbath,1974, Schepers & Sibma,1976, Sivakumar & Virmani,1980). Certainly a perennial crop, such as a tree crop intercropped with annuals can be seen as using time as well as other factors more efficiently (Harwood & Price,1976).

If a reduction in the time span required for two successive crops is attained by mixing the two crops in an intercrop, then a complimentarity could be said to exist with regards to time. This may be measured then as simply kg/month, or tonnes/year or season. However, simply attributing this advantage to time is misleading, as more efficient use of resources used over time may be the reason for the increased efficiency of the intercrop. Sorghum and pigeonpea when intercropped on vertisols in India effectively "lengthen" the season by allowing a near-full (shorter-seasoned) sorghum yield, as well as a respectable slower-growing pigeonpea yield, thereby using the time available more effieciently. However, more light energy was intercepted by a sorghum-pigeonpea intercrop than either sole crop, and a greater percentage of the evapotranspiration was channelled through the intercrop than either sole crop, without making a greater overall demand on soil moisture through the growing season (ICRISAT,1979). Osiru and Willey (1976) found that, whereas an advantage of 20% occurred when an 85 day bean and 120 day corn were grown together, this advantage completely dissappeared when the bean was delayed 28 days, suggesting complimentarity in resource use in the first mixture. The efficiency in the use of growth factors which are evident in these intercrops suggests that a time advantage should be thought of in both aspects: effectively "shortening" the growing season, (a literal time-advantage), and maximizing the growth resources which are used over time.

Two species may also compete or exibit complimentarity with regards to space. Plants do not compete for space per se, (except perhaps at very high densities with no other factor limiting), but instead compete for growth factors, both aerial and edaphic, which are available instantaneously to either species (Donald,1963, Trenbath,1976). In addition to competition for resources there are other interactions between plant neighbors which may occur, affecting the crop balance. These may include the action of toxic plant exudates or allelopathy (Moss & Hartwig,1980), the transfer of microbially fixed nitrogen (Ennik,1969, de Wit et al,1966), and ecological processes resulting from the interaction of rhizosphere saprophytes, parasitic fungi, viruses and other microorganisms (Cristie et al,1974,Valverde et al,1982), and herbivorous insect and mammalian pests (Litsinger & Moody,1976, Johnston et al,1978, Browning & Frey,1969, Dempster & Coaker,1974, Risch,1980). All of these between- and within-species interactions combine to form either an advantage or lack of advantage with regards to plant competition in space.

Plants require factors of light, water, nutrients, oxygen and carbon dioxide for growth, and in healthy young plants the growth rate is responsive to the absorption of any one of them when it is in relatively short supply. In newly established monocrop or intercrop stands the root density and leaf area index is low and the supply of growth factors to individual plants resembles that available to plants infinitely separated in space (isolation ideotype--Donald, 1968). As the crop grows, the proximity of the roots and the above-ground portion leads to mutual interference in the interception and absorption of growth factors. In the first stages of plant competition in intercrops, the interference will primarily be between plants of the same component. However, as the size of the plants increases, the competitive powers of the larger species (and larger plants within each species) increases, as inter-crop competition begins at the interface between the two species (Trenbath,1976).

Inter-crop competition can be quite severe, especially for light, where small differences in height even early in growth can lead to substantial reductions in the light available to the less competitive crop. When a mixture of small and large seeds of subterranean clover (Trifolium subterranean) were planted, the plants from the large seeds so dominated the plants from the small seeds that they obtained only 2% of the incident light after 82 days (Black,1958). In Tanzania, the yield of soybean under a short maize cultivar was 17% more than under a tall maize cultivar (Thompson et al,1976), an effect also observed in corn-cowpea mixtures (Wahua et al,1981). In a 50/50 maize bean intercrop the light available to the beans was reduced by 50% at low corn densities and by 80% under high corn densities and thinner leaves developed in the intercropped beans, characteristic of plants under light stress (Gardiner & Craker, 1981). The average amount of light transmitted by a sorghum canopy to interplanted soybeans ranged from 46% for a low density sorghum to 8% for the high density sorghum (Wahua & Miller,1981). Both of these row-crop expermiments show the importance of density in aerial competition.

Competition for soil factors is often considered less important than light competition in intercrops (Willey & Roberts,1976, Willey,1979, Crookston et al,1975, Gregory & Reddy,1982). Others argue that since there are more soil factors to consider (water, N, P, K, Ca, Mg, etc.), that by the laws of probability, below ground interactions should more often lead to intercropping advantage than above ground interactions. Further, light is rarely limiting in regions where most intercropping is practiced (Snaydon & Harris,1979). Clearly, root interactions are vastly more difficult to describe and so have received less attention.

Some studies have shown that when species (or cultivars) are grown together, they may extract water or minerals from different strata of the soil (Trenbath,1975, Raper & Barber,1970) or utilize nitrogen from different sources (Snaydon & Harris,1979), exploit minerals more efficiently, eg. potassium (Dalal,1974) or nitrogen (Lakhani,1976, Eaglesham et al,1981), or make better use of water in tropical areas (Baker & Norman,1975). The mechanisms for yield advantages due to below-ground interactions are not clearly elucidated, with differences in rooting patterns, temporal effects of peak nutrient and water use to spread out demand, transfer of nutrients from one crop to another, and yield maintenence under conditions of low fertility being proposed (Willey,1979, Snydon & Harris, 1979, Nair et al,1979).

The nature of above and below ground resources for which plants compete are inately different. The below ground resources can be thought of as a pool, which is either depleted or renewed according to environmental conditions, fertility practices and plant uptake. The above ground resources (light primarily) are only available instantaneously, and as a "passing stream" they are either intercepted or not at a certain point in time (Donald,1963). The highly interactive nature of these different factors must also be emphasized. Trenbath (1976) states "If a plant individual or a component of an intercrop absorbs less than its share of one competed-for growth factor, it is likely to aquire a correspondingly small share of all growth factors". Thus a plant with a small shoot and leaf system will receive less light in a dense crop community, resulting in a smaller supply of photosynthate to the root. The relatively smaller root will then compete less favorably for water and nutrients, again making the foliage less competitive for light (Donald,1958, Duncan,1969, Hall,1974). This reinforcing aspect of plant competition present within sole crops can be even more pronounced with inter-species competition, where the size of the plants is likely to differ more severely.

Attempts have been made to separate the above and below-ground competition (Willey & Reddy,1981, Donald,1958, Snaydon,1979). In intercropping such detailed competition studies are rare, and more commonly, the competitive effects between intercrops are evaluated using indices which delineate competitive effects in a broad sense.

"Biological" Criteria.

"Actual vs. Expected" Comparisons. Willey (1979) has proposed the terms "mutual inhibition", "mutual cooperation" and "compensation" to describe three competitive situations which might exist in mixed crops. These are distinguished by comparing the actual yields obtained in an intercrop to those "expected" yields for each for each species, a comparison used as the basis of a "Complimentarity" (C) value by Remison (1978). "Expected" yield is calculated as the yield obtained if the interspecific competition was equal to the intra-specific competition. It is recognized that the competition in intercrops is rarely the same as competition in monoculture, but this provides a basis for comparison. Thus in a replacement series experiment where 50% of the rows of one crop are replaced in a regular fashion by rows of another crop, the expected yield of each component would be 50% of its yield in monoculture, since each intercrop row is directly comparable to equivalent monoculture rows. In a 67/33 mixture, the expected yield of the first crop would be 67% of its monoculture yield.

Mutual inhibition exists when the intercrop yield is less than expected for both crops, with a net decrease in total yield below expected. This has been observed (Ahlgren & Aamodt,1939), but is considered rare in practice. Mutual cooperation is a situation where both crops yield more than expected, leading to a net increase in actual yield over expected. This has been described for some mixtures, especially in mixtures of grains (Johnston et al,1978, Frey & Maldonado,1967). It is clear that in the first case there is no biological advantage to intercropping, and in the second case, there must be a biological advantage. In the case of compensation, the advantage to intercropping is not so obvious. Compensation occurs when one intercrop component yields more and the other component less than expected. This may produce total intercropped yields which are above those expected (positive compensation), yields which remain the same (equal compensation), and in which the compensatory component does not make up for the loss of the dominated component, causing a net loss in total yield (negative compensation, see Figure 1).

There are several problems with this type of comparison. First,it must be decided what the sown proportion of the two crops is. This is difficult in mixtures of broadcast forages, but also when using row crops where the plants are interseeded within a row, immediately beside a row, or when multiple rows are used. Furthermore, plants do not merely grow to fill our Euclidian concepts of space, but instead are inclined to follow their own habit of growth and fill their "plant space" according to their nature and genetic instruction. The allocation of 50% of the land to beans and 50% of the land to corn in an intercrop, for instance, does not mean that these crops will "occupy" and utilize only these portions in geometric fashion. A replacement series alleviates this problem to some extent, this being the only situation where this comparison is applicable (Mead & Riley,1981).

Secondly, Willey (1979) points out that because the species usually differ in competitive ability, the combined mixture yield in such a comparison will contain a bigger proportion of the dominant species than does the combined pure stand yield. Thus if the dominant species is the higher yielding (which is usually, but not necessarily the case), the comparison is biased in favor of intercropping. Conversely, if the dominant species is the lower yielding, the

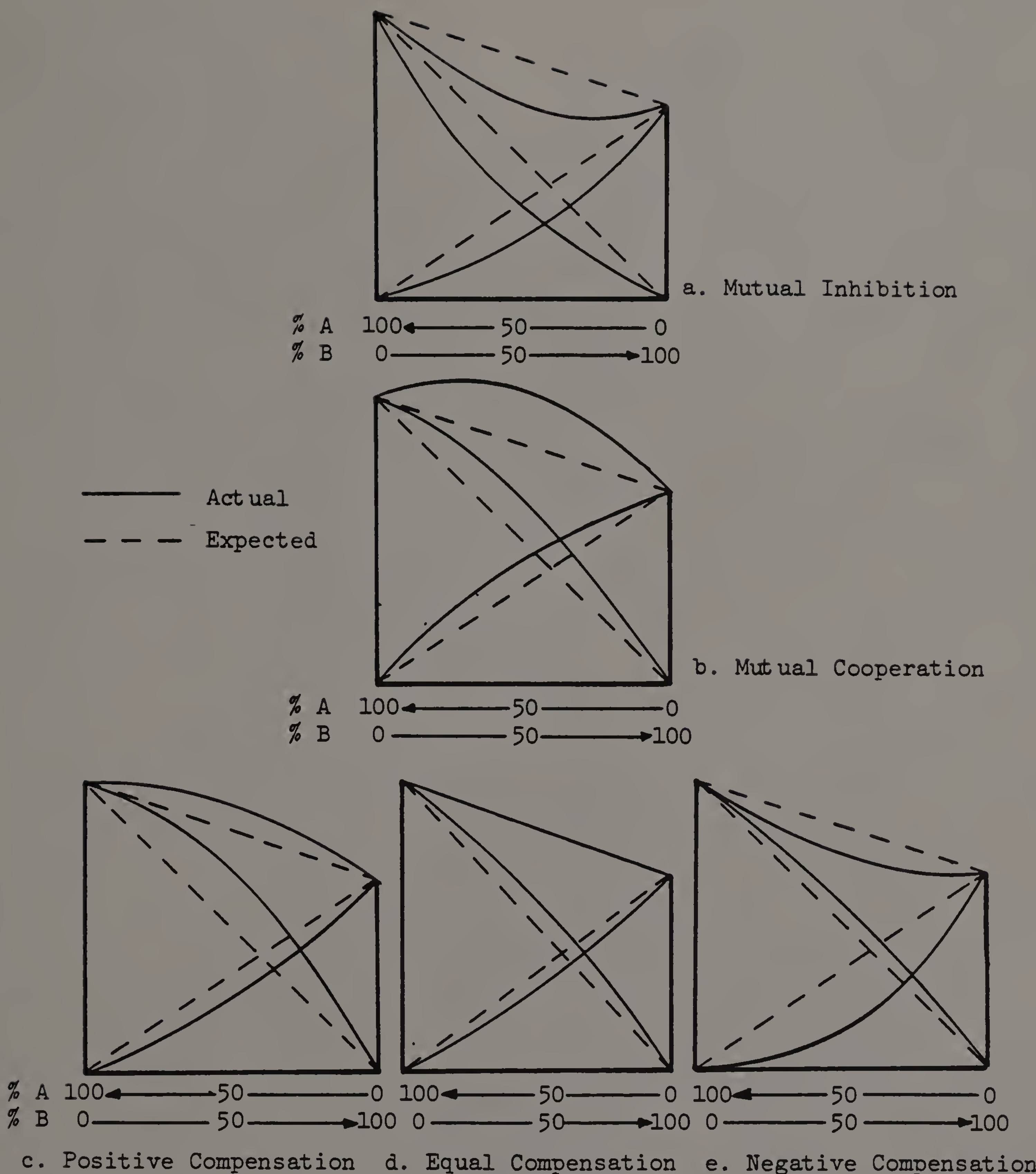


FIGURE 1. Types of "Actual vs. Expected" comparisons (planted areas). Solid line represents actual intercropped yields, broken line represents yields expected if intercrop competition was equal to monoculture competition (adapted from Willey, 1979).

comparison is biased in favor of pure stands. The bias may be eliminated by calculating the proportions of sole cropping which would be required to give the same final yield proportions as in intercropping (Willey & Osiru, 1972), and comparing the actual intercropped yields to expected sole crop yields at the same yield proportion (as opposed to planted proportions- see table 1). The first part of this calculation is the same as that for Land Equivalent Ratio described later in this section. This is a more rigorous test of yield advantage from intercropping than comparing on the basis of planted proportions. When the compensation effect exists in an intercrop (the compensation of the loss of one component by the gain in the other), an advantage shown by comparing sown proportions may not show up when comparing harvested proportions (Table 1, Willey,1979). Comparing the harvested proportions in intercropping would likely be more useful to a farmer, and it is also a "biological" comparison, as the ability of a single unit-area of ground to produce a certain yield is tested for both intercropping and sole cropping. This comparison reflects approximately the same yield advantage level as LER.

Relative Crowding Coefficient. The Relative Crowding Coefficient (RCC) was proposed as a comparison of actual verses expected yield per plant by de Wit (1960) and elaborated on by Hall (1974). Modified for a replacement series, each crop component is given a coefficient (k) which measures the increase or decrease of actual yield verses

TABLE 1. Comparison of two hypothetical 50/50 intercrops on a planted ratio, LER, and harvested ratio basis. Both mixtures show an advantage when compared with monoculture on a planted area basis, but only mixture 1 shows an advantage when compared on a harvested ratio basis. LER reflects the same magnitude of advantage or disadvantage as comparison on a harvested ratio basis (Adapted from Willey, 1979).

	Intercropped Yields[a]	"Expected" Yields[b] (Planted Ratio)	LER[c]	LER Proportion[d]	"Expected" Yields (Harvested Ratio)[e]	Harvested Ratio[f] of (a) and (e)
	t/ha	t/ha			t/ha	
Mixture 1						
Crop X	17	12	.71	.514	12.3	.81
Crop Y	4	3	.67	.486	2.9	.19
Total	21	15	1.38	-	15.1	-
Mixture 2						
Crop X	15	12	.62	.653	15.6	.88
Crop Y	2	3	.33	.347	2.1	.12
Total	17	15	.95	-	17.7	-

a. Actual intercropped yields.
b. Yields "expected" if intercropping competition was equal to monoculture competition (on planted area basis; in this case, yield in monoculture X .5).
c. Units of land area in monoculture required to achieve the same yield as in intercropping.
d. Proportion of land area required in monoculture to achieve the same yield proportion as in intercropping (proportion of component LERs).
e. "Expected" monoculture yields if land was planted to (e) proportion of X and Y.
f. Yield proportion of the mixture (a), and of the calculated sole crop yields (e).

expected yield on a land-area basis. For any crop mixture it can be generalized as:

$$kab = \frac{Yab \times Zba}{(Yaa - Yab) \times Zab}$$

$$K = kab \times kba$$

Where	kab	is the Relative Crowding Coefficient for a within the ab intercrop.
	Kba	is the Relative Crowding Coefficient for b within the ab intercrop.
	K	is the Relative Crowding Coefficient for the ab intercrop.
	Yab	is the yield of a in the ab intercrop.
	Yaa	is the yield of a in pure stand.
	Zab	is the sown proportion of a in the ab intercrop.
and	Zba	is the sown proportion of b in the ab intercrop.

