EVALUATION OF DIFFERENT BEAN DENSITIES IN RELATION TO SEED YIELD, PROTEIN, AND MINERAL NUTRIENT COMPOSITION OF BEANS (*Phaseolus vulgaris* L.) AND MAIZE (*Zea mays* L.) GROWN IN ASSOCIATION AND IN MONOCULTURE

By

M. Emil T. Mmbaga

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ABSTRACT

EVALUATION OF DIFFERENT BEAN DENSITIES IN RELATION TO SEED YIELD, PROTEIN, AND MINERAL NUTRIENT COMPOSITION OF BEANS (Phaseolus vulgaris L.) AND MAIZE (Zea mays L.) GROWN IN ASSOCIATION AND IN MONOCULTURE

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The potential for increasing yields by determining optimum bean population in associated culture was investigated at three densities using two bean cultivars grown in association with maize at East Lansing, Michigan. Nine treatment combinations were tested for three years in a randomized block design with four replications on a fine loamy soil. Pods/m^2, leaf area index, biomass, and seed yield increased with increasing bean plant density. Stem and leaf dry weight of bean in association reached their maximum accumulation during the mid-pod filling phase and declined as physiological maturity was reached. Root dry weight of both bean cultivars at different densities under intercropping was similar throughout the reproductive phases of plant development. Optimum biomass production during the vegetative phase appeared to be a prerequisite for obtaining increased levels of yield components.

Seed yield of both cultivars grown in association with maize was 61 to 68 percent lower than their corresponding monocultural

seed yields. The highest leaf area index obtained from bean in association with maize was 3.3, whereas the monocultural value was 4.3. The relative light interception of the two bean cultivars in association was 47 to 57 percent lower than their light interception level under monoculture. Bean seed yield was positively and significantly correlated with seeds/pod, pods/m^2, biomass, and leaf area index.

The concentrations of macro and micronutrients in bean and maize plants were within the nutrient sufficiency range for normal growth and development. Land equivalent ratio increased with increasing bean densities and ranged between 1.15 and 1.35. An association of maize (40,000 plants/ha) with beans (150,000 plants/ha) produced optimum combined total seed yield per hectare as compared to the other density combinations for both crops.

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INTRODUCTION

Bean production in Africa is concentrated in Eastern Africa, with about 61 percent of the total production divided equally among the five producers, Uganda, Rwanda, Kenya, Burundi, and Tanzania (Landano, 1980). Bean production in Tanzania is concentrated in the Arusha, Tanga, Kigoma, Mbeya, West Lake, Ruvuma, Morogoro, Iringa, Tabora, and Kilimanjaro regions. Arusha is the biggest bean producing region with an annual production of about 65,000 metric tons (Karel et al., 1980). Nearly all beans consumed in Tanzania are produced in associated culture.

Bean yield ranges between 200 and 700 kg/ha (Jacobsen, 1976a). The low yields are associated with the low yield potential of the local cultivars, unfavourable weather, poor soil fertility and crop husbandry, and disease and pest infestation. In general, association of beans with other crops also reduces seed yield. However, with improved cultivars, good crop husbandry, and better disease and pest control, up to 1,500 kg/ha can be harvested (Jacobsen, 1976a). Tanzania bean researchers reported bean seed yields of up to 3,000 kg/ha (Mmbaga et al., 1982).

Associated culture often involves a cereal and a legume, with the cereal being considered the main crop (Nnko and Doto, 1982). Bean yields in associated culture are usually less than those obtained from sole bean stand. However, it is possible that yields could be increased with proper management practices such as the use of optimum density, improved bean cultivars, and disease and pest control. Bean yields in associated culture are a surplus to the main maize crop yield.

Beans in Tanzania are generally produced and consumed locally as whole grain by both the rural and urban populations. Beans are usually boiled until soft, and cooked in accompaniment with maize, potatoes, cassava, and other kinds of food eaten in Tanzania. Red or tan beans are preferred and when cooked look like small chunks of meat. Bean leaves are preferred in some parts of Tanzania and are fried or boiled and eaten as spinach.

Dry beans are the most important grain legume crop and, like maize, beans constitute one of the staple foods in many parts of the country. High protein content of bean (18-32 percent) supplements that of non-legume food crops, thus minimizing malnutrition in the urban and rural communities. Bean protein partially replaces animal protein. The latter is not always available in sufficient quantity to the low-income sector of the population. Young, tender green bean leaves, green shelled seeds, and dry mature seeds provide daily protein, mineral nutrients, and vitamins for consumers.