Thus, in a 50/50 mixture, if the Yab is greater than 50% of the yield of Yaa then k is greater than 1. In general, a crop component which competes successfully in an intercrop has a k greater than 1, and the suppressed component might have a k value less than 1, and in any case, the component with a higher coefficient is the dominant one. To determine if there is a yield advantage to mixing, the two coefficients are multiplied, giving K or the coefficient for the whole mixture. If K is greater than 1, there is a yield advantage to intercropping, if K = 1, there is no difference, and if K is less than 1, there is a yield disadvantage.

It should be pointed out that the coefficient for one component may mean quite different things depending upon the coefficient for the other crop. Thus if one crop had a k value of 1.4, one would conclude that it was the dominant component or at least competed successfully in the mixture. However, the nature of this competition would be quite different if the k value for the other crop was 0.3 or 3.5. The relative value of k for each component can tell you which crop is "more" or "less" competitive, in relation to the sole crop yield, but has been criticized for not really indicating the between or intercrop competition (Willey & Rao,1980).

Aggressivity. Another measure of competition within mixtures, Aggressivity, was proposed by McGilchrist (1965). This gives a measure of how much the relative yield increase in species a is greater than that for species b in a replacement series, and is defined as:

$$Aab = \frac{\text{Intercrop Yield of a}}{\text{Expected Yield of a}} - \frac{\text{Intercrop Yield of b}}{\text{Expected Yield of b}}$$

$$= \frac{Yab}{Yaa \times Zab} - \frac{Yba}{Ybb \times Zba}$$

Where Aab is the Aggressivity value for a in the ab intercrop.
Yab is the yield of a in the ab intercrop.
Yaa is the yield of a in pure stand.
Yba is the yield of b in the ab intercrop.
Ybb is the yield of b in pure stand.
Zab is the proportion of a in the ab intercrop.
and Zba is the proportion of b in the ab intercrop.

An aggressivity value of 0 means that each is equally competitive. For unequal competition, aggressivity values for each species are always of equal value but opposite in sign, and indicate in magnitude the extent of competition and in sign whether the crop is the more competitive (+) or less competitive (-) species (McGilchrist & Trenbath,1971). This has the advantage of simplicity in that at a glance the nature of the competition can be seen. However, this will not give a sense of the level of yield advantage, because it is based upon a simple difference. Thus two different intercrop combinations, both with Aggressivities of plus or minus .5 are equated in terms of competitive abilities , even though the magnitude of yield advantage (measured by LER or Actual vs. Expected comparisons) of one mixture may be quite a bit higher than the other (Table 2).

Competition Index. A technique to formulate a "Competition Index" was proposed by Donald (1963). He sought to answer the question 'How many additional plants of crop a (over the same area) would have the same competitive effect on yield as the intermixture of crop b does on the intercrop?'. An "eqivalence factor" is calculated for each component. For species a, the equivalence factor is the number of plants of species a which is equally competitive (or yields the same) as one plant of species b in the ab intercrop. If the equivalence factor for a species is less than one, then the species is considered more competitive, ie. less than one plant of that species is equally competitive as one plant of the other species.

TABLE 2. Measurement of aggressivity for two hypothetical mixtures, compared with LER and "Expected" yields. Competitive ability (measured by aggressivity) of crops A and C and B and D are equal, whereas yield advantage of Mixture 1 (ability of intercrop to avoid competition and exploit resources more efficiently) is much greater. Crops C and D would best be grown as sole crops (compared with Mixture 2).

Monoculture Yields:

Crop A = 24 Crop C = 28
Crop B = 6 Crop D = 20

Intercropped Yields:

	Component	Yield	"Expected Yield"	Aggressivity	LER
Mixture 1	Crop A	22	12	+0.5	0.92
	Crop B	3	3	-0.5	0.50
	Total	25	15	-	1.42
Mixture 2	Crop C	16	14	+0.5	0.57
	Crop D	6.4	10	-0.5	0.32
	Total	22.4	24	-	.89

The Competition Index puts a value on the competitive association in the intercrop as a whole, and is calculated as the two equivalence factors multiplied together, or as:

$$\frac{\text{Pa X Pb (Number of Plants in Pure Culture Equivalents)}}{\text{Ia X Ib (Actual Numbers of Plants in Intercrop)}}$$

Thus if below 1, the mixture "tolerates" competition at higher total densities and since it is a product of numbers, it gives an appropriate mean sense of this competition. The mixture tolerates greater numbers of the interplanted species than would be predicted on the basis of intra-specific competition alone (Donald,1963). If the competition index is above one, a harmful association is indicated.

However, in order to determine a "competition index", it is necessary to grow each species in pure culture at a sufficient range of densities to construct a density/yield curve, so that equivalent plant numbers can be estimated. This is not only time-consuming, but can be prone to greater error. Given the wide range of densities to be considered in intercropping and the cumbersome task of constructing "pure culture equivalents" (Willey & Osiru,1972), the use of this competition index is of limited practical use, although the concept is useful (Willey,1979, Mead & Riley,1981).

<u>Land Equivalent Ratio.</u> A simpler proceedure has been propsed to descibe the advantages or disadvantages to intercropping, called the

Land Equivalent Ratio (Mead & Willey,1980). This is defined as the amount of land required in monoculture to give the same yields as those attained in intercropping. An LER term for each crop component in the mixture is calculated as:

$$La = \frac{Yab}{Yaa} \quad \text{and} \quad Lb = \frac{Yba}{Ybb}$$

and the sum of these is the total LER or:

$$LERab = La + Lb$$

Where	La	is the land equivalent ratio for crop a in the ab intercrop.
	Lb	is the land equivalent ratio for crop b in the ab intercrop.
	Yab	is the yield of crop a in the ab intercrop.
	Yba	is the yield of crop b in the ab intercrop.
	Yaa	is the yield of crop a in pure stand.
	Yaa	is the yield of crop b in pure stand.
and	LERab	is the land equivalent ratio for the ab intercrop.

If the LER is above one, a "land efficiency" is attained and there is an advantage to intercropping, and if less than one, the land is better put to use in monoculture. The LER is analagous to the Relative Yield Total or RYT described by de Wit and van der Bergh (1965).

There are several important advantages to this method of evaluation, the least of which is its simplicity in conception and calculation. A replacement series is not required to evaluate yield advantage as it is in the other indices mentioned. Only sole crops grown at appropriate densities for maximum yields for purposes of comparison are needed. Thus any type of mixture can be tested including within row and broadcast mixtures. Secondly, crops with different levels of yield are put on a relative and directly comparable basis. This not only gives an indication of the relative competitive abilities of the component crops in the intercrop, but also shows the actual value of any intercropping advantage. An LER of 1.20 of an intercrop expresses an intercrop advantage over sole crops of 20% on a land-area basis. This is especially pertinent in that most yields are expressed on a land area basis. The biological advantage is expressed on a relative yield basis rather than on theoretical comparisons based upon planted area as is the case with aggressivity and the relative crowding coefficient. The LER comparison has been received widely in intercropping work in recent years.

Some workers have emphasized that LERs for intercrops be based upon densities for the highest attainable sole crop yield, recognizing that the ideal populations in monoculture may be quite different than those in intercropping (Rao & Willey,1980, Huxley & Maingu,1978). This is undoubtably a more rigorous comparison than comparing (row equivalent) densities when density is varied in a replacement series. However, inferences about biological competition can be drawn from both types of comparisons. When the same density on a row equivalent basis is used as the denominator, the competitive effect of replacing, for instance, a row of crop a with a row of crop b is measured at each density. Using the highest attainable sole crop yield as a measurement of intercropping success, the ability of the land to sustain optimum popoulations in monoculture and in intercropping is evaluated, a measurement of overall biological success.

Methods of standardization for LER have been reviewed by Mead & Riley,1981 and further explored by Oyejola & Mead,1982. Precision of treatment comparisons was improved by using the highest yielding genotype or the average genotype verses using individual genotypes sole crop yields for calculation of LER in an intercropping experiment using 4 millet and 4 sorghum genotypes in a randomized block design (Mead & Riley,1981, Pantelides,1979). In another comparison of six methods of calculation of LERs (sole crop divisor as the average of all treatments, each treatment, or the best treatment both from all blocks and from each block), researchers could detect no reasons to use different divisors in different blocks. It was recommended that the calculation of LERs should be made using a single sole crop yield for each crop (ie average of all or the best sole crop), and the same sole crop yields should be used for all blocks (Oyejola & Mead,1982).

Competitive Ratio. More recently, researchers have proposed the idea of a "Competitive Ratio" to quantify the competition between intercrops (Willey & Rao,1980). This encompases the ideas of Aggressivity and the Land Equivalant Ratio and proports to answer the objections to the "Relative Crowding Coefficient" discussed earlier. The Competitive Ratio is calculated as:

$$CRa = \frac{Yab}{Yaa \times Zab} \div \frac{Yba}{Ybb \times Zba}$$

$$= \left(\frac{Yab}{Yaa} \div \frac{Yba}{Ybb}\right) \times \frac{Zba}{Zab}$$

$$= (LERa / LERb) \times \frac{Zba}{Zab}$$

Where	CRa	is the Competitive Ratio for a within the ab intercrop.
	Yab	is the yield of a within the ab intercrop.
	Yba	is the yield of crop b in the ab intercrop.
	Yaa	is the yield of crop a in pure stand.
	Ybb	is the yield of crop b in pure stand.
	Zab	is the proportion of a in the ab intercrop.
	Zba	is the proportion of b in the ab intercrop.
	LERa	is the LER for crop a in the ab intercrop.
and	LERb	is the LER for crop b in the ab intercrop.

This is then just the ratio of the terms used in the aggressivity equation (rather than a difference), and is also equal to the ratio of the individual LERs for each component crop, corrected for the proportion in which the crop was initially sown.

In a 50/50 intercrop, the proportion term drops out, and the Competitive Ratio is just the ratio between LERs for each crop component, or stated differently, the land efficiency of one crop in relationship to the land efficiency of the other crop. The CR terms for the two components of a mixture are reciprocals of each other. Suggested uses of the Competitive Ratio have been to test competitive changes within a given combination (ie. density), the identification of characters determining competitive abilities, and the determination of the optimum balance of competition between intercrop components (Willey & Rao,1980).

The CR is also limited to a replacement series, as the term is corrected for planted area, excepting that the LER component may be figured using the highest attainable sole crop yield as shown earlier. Also, no overall term (such as K or total LER) is developed to indicate a competitive advantage or disadvantage to the intercrop as a whole. Thus, if each component of the intercrop produced LERs of .8 in the intercrop (unlikely, but possible), the two crops undoubtably would be equally competitive (CR=1), but the overall competitive advantage (the ability to avoid competition for resources in the mixture) would not be apparent.

Other Indices. Several additional indices have been developed to measure yield gains in multiple cropping systems, not necessarily narrowly limited to intercropping, but as applied to a whole range of multiple cropping situations. The Multiple Cropping Index (MCI) is the sum of areas planted to different crops and harvested during a single year divided by the total cultivated land area times 100 (Dalrymple,1971). The Cultivated Land Utilization Index (CLUI) is calculated by summing for the whole cropping system: the amount of land planted to each component crop multiplied by the actual duration (in days) of that crop, divided by the total cultivated land area times 365 days (Chuang, 1973). Such an index might be helpful in asessing advantage with regards to time, but says nothing about the relative yields of each component. It has been proposed that the intensity of land use in a multiple cropping system be measured with the use of a Crop Intensity Index(CII). This "asesses a farmer's actual land use in area and time relationaships for each crop and group of crops compared to the total available land area and time, including land that is temporarily available for production" (Menegay et al,1978). It is calculated by summing for the whole cropping system: the amount of land planted to each component multiplied by that crops' duration in the field, divided by the product of the farm operator's total available land area multiplied by the time period being studied (usually one year). This is added to the sum of products for temporarily available land multiplied by the time that these are actually available. Two derivatives of the CII, the Specific Crop Intensity Index (SCII), and the Relative Crop Intensity Index (RCII) compare the amount of area-time available to a crop or group of crops in relation to the total area-time available, and area-time actually used, respectively.

These indices are oriented towards asessing multiple cropping systems for rural economic planners, and for chosing systems which will be most highly productive for small farmers. There is some overlapping of purposes in several of the above-mentioned indices, for instance, the MCI is analogous to the LER term. However, the MCI does not consider yields in its calculation. The terms considered under

"Other Indices" are concerned mainly with time-complimentarity not yield complimentarity, and furthermore are not applicable to intercrops which must be harvested at the same time.

Comparison Between Methods. A comparison between Relative Crowding Coefficient, Aggressivity, LER and Competitive Ratio for two mixtures studied in Massachusetts in 1981 (Herbert & Putnam,1981) is made in Table 3. All of the functions indicate which crop is the more competitive of the two. Only the Relative Crowding Coefficient and the LER term indicate the competitive advantage of the entire mixture. On the degree of competition there are some descrepancies. The CR term implies, according to its authors (Willey & Rao,1980), that the corn was 2.1 and 1.4 times as competitive as the soybean in Mixture 1 and 2 respectively. The Relative Crowding Coefficient and Aggressivity gives a different quantitative picture of competition if one extrapolates in the same fashion. The k value (Relative Crowding Coefficient)is calculated by comparing the yield in intercrop with the missed yield or reduction of yield from monouculture (Yaa - Yab), corrected for the planted ratio. The denominator is continually changing, giving multiplicative leaps in the coefficient with higher intercrop yields. This makes the quantitative nature of competition difficult to interpret using this index, although qualitatively it gives the same description of competitiveness of the whole crop as LER (Table 2).

TABLE 3. Comparison Between Relative Crowding Coefficient, Aggressivity, Land Equivalent Ratio and Competitive Ratio. Data is for two 50% corn/50% soybean mixtures in a replacement series (Herbert & Putnam, 1981).

COMPONENT	YIELD	RCC	AGGRESSIVITY	LER	CR
	t/ha				
Mixture 1					
Corn	19.5	k = 3.31	A = 0.817	.768	2.14
Soybean	4.2	k = 0.56	A = -0.817	.359	.47
Total	23.7	K = 1.85	-	1.127	-
Mixture 2					
Corn	16.0	k = 1.70	A = 0.388	.630	1.44
Soybean	5.1	k = 0.68	A = -0.388	.359	.69
Total	21.1	K = 1.16	-	1.066	-

The Aggressivity term implies a hpothetical "equally competitive" 0 point, which might represent plants exactly in-between the competitive abilities of the two component crops; the idea of a "competitive mean", to which the intercrop component is either more (+) or less (-) competitive than. The implied mathematical assumption here is somewhat misleading, as the differences in competitive abilities may not be equally distributed between species. One crop may gain in its exploitation of resources in a mixture, but all of this gain may not be at the expense of the companion crop, which may also compete adequately.

Only the LER term may be translated into units (ie. land area required in monoculture) therefore is perhaps more meaningful measure of competition.

It is debatable whether such quantitative inferences about competitive ability are valid, given the vast complexity of the competitive relationship in the field. Difficulties arise in interpreting a coefficient of dominance in that apparent dominance is related to sole crop yields. It is possible to reverse dominance patterns by changing sole-crop densities (Mead & Riley,1981).

Willey (1979) compared the Relative Crowding Coefficient, Aggressivity, and the LER using a 4 x 4 factorial experiment with 4 millet and 4 sorghum genotypes. All of the functions agreed on which species were dominant, which dominated, and on where neither species were dominant for each combination. The RCC and the LER showed the same pattern of yield advantage or disadvantage, although they differed on the magnitude thereof. Willey argued for the LER as the most useful because it showed the true magnitude of advantage and because it is not confined to a replacement series.

In spite of these difficulties, from an agronomic point of view it is useful to describe the biological competition which exists in mixed stands. Competitive ability was negatively correlated with root yield in monoculture cassava and the yields of beans and soybeans were negatively correlated with vegetative vigor of the associated cassava genotypes in a cassava/bean intercrop system in Columbia (Kawano & Thung,1982). It is important, however, to distinguish the goals of intercropping experiments from the goals of competition experiments with mixtures. In an intercropping experiment, the objectives are essentially agronomic: determining the best way of growing an intercrop and the value of certain treatments in meeting a farmers yield goals. In competition experiments, the goals are purely biological: to learn the mechanisms of competition between species and the effects of treatments upon competiton (Mead & Riley,1981). Describing the competitive relationships are important to the agronomist since the optimum balance of competitive forces in the crop may lead to a yield advantage.

<u>Yield-Goal-Dependent Criteria.</u> It may not be so obvious that different yield requirements must be satisfied in different intercropping situations and that the method of assesssment must reflect this. Willey (1979) describes three situations in which the

yield requirements for intercropping are distinct. These may be termed "yield-goal-dependent criteria", and may vary according to region, level of management, crop, or from farm to farm:

1) Where intercropping must give a full yield of a "main" crop and some yield of a second crop.
2) Where the combined intercrop yield must exceed the higher sole crop yield (ie. grassland mixtures).
3) Where the combined intercrop yield must exceed a combined sole crop yield.

The first situation is often applicable to farmers who must have a full yield of some staple crop, plus some "bonus" crop, which is interplanted. The yield is then clearly assesssed by any additional yield of the second crop. Intercropping of sorghum/pigeonpea and other mixtures in India have been evaluated this way (ICRISAT, 1979 The second situation arises when either crop is equally acceptable, such as in grassland mixtures (Donald,1963). The most advantagous cropping system is the highest yielding system, regardless of the percentage of either crop. The assesssment of yield here is relatively straight forward (Frey & Maldanado,1967, Trenbath,1974). The third situation is one in which the farmer needs to grow more than one crop for various reasons, ie. for a balanced diet, for economic reasons, to spread out labor peaks, etc. A yield advantage would occur if the intercropping treatment gives higher yields than growing both of the component crops separately. In this case "growing separately" might be evaluated, as discussed above, in terms of yield ratios, planted ratios, or LERs. The combined intercrop yield does not have to exceed the higher sole crop yield, as this is not a viable alternative to the grower. The assessment of magnitude or even existence of yield advantage is often elusive under these criteria, and the use of competitive functions which compare intercrop competition with sole crop competition may be most useful (Willey, 1979).

To these three yield-goal situations we might add a fourth:

4) When an <u>acceptable</u> yield must be maintained with an increase in yield quality.

This situation is applicable to growers attempting to improve the quality of corn silage fed to ruminants, or to increase the protein content in grass-legume mixtures, and perhaps even to subsistance farmers who want to improve the quality of their own diets. This is distinct from the situation described in (3), as "acceptable" intercropped yields may be equal to, greater than, or less than the higher yielding sole crop. Thus, yield evaluation would be tied in with any corresponding increase in yield quality that was attained. A higher yielding 90% corn, 10% soybean silage may not be as desireable as a lower yielding 60% corn, 40% soybean silage. Conversely, some farmers would not be willing to accept a decrease in yield for an increase in protein, and so "acceptable" would be equal to the higher yielding corn monoculture component. Several of the biological comparisons mentioned earlier are useful in a general sense for this situation but will not tell a farmer at a glance whether a mixture is worthwhile or not. Such decisions are inevitably based upon micro-economic and land-use conditions peculiar to each farmer, and are difficult to generalize.

Economic Yield Criteria. When considering yield-goal-dependent criteria for intercropping success, the more practical observer would ask the question "Does it pay?". Because of the variability of economic forces, and the complexity of some economic assumptions, this criteria has been used only infrequently in evaluating intercrops. Schroder and Warken (1981) compiled economic data on nine intercropping treatments involving yam and found that labor productivity, land productivity, gross margin, returns to management, risk and capital requirements were greater for all intercropping systems than for yam monoculture. The authors state that "economics and agronomy are inseparable in researching intercropping systems". When corn, sorghum and eight legumes were intercropped in semi-arid India, the yield was measured in gross returns, with the most increase in gross returns coming from a sorghum-groundnut mixture (as compared with sorghum alone) (Reddy et al,1980). Economic criteria can give quite a different assessment of the success of an intercrop than pure yield data. A corn-groundnut intercrop which yielded 29% more than corn alone in the above mentioned study, gave an increase of 56% in gross returns (Reddy et al,1980).

Hildebrand (1976), recognizing the problems and complexities of evaluating multiple cropping systems, lists five criteria for the units to be used in evaluating a cropping system. These are that it 1) must be common to all products (ie protein or dry matter), 2) be easy to measure, 3) be capable of reflecting quality differences between the products, 4) provide a means of comparing different cropping systems, and 5) be meaningful to the farmer. Although other measurements, such as energy, come close to satisfying these criteria, Hildebrand claims that only the market value of the products meets all five criteria, and so is the unit of choice.

Several economic-based indices have been used to evaluate multiple cropping systems (not confined to intercropping). The Diversity Index (DI) measures the multiplicity of crops or farm products which are planted during a single year by computing the sum of squares of the share of gross revenue receive from each individual farm enterprise during a single year (Strout,1975). The Harvest Diversity Index (HDI) is computed using the same calculations as the DI except that the value of each farm enterprise is replaced by the value of each harvest (Strout,1975). The Simultaneous Cropping Index (SCI) is computed by multiplying the HDI times 10000 and dividing the product by the MCI (Multiple Cropping Index, described in preceeding paragraphs).

Monetary values have been used in evaluating some intercrop systems (ICRISAT Report, 1977-78, Natarajan & Willey,1980a, Edge et al,1976, Gomez & Zandstra,1977, Francis,1978, Reddi et al,1980, Ahmed & Rao,1982) although the indices mentioned have not been widely used.

Conclusion. Perhaps the message in this (often confusing) array of different methods used to assess yield advantage in multiple cropping is that the complexity of polyculture demands specific criteria to fit varying needs. The agronomist's role is to provide the yield information for a variety of intercropping treatments and to study the plant interactions involved so that intelligent decisions may be made. Evaluation of competition is important in judging potentials for modification of an intercropping system. However, it is important to consider the yield objectives of each situation so that correct comparisons can be made in relation to the needs of the farmer. In most cases, more than one comparison should be used in evaluating intercropping (Mead & Stern,1980). Both biological and yield dependent criteria should be used specifically befitting each situation encountered.

CHAPTER III

METHODS AND MATERIALS

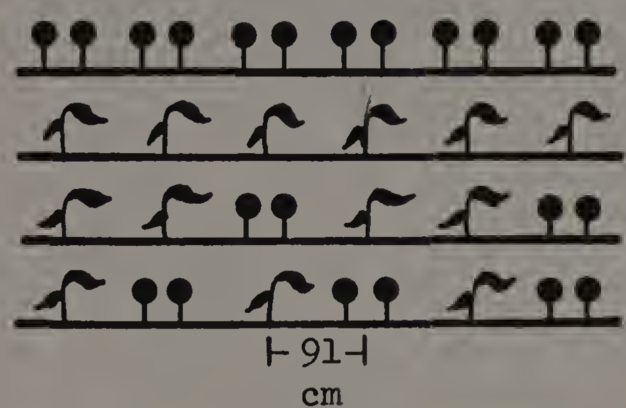
Cornell 281 field corn was interplanted with Williams (Maturity Group III) soybeans in ten treatment combinations (including controls) at the South Deerfield, Massachusetts Agricultural Experiment Station Farm in 1981. The soil type is a Hadley silt loam, a Typic Udifluvent.

The site was fertilized at the rate of 25.8 kg N, 11.3 kg P, and 21.4 kg K per hectare and lime applied at the rate of 3672 kg/ha. The site was preceeded by corn in 1980.

Corn was intercropped with soybeans in a modified factorial, randomized block design, with the factorial described as three corn densities by three planting patterns involving corn plus one soybean monoculture (10 treatments with four replications). The planting patterns as diagrammed in Table 4 were 1) Soybeans alone planted in double rows 35 cm apart on 91 cm centers, 2) Corn planted alone in rows 91 cm apart, 3) Corn and soybeans intercropped in a 50/50 ratio, with alternate rows of corn replaced with a double row of soybeans 35 cm apart, 4) Corn and Soybeans planted in a 67/33 ratio, with every third row of corn replaced with a double row of soybeans 35 cm apart. Three corn densities of 49420, 74130,and 98840 plants/ha (monoculture basis) were obtained by changing the between-plant spacing, which

TABLE 4. Treatment planting patterns and densities forming a replacement series. Two rows of soybean replace one row of corn when intercropped.

PLANTING PATTERN	DENSITY			
	CORN			SOYBEAN
	Low	Med	High	
	plants/M of row			
SOYBEAN-SOYBEAN	-	-	-	18
CORN-CORN	4.5	6.8	9.0	--
CORN-CORN-SOYBEAN	4.5	6.8	9.0	18
CORN-SOYBEAN	4.5	6.8	9.0	18



corresponds to 4.5,6.7 and 9.0 plants/meter of row respectively. The intercropping treatments are a part of a replacement series, which means that the corn and soybean densities in intercropping are directly comparable to the monoculture treatments on a row equivalent basis (not a land-area basis). Plots were six (row equivalent) rows wide and 10.7 meters long. Planting was accomplished with a cone-type seeder. The corn was planted on May 25, 1981 and soybeans on May 26, 1981.

Weeds were controlled by the use of a post-emergence treatment of Dinoseb (2- *sec* -butyl-4,6-dinitrophenol) at the rate of 4.26 kg/ha.

Soybean and corn growth samples (0.3 m2) were taken approximately every two weeks beginning June 25 (31 days after planting). Fresh and dry weight of stems, leaves, and pods were taken, and height and leaf area were measured at each sample date.

Measurements of leaf area were made on the leaf and petiole of soybeans, and on all leaves, including ear leaves of the corn to leaf node using a Licor LI-3100 Area Meter. Height measurements on corn were taken from the soil to the tallest leaf or tassel, and for soybeans from soil to growing point.

Soil moisture was determined gravimetrically 39, 53, 81, and 94 days after emergence. samples were taken at two depths, 0-30 cm and 30-60 cm and at two locations, within the row (in soybean this was between the double row centers) and midway inbetween rows for all treatments. In intercropping treatments, within row samples were taken from each species, and the between-row sample was taken between corn and soybean rows.

Final yields were measured September 8, when the corn was at physiological maturity and the soybeans were at growth stage R6 (Fehr & Caviness, 1977). Three meters of row of both corn and soybeans were measured and number of plants, height of plants, number of ears, weight of ears, and fresh weights were recorded. Corn subsamples of ears and stover and soybean subsamples were taken for dry matter determination. An additional soybean subsample of 10 plants was taken for determination of fresh weight, height, pod weight, seed weight, and growth stage.

Subsamples of corn and soybeans were dried to a uniform moisture content, finely ground and recombined in the correct dry matter yield proportions for determination of crude protein using the Kjeldahl method for determination of total nitrogen (AOAC,1975).

CHAPTER IV

GROWTH AND DEVELOPMENT OF A CORN-SOYBEAN INTERCROP

Introduction

Plant competition in a crop community begins when some growth factor becomes less available to the plant in a community than what is available to a plant in isolation (Trenbath,1976). In mixed row crops, interference will first be between plants of the same species, but as the size of the plants increases, interaction between species becomes more important.

Interaction between species may be manifest as a reduction in yield of the less competitive crop (the dominated component), and/or as an increase in in yield of the dominant species at any time during the growing season. This is the most common competitive situation in mixed crops, although mutual cooperation and mutual inhibition are also possible (Willey,1979).

A description of the accumulation of dry matter and leaf area over time can indicate how the plants interact during the growing season and when such competition takes place. This information can be useful in proposing alternatives in cropping patterns such as time of planting, densities, and cultivars which may cause a reduction in any deleterious competitive effects observed during critical times of growth.

The object of collecting growth data for this study was to identify the level and time of inter-specific competition within the intercropping treatments and how the degree of competition was related to corn density and planting pattern.

Results and Discussion

The accumulation of dry matter in the intercrops is compared to the accumulation expected if intercrop competition was equal to intra-crop competition in Figures 2 and 3. The "expected" lines are calculated as the respective proportions of planted area in intercropping times the monoculture yield (.5 and .67 X corn monoculture, .5 and .33 X soybean monoculture yield for the corn-soybean and corn-corn-soybean patterns respectively). In both patterns, corn was increased above and soybean reduced below the expected yield by the end of the growing season. The reduction in soybeans was not as great as the increase in corn by the last sample date in all treatments except the low density corn-corn-soybean treatment. The supression of soybeans was more pronounced and the differences between actual and expected occurred ealier in the corn-soybean pattern than in the corn-corn-soybean pattern.

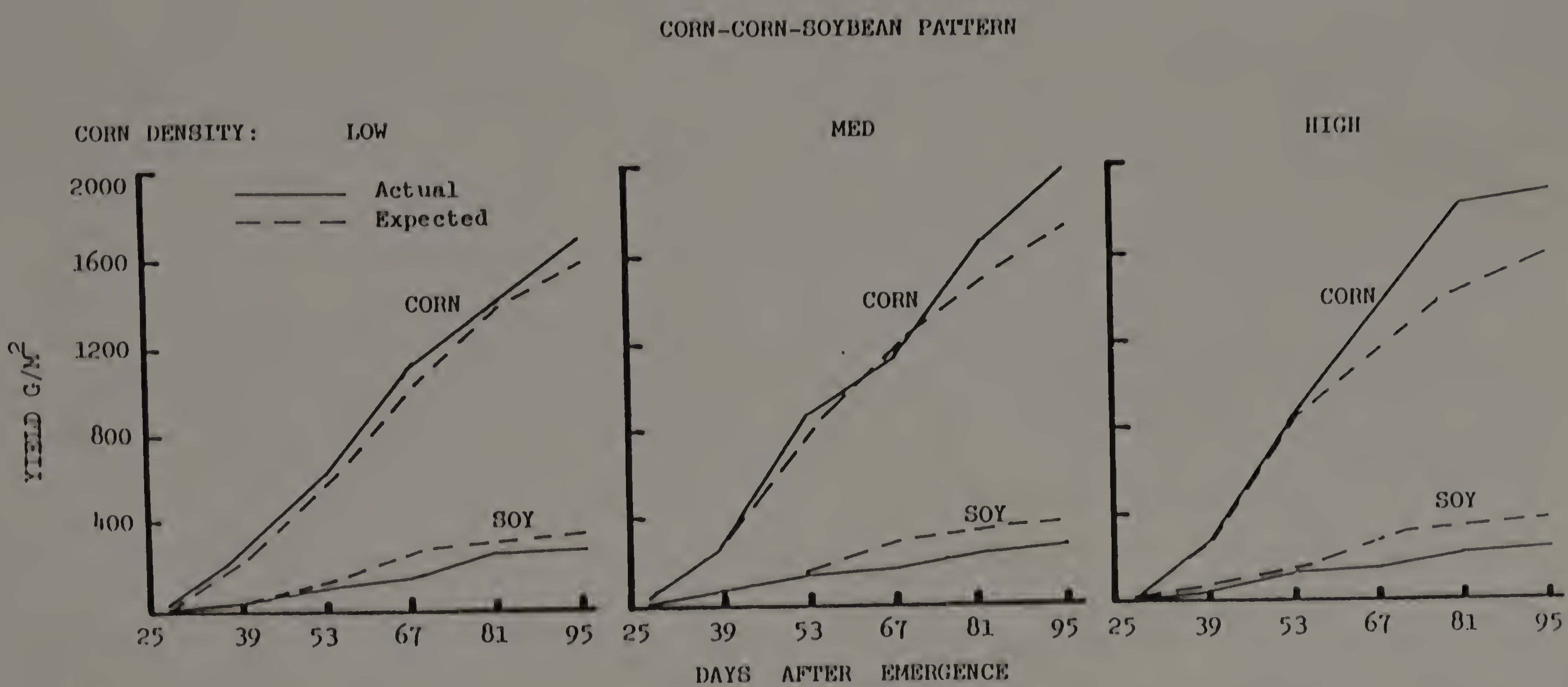


FIGURE 2. Corn and soybean dry matter accumulation. Broken line represents yield expected if intercrop competition was the same as monoculture competition.

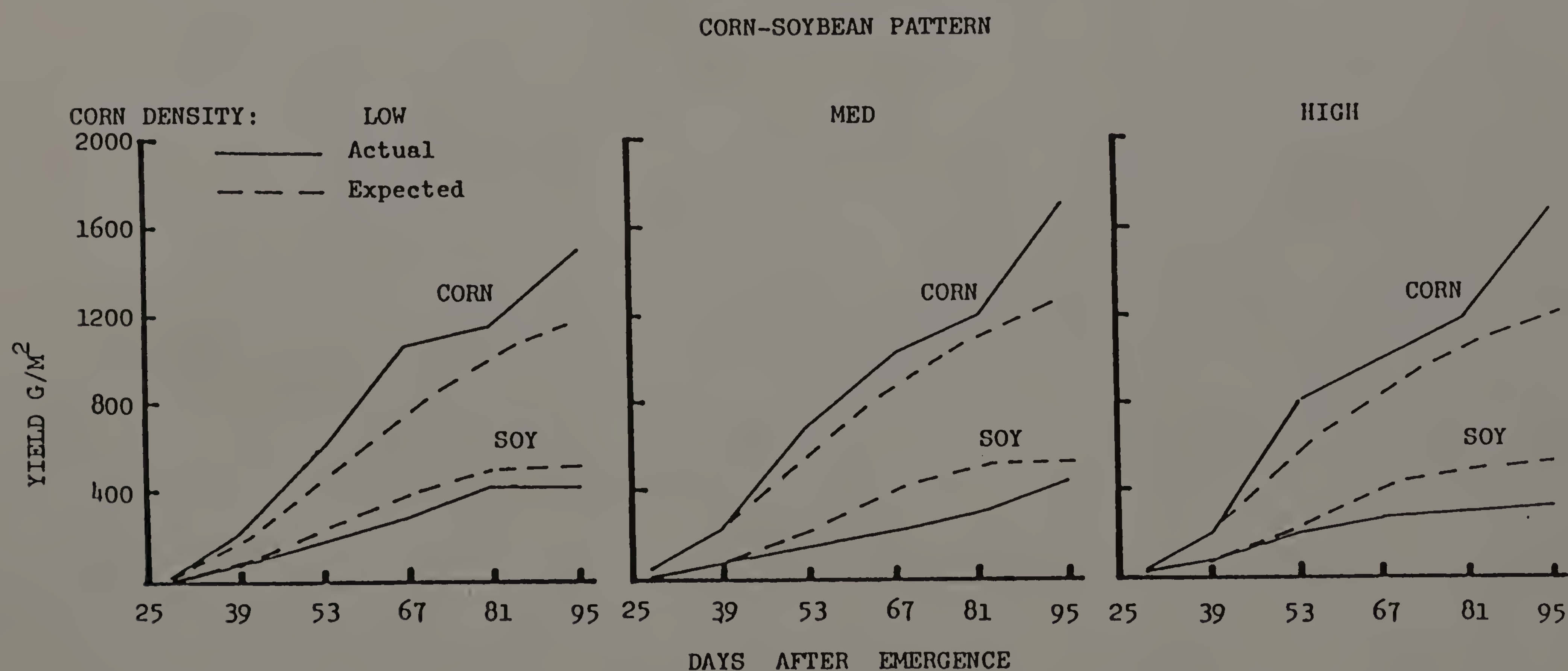


FIGURE 3. Corn and soybean dry matter accumulation. Broken line represents yield expected if intercrop competition was the same as monoculture competition.

The components of yield reflected the compensatory effect of corn for soybean (Figures 4 & 5). The differences between actual and expected ear development was responsive to increased densities in both planting patterns. Corn stover yield in the intercrops was maintained at or above "expected" throughout the growing season, while soybean stover and pod yield was suppressed.

In both medium and high density intercropping patterns, a greater corn ear component was evident 81 days after emergence (Figure 6). Increased densities resulted in a significant reduction of ear weight per plant after 81 days in the monoculture, but this reduction was much less in intercropping (significant Pattern X density interaction, P=0.05, days 81 and 95).

Soybean leaf area index (LAI) was supressed in the intercropping 67 days after emergence, but by the last sample date, the leaf area indices in intercropping were greater than or equal to monoculture due to loss of leaf area in monoculture at the later stages of maturity (Figure 7). The intercropping treatments showed a significant loss in leaf area due to increased corn density at day 67 in the corn-corn-soybean treatment and at day 81 in the corn-soybean treatment. Corn component LAI was increased by increased density early in the growth of the crop in all treatments, a trend that was not significantly affected by planting pattern (Figure 8). The total LAI of the intercrops was maintained at the same level after day 53 wheras in the monoculture, LAI tended to decline (Figure 9). The effect of corn density on increasing LAI of corn and decreasing LAI of

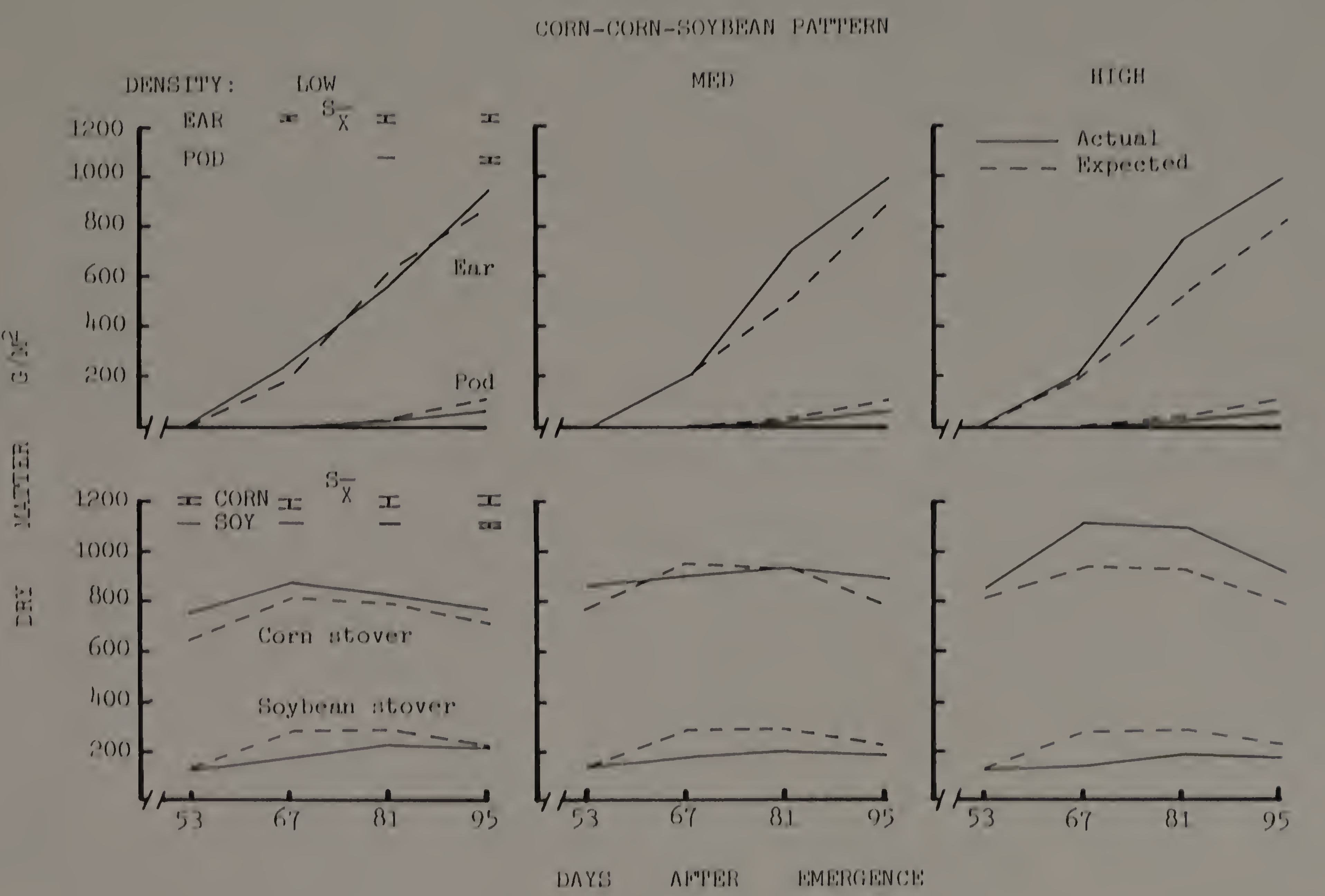


FIGURE 4. Accumulation of dry matter in yield components. Broken line represents yield expect if intercrop competition was the same as monoculture competition.

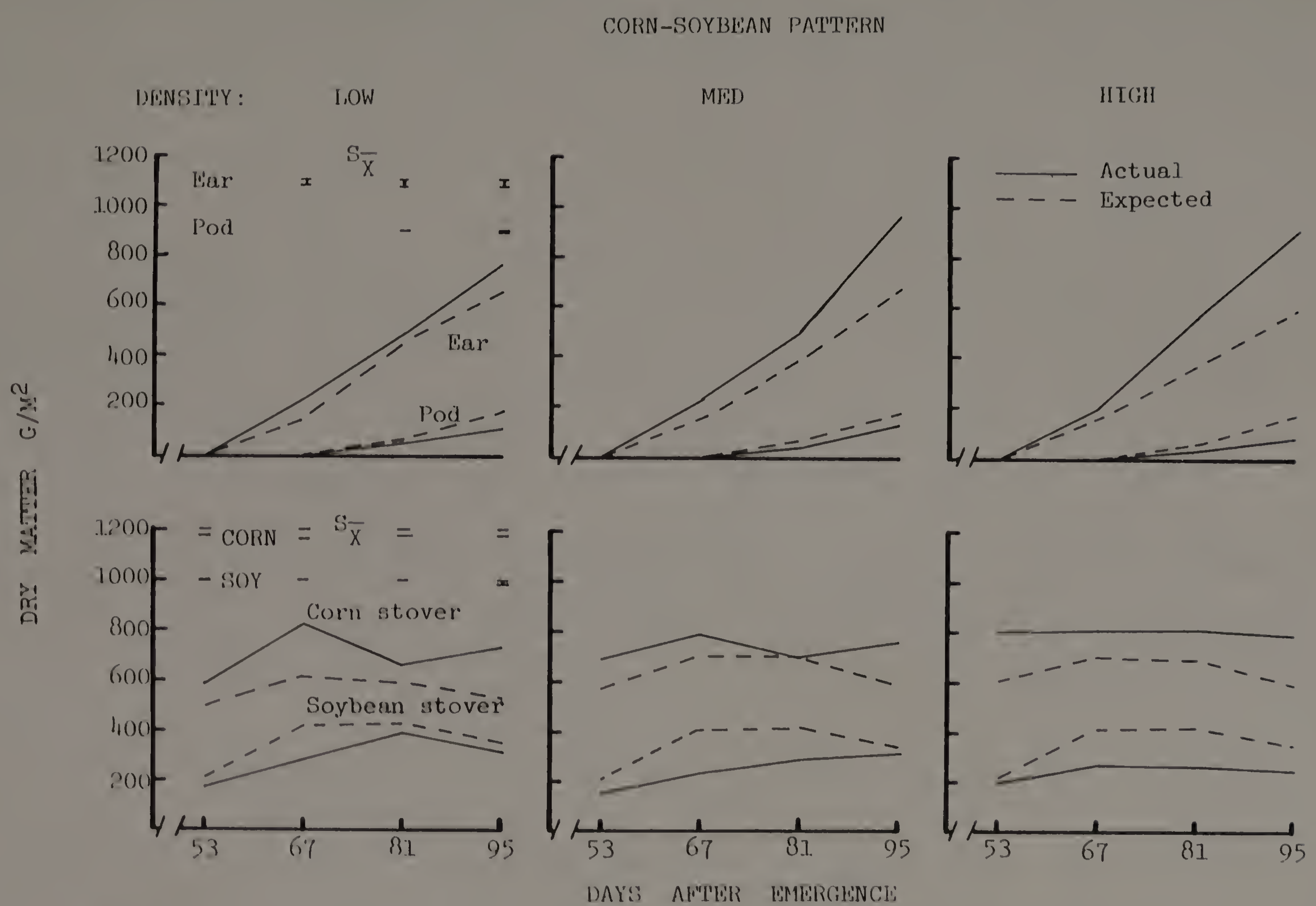


FIGURE 5. Accumulation of dry matter in yield components. Broken line represents yield expected if intercrop competition was the same as monoculture competition.

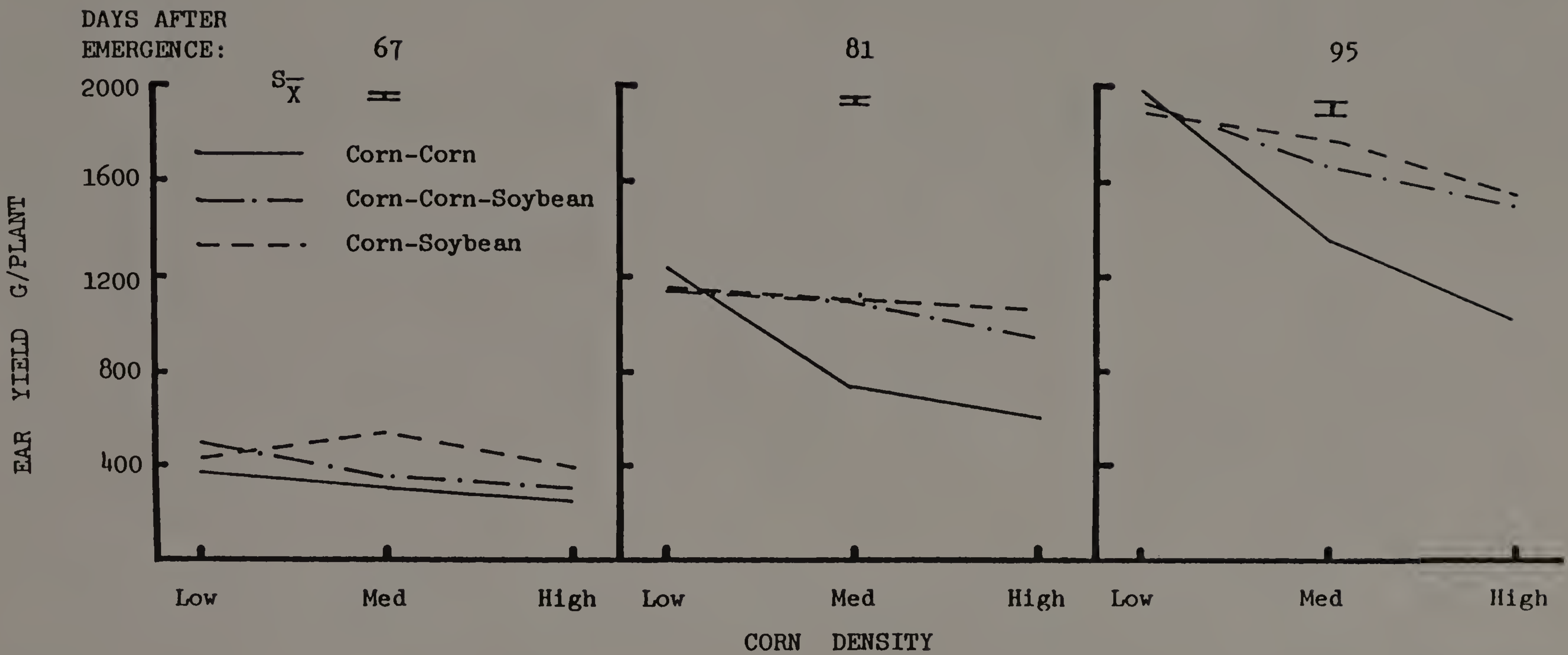


FIGURE 6. Ear yield over time, on a per plant basis.

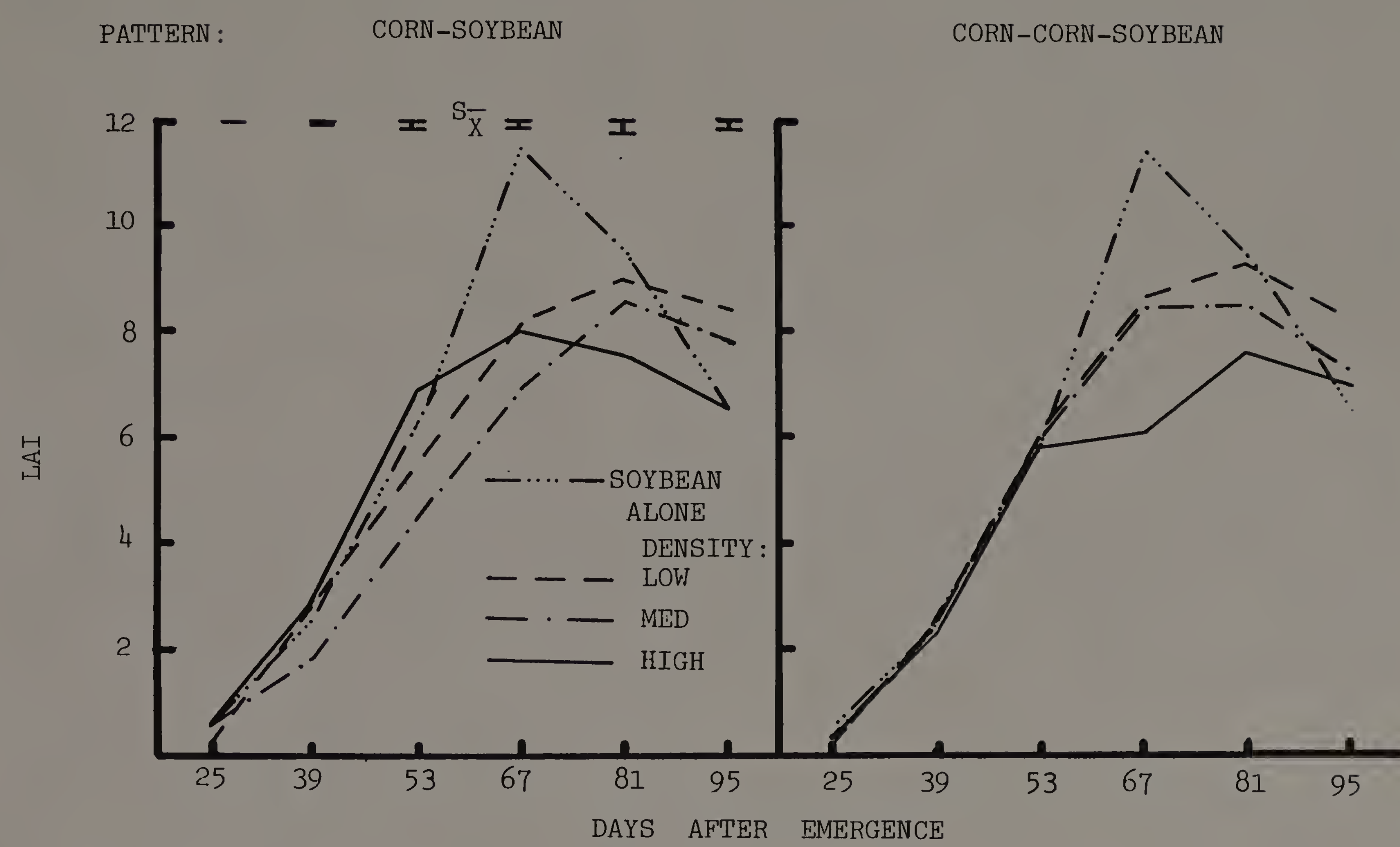


FIGURE 7. Soybean component leaf area index over time.

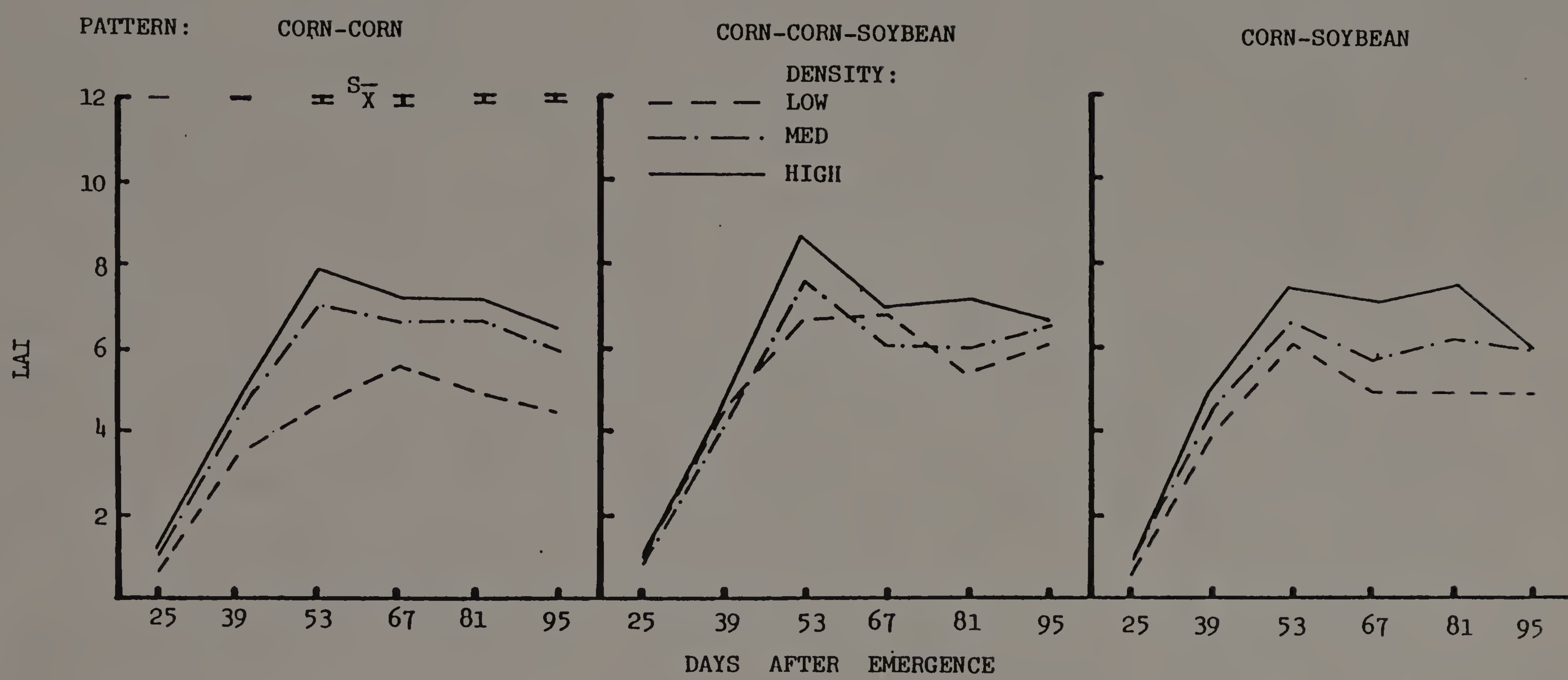


FIGURE 8. Corn component leaf area index over time.

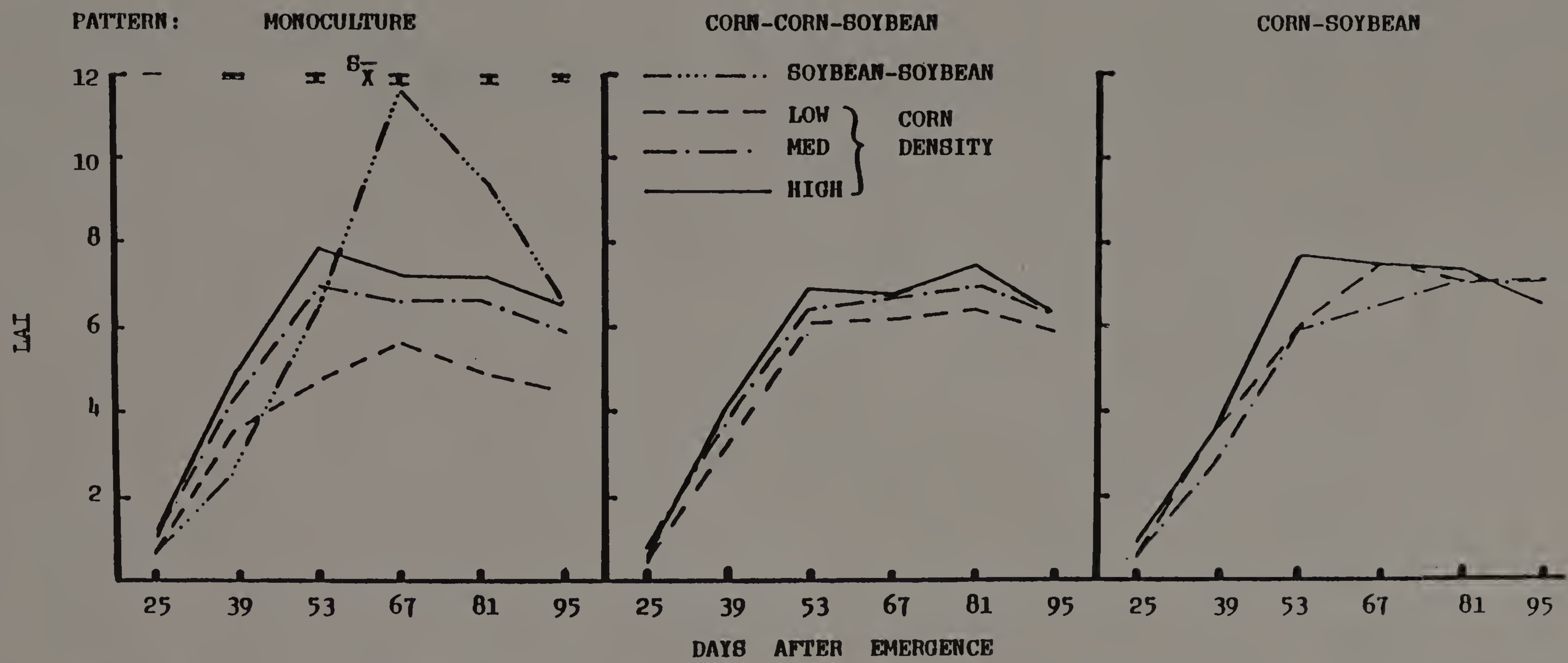


FIGURE 9. Total leaf area index over time.

soybean cancelled each other out resulting in no density effect for total LAI in the intercrops.

After day 53, the soybean monoculuture treatment contained more moisture than the intercropped soybean rows at both locations (between and within the row), and in both planting patterns (Figure 10). This pattern of moisture use was the same for the 30-60 cm strata sampled (Figure 11). The greater moisture-use in intercropped soybean rows compared with monoculture soybean rows could indicate that corn was utilizing moisture from the soybean rows. Since row equivalent soybean yields were lower in intercropping compared with monoculture, then it is unlikely intercropped soybean plants transpired more than monoculture soybean plants, further supporting the concept that corn plants utilized water from the soybean rows. However, for most of the growing season, it is probable that soil moisture was not an important limiting factor for either crop.

There was no consistant density effect on soil moisture throughout the growing season, except that higher corn density treatments tended to have less soil moisture by the last sample date.

The competitive balance in the intercrop can be described by the use of a competitive ratio (Willey & Rao, 1980). Although some variation is evident, an increase in the competitiveness of corn was apparent on the 67th day after emergence in both planting patterns (Figures 12 & 13). Corn density effects on the competitive balance in the intercrops was evident after day 81, the high density making corn more and soybean less competitive during this time period.

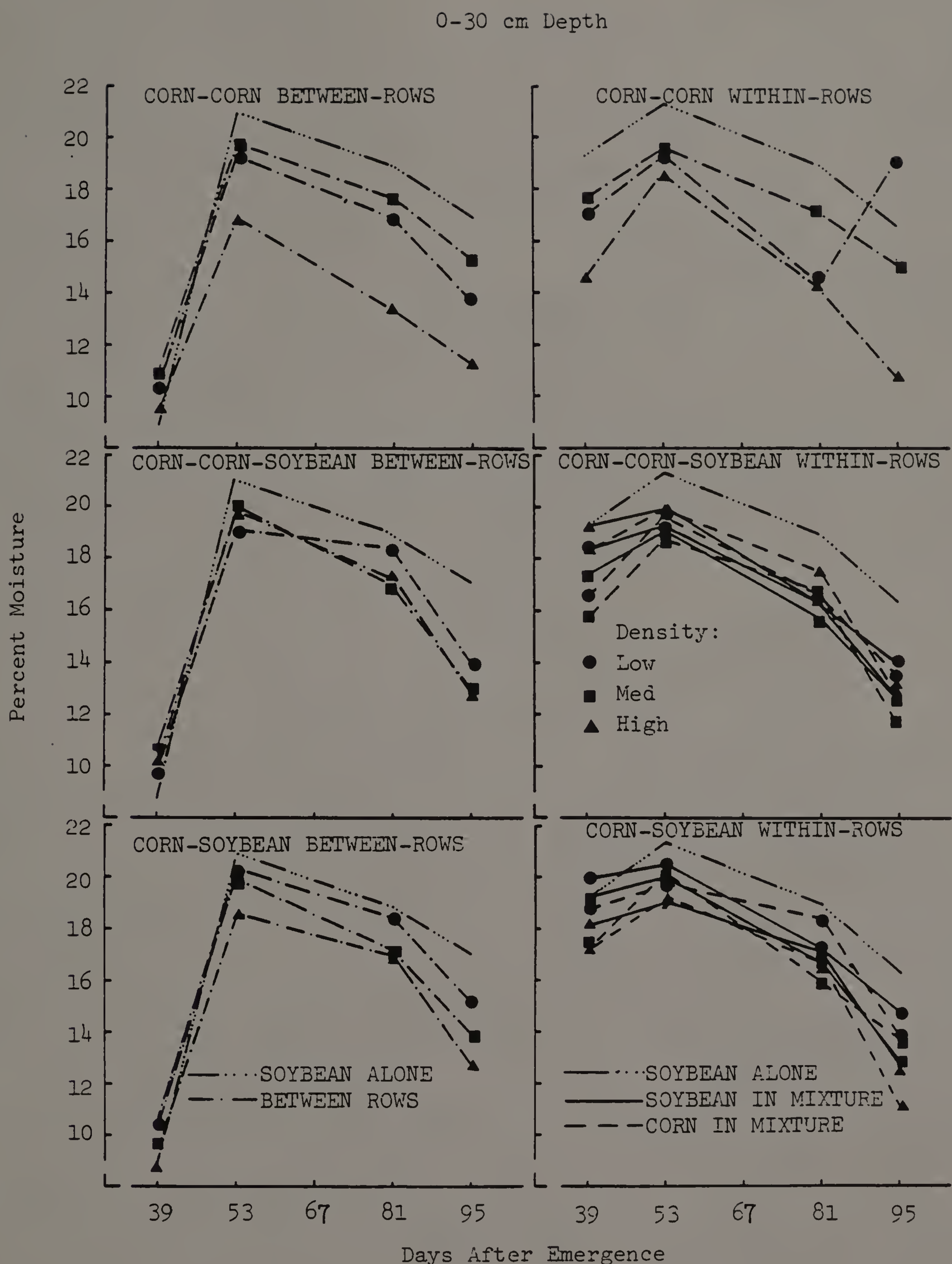


FIGURE 10. Percent Moisture at 0-30 cm Depth, Between and Within Rows.

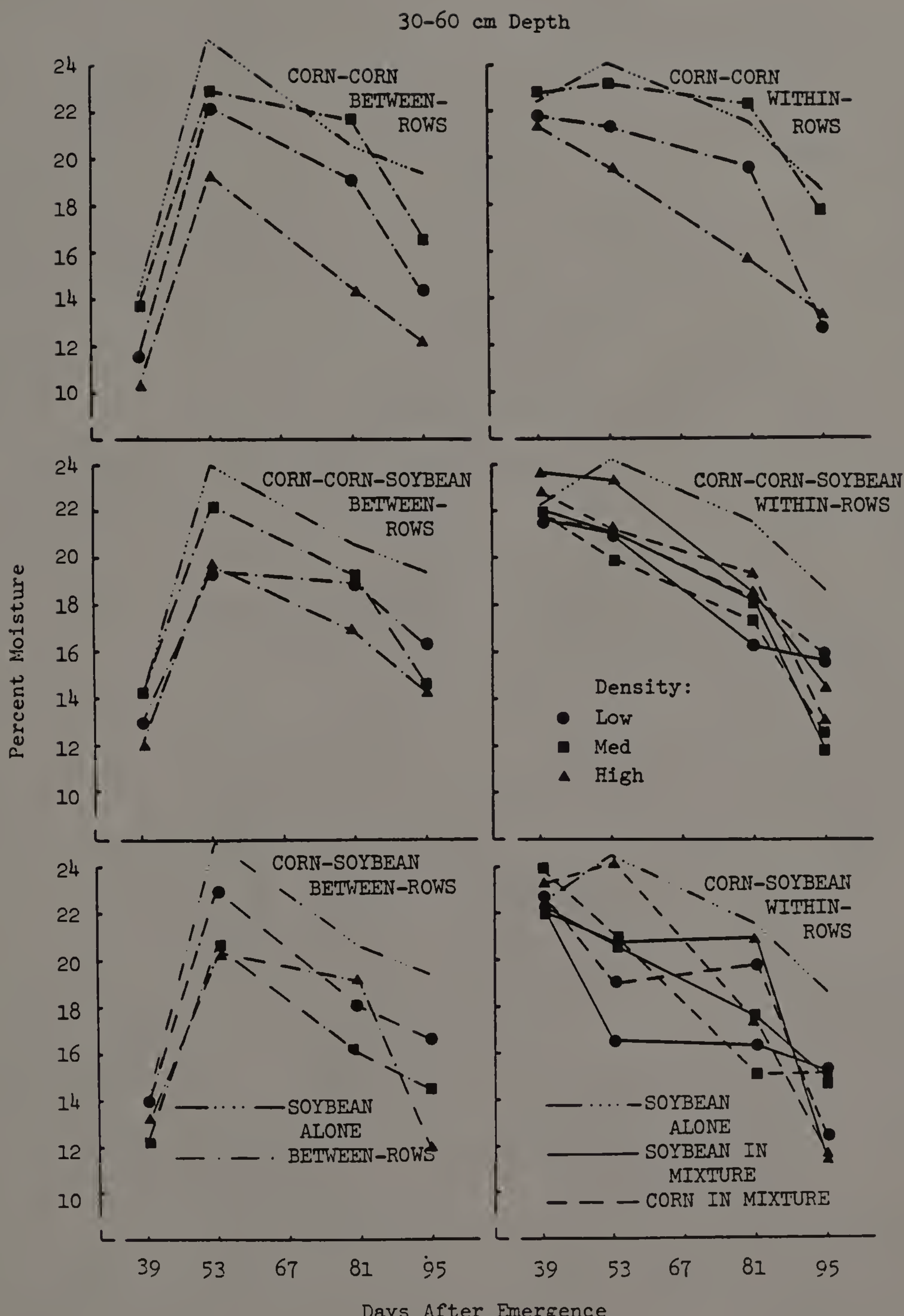


FIGURE 11. Percent moisture at 30-60 cm depth, between and within rows.

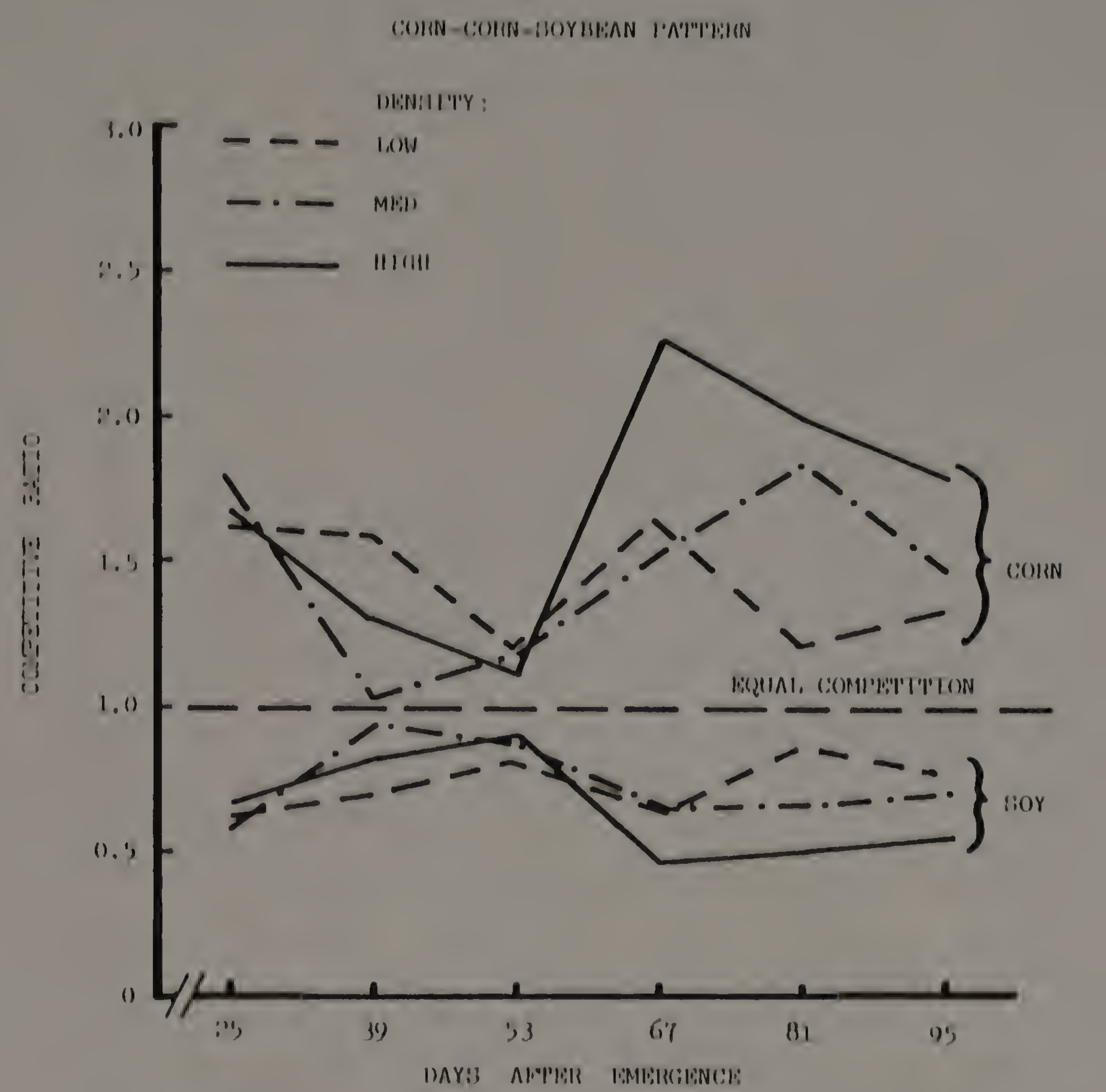


FIGURE 12. Competitive ratio over time. Broken line represents point of equal competition.

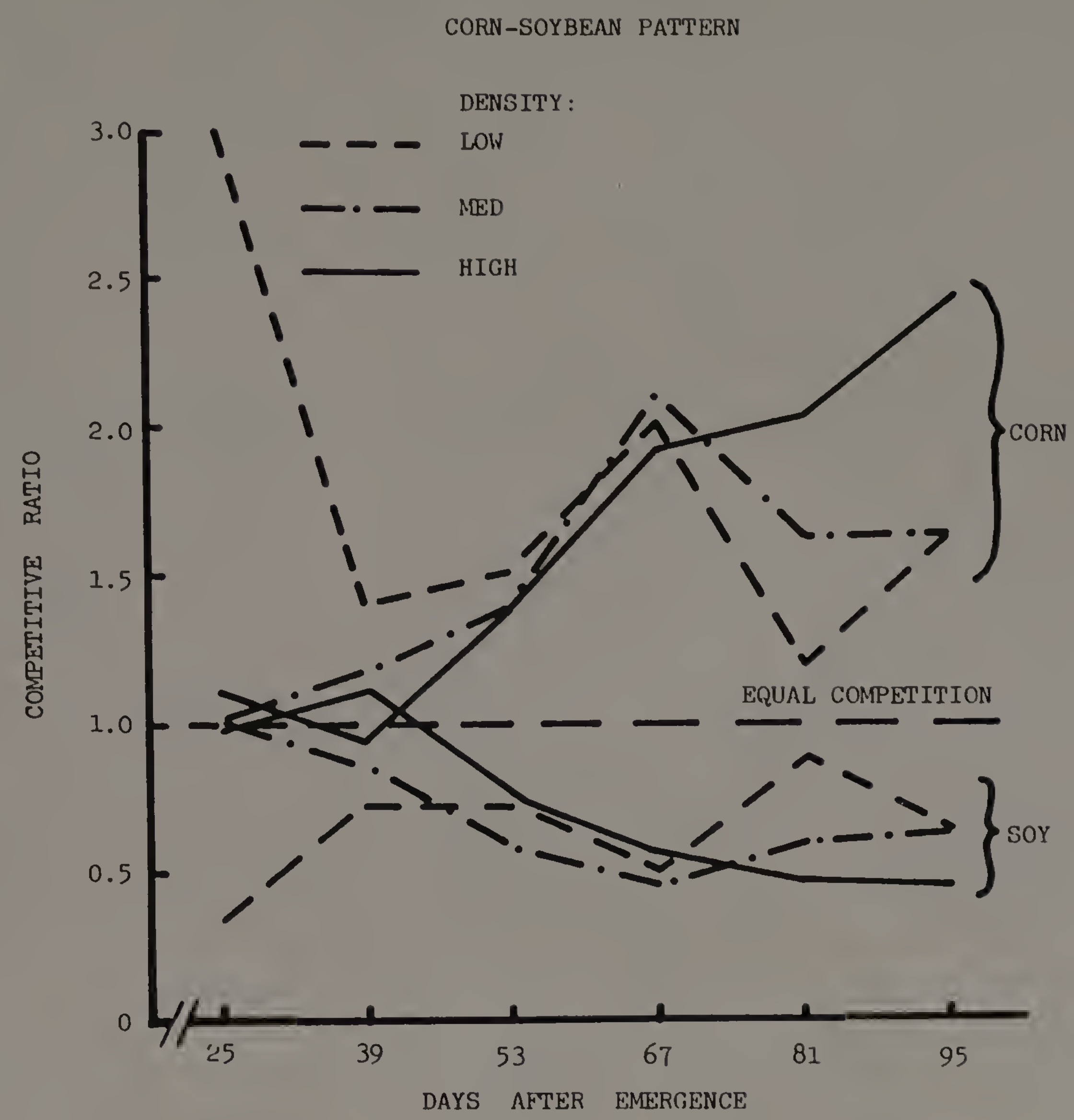


FIGURE 13. Competitive ratio over time. Broken line represents point of equal competition.

CHAPTER V

YIELDS AND YIELD COMPONENTS OF A CORN-SOYBEAN INTERCROP

Introduction

Component density and total population have been identified as important contributors to the possible advantages of intercropping (Willey,1979). The varieties of planting patterns and densities reported in the above studies suggests that the variation encountered in yield and composition of yield might as much be explained by these factors as by differences in cultivars and environmental conditions. In many studies, increased populations were necessary to produce maximum yields (Osiru & Willey,1972, Andrews,1972, Natarajan & Willey,1980a), yet in Virginia, rates of over 20,000 plant/A in an alternate corn/soybean intercrop gave no yield advantage (Alexander & Genter,1962).

The need for a greater on-farm production of protein in dairies in the Northeast is apparent, as a significant portion of protein must be purchased from off-farm sources. Purchased dairy concentrates accounted for 31% of all cash operating expenses on 600 New York dairy farms in 1980 (Smith,1981). The potential of corn/soybean mixtures to raise the protein content of silage in order to reduce the use of expensive concentrates has been demonstrated in some of the mixtures cited here. The purpose of this study was to evaluate two planting patterns of corn and soybeans intercropped at three corn densities for silage yield, protein content, and land efficiency.

Results

The silage yields of the intercropping and monoculture treatments and the percent soy in the mixture are given in Table 5. Corn monoculture yields were more than twice those of soybeans grown alone. There were no significant differences in corn monoculture yields at the three densities, with a slight reduction at high densities. Replacing alternate rows of corn with two rows of soybean at the low corn density resulted in a reduction in silage yield compared to corn alone. Doubling corn density in this alternate row pattern increased the silage yield from 47.1 t/ha in the low density treatment to 59.6 t/ha in the high corn density, which was not significantly different from the corn monoculture yields. The increase in yield was less pronounced in the treatments where every third corn row was replaced with two rows of soybean, occurring only between the low and medium densities. In this planting pattern the medium and high densities had a similar silage yield to the corn monoculture.

TABLE 5. Silage yield and percent soybean in the final yield mixture.

PLANTING PATTERN	SILAGE YIELD (70% moisture)[†]			PERCENT SOYBEAN		
		t/ha			%	
SOYBEAN-SOYBEAN		23.5			100	
	CORN DENSITY					
	Low	Med	High	Low	Med	High
		t/ha			%	
CORN-CORN	60.8	62.7	62.0	0	0	0
CORN-CORN-SOYBEAN	52.6	61.1	61.1	13.4	8.7	8.1
CORN-SOYBEAN	47.1	54.7	59.6	23.4	30.1	14.3

[†] Significant Linear Trends: Pattern and Density ($P \leq 0.01$), Pattern X Density ($P \leq 0.05$).

Percent soybean in the mixture varied significantly with corn density and planting pattern and was inversely related to higher corn densities, yields, and number of corn rows in the mixture. Increasing corn density or number of corn rows in the intercrops caused a reduction in the contribution of soybean, a function both of increased corn yields and suppression of the soybean (Table 5).

The percent crude protein in the final yield mixture reflected these changes in percent soybean in the silage (Table 6). The alternate corn/soybean row pattern at medium corn density raised the percent protein in the silage to 10.2%, an increase of 22.5% compared to the best corn monoculture treatment, and an increase of 31.6% compared to corn alone at medium density. Percent crude protein of the soybean monoculture was significantly higher than corn monoculture or intercrops. There was a significant linear effect for percent protein for both density and planting pattern. In terms of protein produced on a land area basis, soybean produced significantly less than either corn alone or intercopping. The mean of the intercropping treatments produced significantly ($p=0.06$) more protein per hectare than either corn or soybean alone (Table 6).

The total corn, ear, and soybean yield components of the silage which were obtained in intercropping can be compared to those expected if the intercrop competition was the same as the intra-crop competition (Figure 14). In all intercropping treatments the yields of corn were more than "expected" and the yields of soybean reduced below those expected from equivalent proportions of monoculture corn

TABLE 6. Percent crude protein and crude protein yields on a dry matter basis.

PLANTING PATTERN	PERCENT CRUDE PROTEIN†			CRUDE PROTEIN YIELD‡		
	%			kg/ha		
SOYBEAN-SOYBEAN	18.8			1324		
	CORN DENSITY					
	Low	Med	High	Low	Med	High
	%			kg/ha		
CORN-CORN	8.3	7.7	7.8	1517	1456	1446
CORN-CORN-SOYBEAN	10.0	8.8	8.9	1569	1608	1620
CORN-SOYBEAN	10.1	10.2	9.3	1431	1666	1661

†Significant Linear Trends: Pattern and Density ($P \leq 0.01$), Pattern X Density ($P \leq 0.05$).

‡Significant Comparisons: Soybean vs. others ($P \leq 0.05$), Intercrops vs. corn ($P \leq 0.06$).

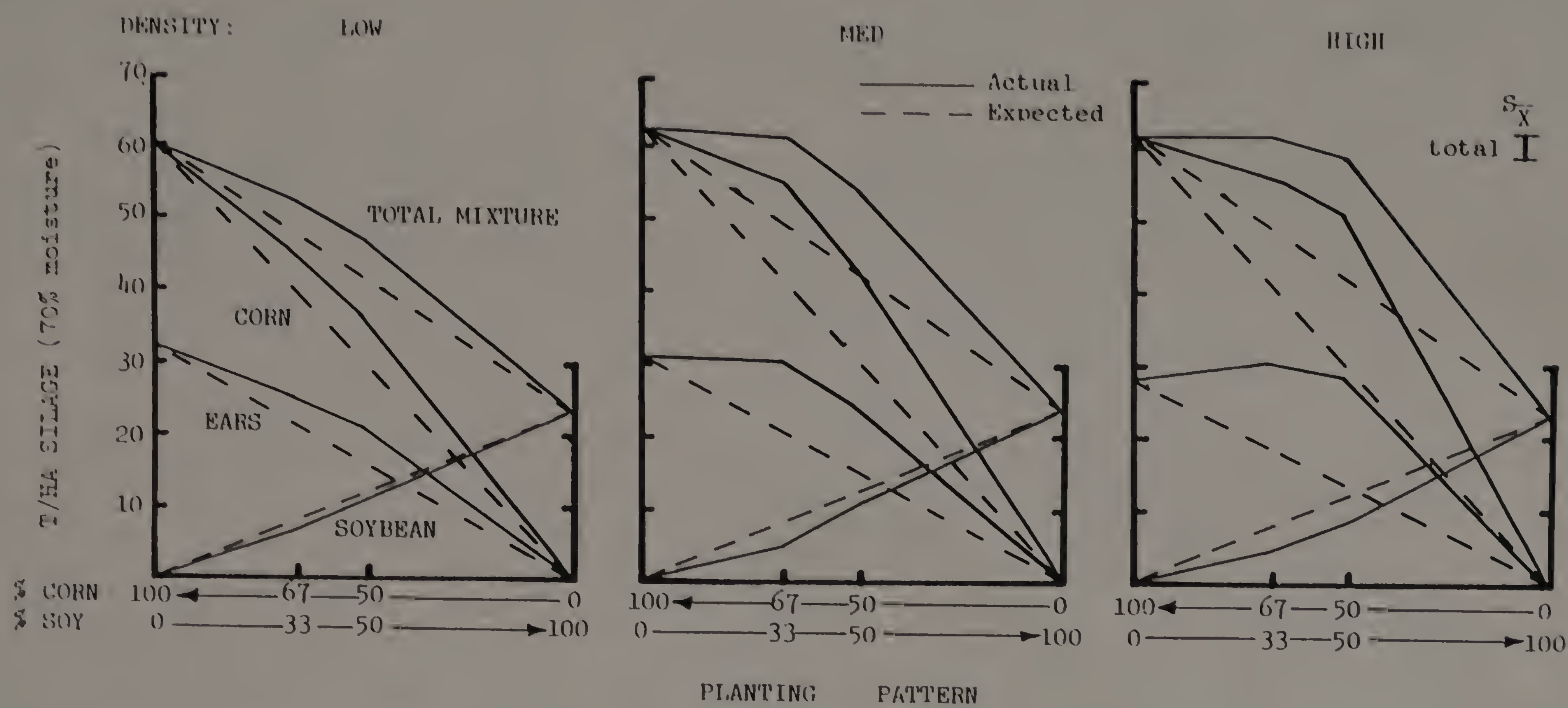


FIGURE 14. Contribution of corn, ear, and soybean to total yield. Broken lines represent the yields expected if intercrop competition was equal to monoculture competition.

and soybean. The intercropped corn compensated for the loss in soybean yields, with the result that the total yield mixture was greater than "expected" in all cases. This effect was more pronounced with increased density, so that at high densities yields from both intercropping patterns were similar to corn monoculture.

However, this comnparison has its limitations (discussed in Chapter III). A more rigorous test of yield advantage is a comparison of treatments on a harvested proportion rather than on a planted proportion (Willey,1979). The yield advantage for low density treatments indicated in Figure 14 doesn't exist when the treatments are compared with sole crops on a harvested ratio basis (Figure 15). A yield complimentarity is still idicated for medium and high corn density treatments, and crude protein yields for all but the low density corn-soybean treatment were greater than those expected from equivalent yield proportions of monoculture plantings (Figure 15).

The increase in corn yields with increased densities in intercropping enhanced the contribution of the ears to the total mixture at harvest (Figure 14 and Table 7). In contrast, in corn monoculture, there was a significant decrease in percent ears with increased corn density (Table 7). There was a significant linear effect for both density and planting pattern, for both ears and stover, and a significant density X pattern interaction was found for ears but not for stover. A greater ear yield occurred at high density in both intercropped patterns, utilizing 1/2 or 2/3 of the planted area compared to corn monoculture at high density (Figure 14).

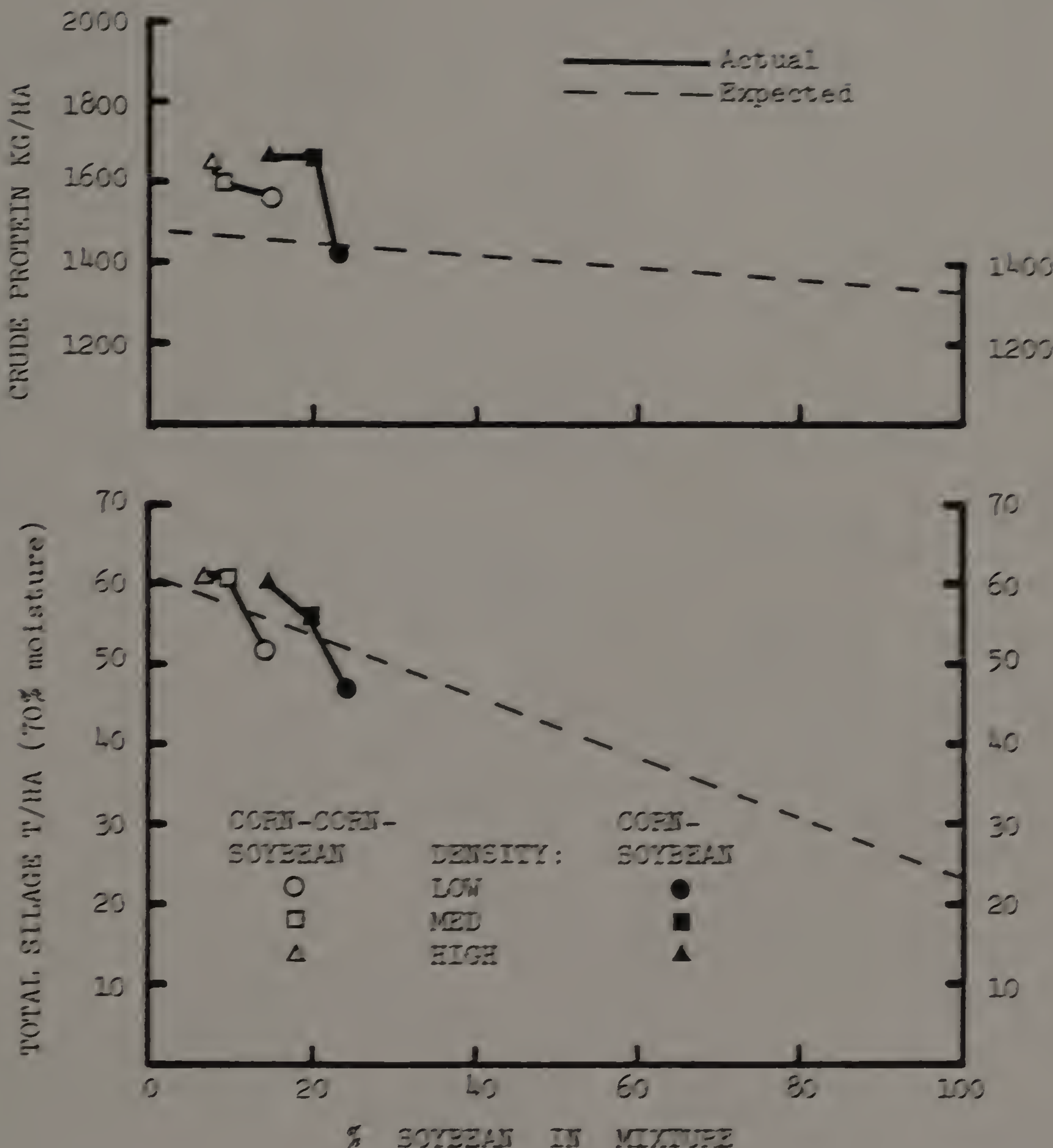


FIGURE 15. Crude protein and silage yields on a harvested ratio basis (rather than planted area). Broken lines indicate yields expected if equivalent yield proportions were obtained from monoculture.

TABLE 7. Ears as a percentage of corn and as a percentage of the total yield mixture.

PLANTING PATTERN	PERCENT EARS					
	Of Corn Component†			Of Total‡		
	CORN DENSITY					
	Low	Med	High	Low	Med	High
	%					
CORN-CORN	55	51	45	55	51	45
CORN-CORN-SOYBEAN	54	54	54	47	50	49
CORN-SOYBEAN	57	54	56	44	43	48

†Significant Linear Trends: Density ($P \leq 0.05$), Pattern ($P \leq 0.01$).

‡Significant Linear Trends: Pattern ($P \leq 0.01$), Density X Pattern ($P \leq 0.01$).

TABLE 8. Row-equivalent yields of corn bordered by corn, soybean, or corn and soybean on either side.

PLANTING PATTERN	CORN YIELD†								
	EARS‡			STOVER§			TOTAL¶		
	CORN DENSITY								
	Low	Med	High	Low	Med	High	Low	Med	High
	g/m^2								
CORN-CORN	1003	946	842	821	935	1017	1824	1882	1859
CORN-CORN-SOYBEAN	1107	1360	1354	942	1149	1172	2049	2509	2526
CORN-SOYBEAN	1245	1423	1722	921	1195	1344	2166	2619	3066

† Comparing monoculture rows with intercropped rows.

‡ Significant Linear Trends: Density and Pattern ($P \leq 0.01$), Density X Pattern ($P \leq 0.01$).

§ Significant Linear Trends: Density and Pattern ($P \leq 0.01$).

¶ Significant Linear Trends: Density and Pattern ($P \leq 0.01$), Density X Pattern ($P \leq 0.01$).

A measure of intra- and inter-crop competition can be made from a comparison of the yields of a row of corn bordered by corn (monoculture), a row of corn bordered by corn and soybean (corn-corn-soybean pattern) and a row of corn bordered on both sides by soybean rows (corn-soybean, see Table 8). Intercropped corn rows yielded more dry matter than monoculture rows at all corn densities. The largest increase was in the contribution of ears to total corn dry matter. This increase in ear contribution was greatest in high corn density and in the alternate row planting pattern. While in corn monoculture, ear yield declined 16% from 1003 kg/ha to 842 kg/ha when corn density was increased from low to high, in the alternate row planting pattern ear yield increased with increasing corn density by 38% from 1245 kg/ha to 1722 kg/ha (Table 8). This increase resulted from a lesser decrease in ear size for the alternate row pattern with increasing corn density and a greater number of ears produced per unit area than for equivalent densities of corn monoculture (Table 9).

The silage yield of soybean rows bordered by one corn row (corn-soybean) or two corn rows (corn-corn-soybean) was significantly less than for soybeans alone (Table 10). A significant linear effect ($P= 0.05$) for corn density but not for planting pattern was found. The number of pods per plant and number of nodes per plant was also significantly more for the monoculture soybeans than for the intercropped soybean rows (Table 10). No significant linear effects were found for pods/plant or number of nodes for either planting pattern or density. There was no difference in the average height of

TABLE 9. Ear weight and number of ears on a row-equivalent basis.

PLANTING PATTERN	Ear Weight†			Ear Number‡§		
	CORN DENSITY					
	Low	Med	High	Low	Med	High
	g/ear			ears/m^2		
CORN-CORN	163	121	91	6.2	7.9	9.4
CORN-CORN-SOYBEAN	175	148	131	7.1	9.2	10.3
CORN-SOYBEAN	156	171	138	8.0	8.3	12.5

†Significant Linear Trends: Density and Pattern ($P \leq 0.05$), Density X Pattern ($P \leq 0.05$).

‡Significant Linear Trends: Density and Pattern ($P \leq 0.01$).

§Comparing monoculture rows with intercropped rows.

TABLE 10. Row equivalent yields of soybean bordered by soybean and the mean of the intercrop treatment soybean rows.

PATTERN	SOYBEAN YIELD[†]	
	POD NUMBER	FORAGE YIELD
	pod/plant	g/m^2
SOYBEAN-SOYBEAN	31.1[‡]	703.0[‡]
MEAN OF INTERCROPS		
Low[§]	24.1	647.0
Med[§]	26.2	569.5
High[§]	20.0	476.5
TRENDS:[¶]	Q	L

[†]Comparing monoculture rows with intercropped rows.

[‡]Significantly different from intercrops ($P \leq 0.05$).

[§]Corn density treatments.

[¶]Q = quadratic trend significant ($P \leq 0.06$),
L = linear trend significant ($P \leq 0.01$).

10 soybean plants, height of canopy, lodging score, or number of branches.

The land equivalent ratios (Mead & Willey, 1979) for all intercrops were greater than 1.0 (Figure 16). LERs of 1.06, 1.17, 1.19 and 1.04, 1.12, 1.12 were obtained for the corn-soybean (low, medium and high densities) and the corn-corn-soybean (low, medium and high densities) treatments respectively. Land "efficiency" was raised most with an increase from low to medium density, with negligible gains from medium to high density in both patterns. The unequal competative effects are shown by the fact that the corn contributes more to the land-use advantage than does soybean, that is, the LER point falls to the "corn side" of an equal competition line (where LERsoybean = LERcorn in the corn-soybean treatment and LERsoybean = LERcorn/2 in the corn-corn-soybean treatment).

The competitive relationships in the intercrops are further described by using a competative ratio (Willey & Rao, 1979, see Chapter II). As the population of corn was increased, the competitive ability of corn (in relation to soybean) increased and the competitive ability of soybean decreased (Figure 17). There is an increase in the competitive ability of corn with the corn-corn-soybean pattern at the mid density, but there was no pattern linear effect, and the CR of that pattern was reduced to below the corn-soybean pattern at high corn density.

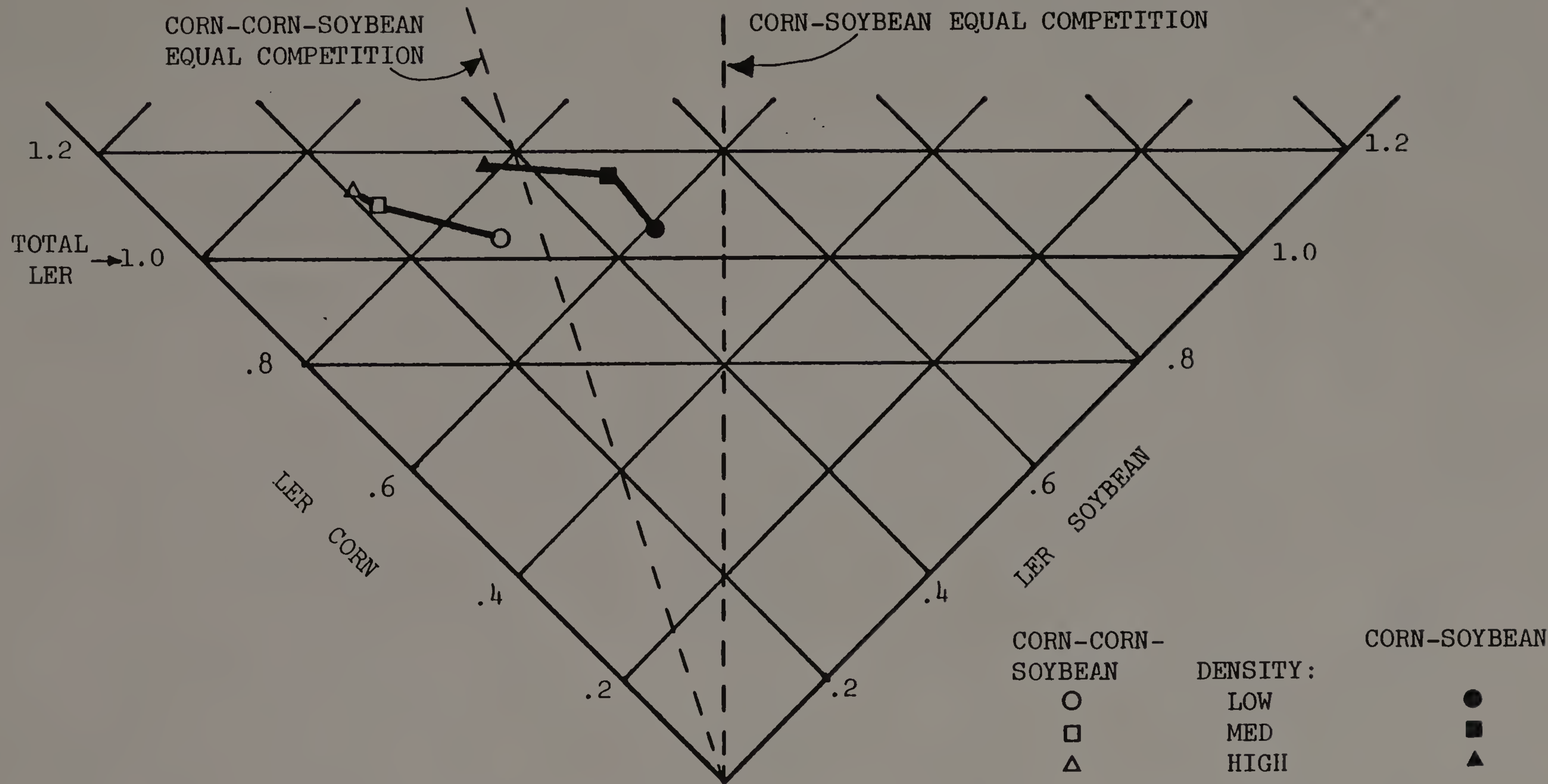


FIGURE 16. Total and component Land Equivalent Ratios. Broken line indicates LER expected if the two crops were equally competitive.

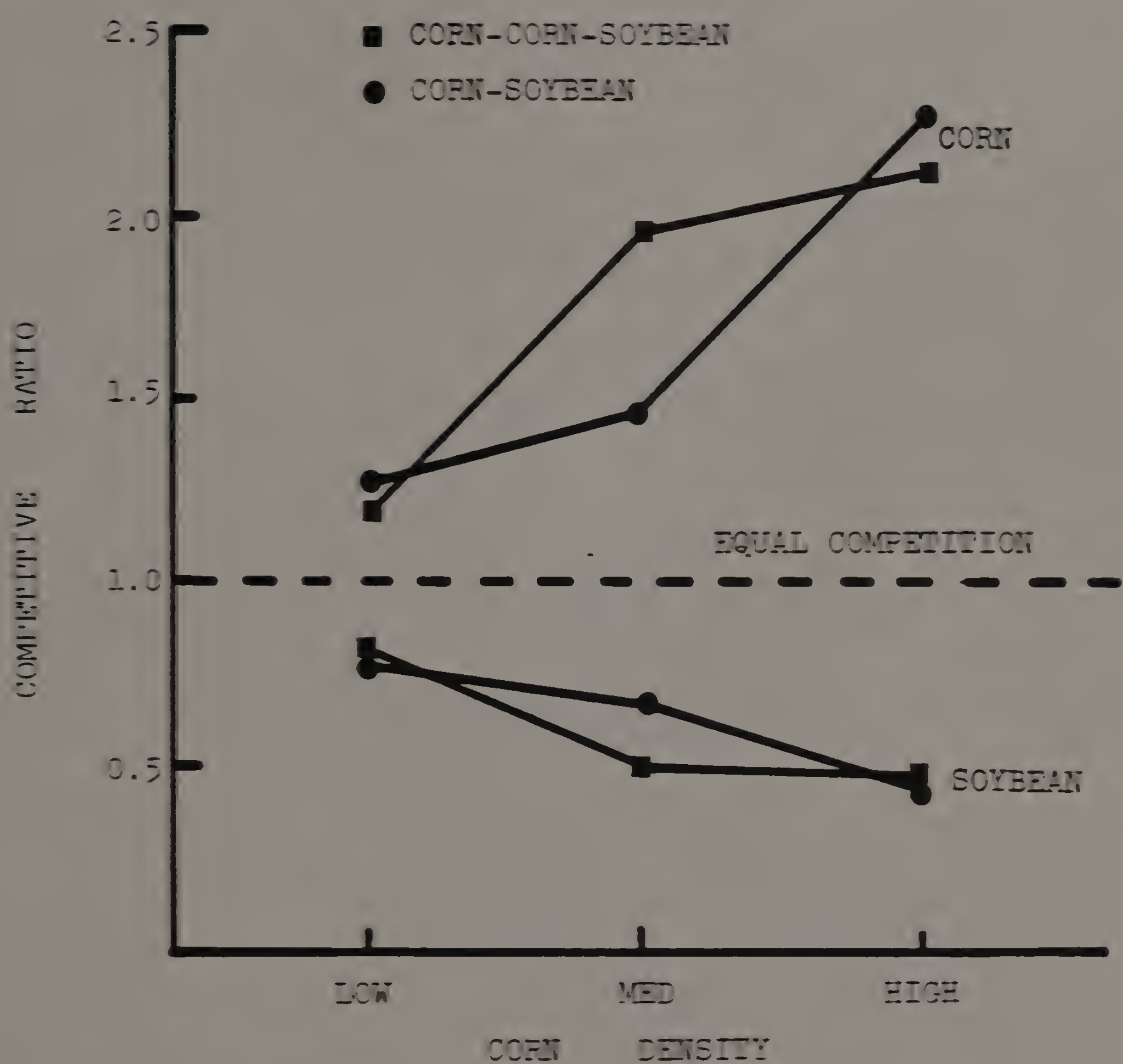


FIGURE 17. Competitive Ratio of Corn and Soybean at Harvest. Broken line represents point of equal competition.

Discussion

The production of total dry matter is of primary concern in a ruminant feeding program as this is the primary determinant of the energy value of corn silage (Church,1977). However, composition of the dry matter is also of major importance as protein, digestability, and palatability are prime factors in determining the productivity of an animal (Miller,1979).

An intercropping pattern for silage will be successful if the dry matter production is similar to corn monoculture yields and there is a corresponding increase in quality, especially protein. It is recognized that some farmers may accept a slight reduction in yield if the quality of the silage is increased, while others may not.

At medium and high densities the silage yields in intercropping were maintained at a level similar to corn alone at both planting patterns. When the number of corn plants in the intercropping treatments were increased by either adding another row (in the corn-corn-soybean pattern) or by increasing the number of plants per meter of row (density), the effect was to increase the total yield. The silage yield was significantly correlated with percent corn in the mixture and corn density, and negatively correlated with soybean yields.

This increase in yields at higher corn density, resulting from increased corn yields in mixture, was indicative of the superior competitive ability of corn also shown by the LER and Competitive Ratio trends. The data indicates that the already superior competitive ability of corn over soybean is increased by adding numbers of corn plants to the row, whereas increasing the plant density of corn in monoculture had little effect of total yield. Replacing rows of corn with two rows of soybean reduced intra-row plant competition in the corn. The corn-corn-soybean intercrop pattern was more similar to monoculuture than the corn-soybean intercrop pattern, since an increase in yield occurred among all three densities in the latter while a yield increase occurred only between the low and medium densities in the former.

In the corn-soybean treatment, the average reduction (-13%) of soybean yield by introducing corn in the row on either side was not as great as the increase in corn (+41%) when bordered by soybean (comparing row equivalents). In the corn-corn-soybean treatment, however, the loss of soybean (-26%) bordered by corn was about the same as the gain in corn yield for that treatment (+27%). The LERs were also greater for the corn-soybean treatment than for the corn-corn-soybean treatment. Considering the planting pattern alone, the latter pattern is more similar to corn monoculture than is the former, and is a less "intimate" mixture. This comparison of row-equivalents in the different treatments and the LERs indicates that whatever complimentariy exists between the two crops in a replacement series is increased by mixing the crops more thoroughly (Figure 18).

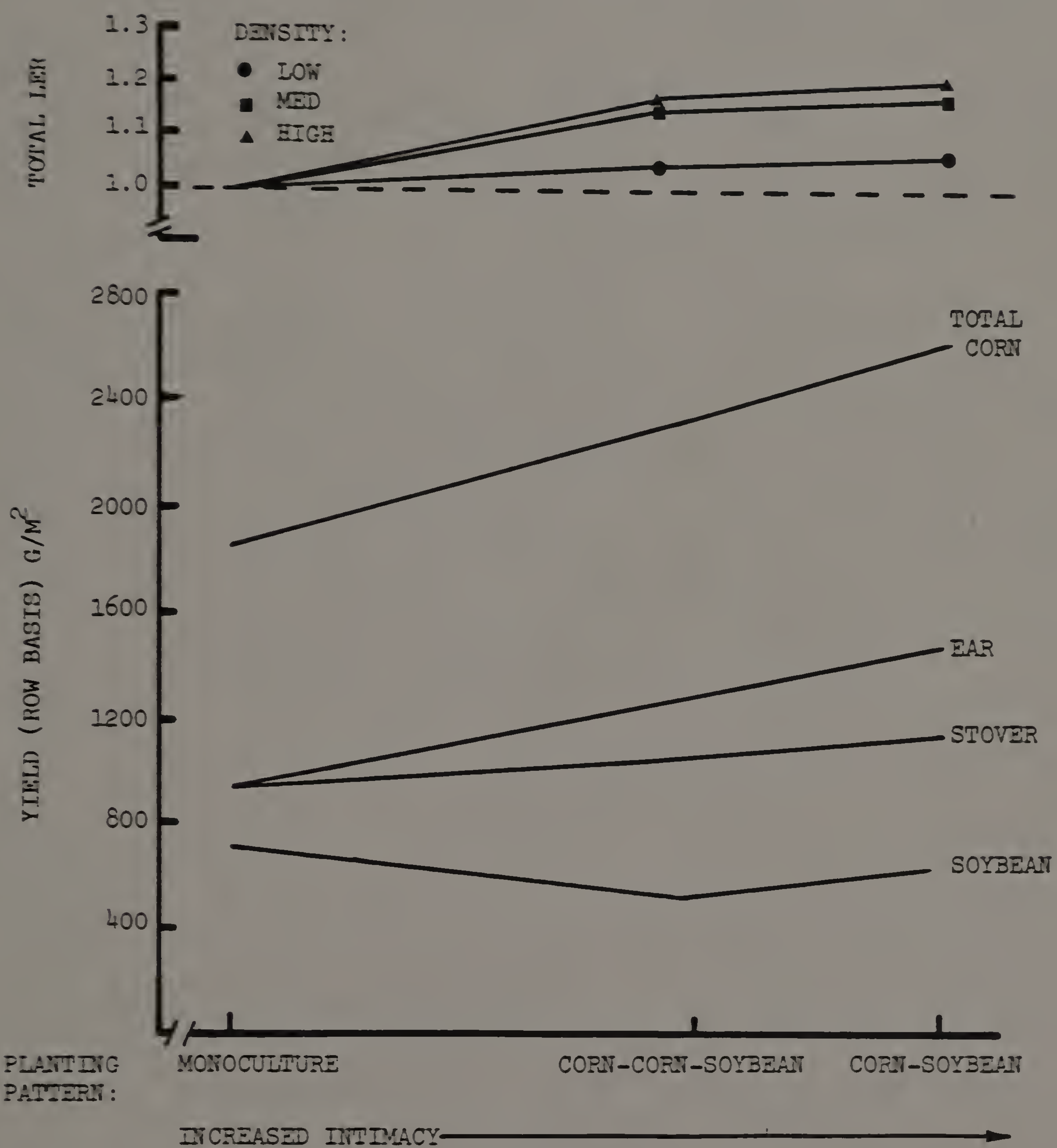


FIGURE 18. LER, corn, ear, stover, and soybean component yields (row basis), as a function of the intimacy of the mixture.

The ability of corn in the intercropped patterns to maintain a high ear/stover ratio at high intra-row densities (as compared with corn monoculture) is further evidence of the reduced competitive pressure on the corn bordered by soybeans instead of corn. The corn rows without neighboring corn rows produced slightly more stover, a much greater yield of ears, more ears per meter sqared, heavier ears, and a percentage of ears higher than monoculture rows at corresponding densities. When yields were corrected for planted area, the ear yield in intercropping was not equal to corn alone except at high densities, where the ear yields (but not the corn yields) were similar to or greater than monoculture ear yields at that intra-row density for half or two thirds the planted area. This is similar to the border effect described by Pendleton et al (1963), where corn without as much self-competition can utilize a greater portion of the environment than allowed in the middle of a thick monoculture crop community. He observerd that border rows yielded up to 39% more grain than corn rows bordered by corn.

To cattle feeders a high grain/stover ratio is often desireable (Genter and Camper, 1973), and the ear component of corn ranks higher in in vivo digestibility trials than do the stalk and leaf (Morrison, 1956). Furthermore, corn stover is about 6.8% crude protein, while mature ears range from 9.3% to 10.2% crude protein (N. A. S.,1971). A high ear-stover ratio would tend to increase the percent crude protein in the silage, which is shown by the corn monoculture data, where low density silage (55% ear) was higher in protein than high density corn (45% ear in silage). Although we did not measure the contribution to percent crude protein by the various components, the writer's conclusion is that whatever protein complimentarity exists in the intercrops is contributed to by the well-eared corn as well as the soybean in the mixture.

The corn-soybean intercrop at medium corn density produced the highest percent crude protein and also was the treatment which produced the highest yield of protein on a land area basis. Total yield in this treatment was 55 tonnes/ha compared to a maximum of 60 to 63 t/ha for corn monoculuture and some intercrops, yet the yield might be considered acceptable because of the higher protein content. This suggests that some yield reduction of the mixture might be neccessary to optimize the protein production from corn-soybean mixtures--a reduction in corn competition would lead to an increase in the percentage soybean in the mixture.

The soybean treatment produced significantly less protein on a land area basis than did the corn monoculture or the intercrops, and the intercrops produced more than either soybean or corn monoculture. The production of protein on a land area basis might be interesting from a land-efficiency basis, when protein production is considered as a separate goal, but it is not of paramount concern when considering the value of silage fed to ruminants. For this purpose, percent protein is much more meanigful, as this is how feed rations are formulated, and how any monetary benefit from a mixture would be realized.

In summary, dry matter yields in intercropping were quite responsive to increases in corn density and high corn densities were neccessary to maintain intercropped yields at levels similar to corn monoculture. Mixtures of corn and soybean were able to tolerate higher corn densities better than corn alone. A better-eared, higher yielding corn plant resulted which tended to compensate for the loss of soybeans at high corn densities in intercropping. Although increases in protein were found at high intercropped densities, it may be that to optimize protein content, some reduction in total dry matter may be required, a decision to be based upon the requirements of each farm situation. Future research my be centered upon finding corn cultivars which are benefitted by the mixture, but allow the soybeans to compete to a greater degree.

CHAPTER VI

SUMMARY

The objectives of this study were to examine different planting patterns and densities of corn-soybean intercrops to increase the yield quality of silage. Three densities of corn in 91 cm rows (4.5, 6.7 and 9.0 seeds/m of row) and double rows of soybean, 35 cm apart on 91 cm centers (18 seeds/m of each row) were planted as sole crops and in two intercropped treatments, where alternate and every third row of corn was replaced with two rows of soybeans 35 cm apart (a replacement series). Soybean alone produced 23.5 t/ha silage, compared to from 60.8 to 62.7 t/ha silage for corn monoculture.

When alternate rows of corn were replaced with a double row of soybeans, low, medium and high density treatments produced yields of 47.1, 54.7 and 59.6 t/ha silage respectively. When every third row of corn was replaced with a double row of soybeans, yields of 52.6, 61.1, and 61.1 t/ha silage resulted. Higher corn densities were required to maintain yield in the intercrop whereas density had little effect on the yield of corn monoculture.

Percentage ear of the corn component for both intercrop patterns was maintained at near 55% from low to high corn densities while in corn monoculture, percent ear decreased from 55% to 45% when density was doubled. Similarly, weight per ear was reduced less severely and

ears/m2 increased to a greater degree in intercropping with increased corn densities compared to monocultures so that at high corn densities, a greater ear yield was acheived in both intercropped patterns than in monoculture at high density, for 2/3 or 1/2 the planted area.

The higher corn densities required to maintain yield in intercropping reduced the soybean contribution to yield, yet the percent soybean in the alternate row pattern was sufficient to significantly raise the percent crude protein from 7.7 to 8.3% in corn monoculture to 10.1, 10.2, and 9.3% for the low, medium, and high densities respectively. For the total cropped area, intercropped patterns produced significantly more protein than corn alone, and corn alone produced significantly more protein than soybean alone.

Competitive ratios at harvest indicated that the superior competitive ability of corn increased and the soybean competitive ability decreased with increasing corn density. The competitive differences of the two crops was evident at 67 days after emergence. In all intercropping treatments, Land Equivalent Ratios were greater than 1.0.

Dry matter accumulation reflected a complimentarity between the crops early in the season, accompanying increased competition of the corn component. The corn in mixture possibly utilized water from the soybean rows, but it is not clear from this data that water was ever limiting to either crop at any time during the growing season. Soybean LAI decreased with increased corn densities, and corn LAI increased with increased corn densities.

In conclusion, the potential for raising silage protein content by intercropping corn and soybean exists, but a decrease in yield may be necessary to maximize protein content. The applicability of a corn-soybean intercrop system will depend upon solving mechanical harvest problems, and upon meeting the yield goals of each farm situation.

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