Increases in food production have not been able to keep pace with the rapid population growth, probably due to general poverty, unfavourable environment, and lack of technology in developing countries. World food production has increased by 1.5 percent while population has increased by nearly 3 percent annually (Steiner, 1984). Tanzania is no longer self-sufficient in food production and needs to import food at least in years when rainfall is insufficient. The rapid population growth has also caused land pressure in productive regions of the country. As a result, farmers are seriously constrained by land, labour, and capital. Consequently, intercropping of two or more crops in a given land area offers farmers the best option for sustaining their daily food supply.

There is no indication of any decrease in the importance of mixed cropping. The system has evolved in different areas and is so deeply established among farmers that a complete change of the system may not be acceptable to most farmers. Greater biological efficiency and higher net income in some cereal-legume combinations suggest that the farmers with their limited resources are making a rational decision in maintaining their own mixed cropping system. However, improvement of the system is essential for the benefit of those limited resource farmers who depend upon farming for their livelihood.

Increasing food production by introducing new technologies relying on commercial inputs did not produce the expected results. The new methods were mainly adopted by a few large, rich farmers but hardly by the majority of the small-scale farmers who constitute about 90 percent of the farmers in Tanzania. Since land, labour, and capital are limited, it is highly unlikely that farmers will grow sole crop stands of maize and beans. As efforts to introduce sole cropping had often failed, it is currently a governmental policy to increase food production by improving the existing systems. A series of workshops on intercropping held at Morogoro, Tanzania (Keswani and Ndunguru, 1982; Monyo et al., 1976) emphasized the willingness of the government to improve the associated culture system.

It is hoped that improvement of the intercropping system would result in surplus food crop production and consequently improve the standard of living of the community. Bean and maize are commonly desirable intercrop species because different growth rates and morphology of these crop species allow increased utilization of the environmental resources with minimum competition. Maize and bean in association provides a source of income, a balanced diet, and reduces labour peaks for farmers.

It is worthwhile to develop cropping systems that have the capacity to maximize crop yield per unit land area while keeping fertilizer nitrogen applications to a minimum. Choice of compatible component crops with diverse morphology, optimum crop density, optimum relative sowing time of component crops, and minimum crop competition will improve combined yields in associated culture. Intercropping intensifies crop production and may exploit environments with limiting or potentially limiting growth resources more efficiently (Papendick et al., 1976; Trenbath, 1982).

Combinations of crops are determined primarily by the length of the growing season and the adaptation of crops to particular environments. In areas with annual rainfall of less than 600 mm and a short growing season, early-maturing and drought-tolerant crops such as millet and sorghum dominate (Andrews, 1972; Baker, 1979). In areas with annual rainfall more than 600 mm, cereals and legumes of varying maturities are used. In Central and South America, maize and different types of beans dominate the intercropping systems (Francis et al., 1976). Bean and maize seed and leaf protein, mineral nutrient, carbohydrate, and vitamin concentrations usually determine the quality of human diets and livestock feeds.

Intercropping has characteristics that would provide flexibility in crop combinations for farmers. If appropriate technologies can be developed to exploit the potential of associated culture, farmers could become self-sufficient in food production. The objective of this experiment was to determine the optimum bean density that would accumulate adequate dry weight during the vegetative phase in order to increase seed yield in associated culture. The ultimate aim was to improve farmers' benefits from the cropping system. This study was undertaken to determine:

(1) Optimum bean density combinations with maize (40,000 plants/ha) that are capable of early storage of adequate dry weight before the peak competition from maize.

(2) If the combined yield of the component crops in associated culture will be higher than monocultural component crops or higher than the best monocultural crop species yield due to more efficient utilization of natural resources.

CHAPTER 2

REVIEW OF THE LITERATURE

2.1. Bean Seed Yield and Yield-Related Traits

2.1.1. Bean Seed Yield in Association

Productivity in associated culture is increased due to phase differences in periods of peak demand for natural resources (Steiner, 1984) and improved water use efficiency by the component crops (Mkandawire, 1987). Associated culture persisted for many years due to increased yield stability, reduced disease and insect risks, better utililization of labour, and high productivity per unit land area (Andrews and Kassam, 1976). Maximum productivity in an intercropping system is achieved when inter- and intra-crop competition is minimized for growth-limiting factors and the density of each crop is adjusted to minimize competition between the crop species (Huxley and Maingu, 1978). Cereals have stronger competitive ability than the companion legume even though the density of the legume may be greater than that of cereals (Osiru and Willey, 1972).

Yield potentials of climbing beans (4 tons/ha) and bush beans (3 tons/ha) in monoculture were reduced to a common level of one ton per hectare when associated with maize (Clark and Francis, 1985). Beans in association produced only 25-60 percent of their monocultural yield potential at comparable bean densities (Francis et al., 1976). Mmbaga (1980) observed seed yield of bean in associated culture ranging from 34 to 55 percent of their seed yield under monoculture at East Lansing, Michigan. In Kenya, Hasselbach and Ndagwa (1982) observed that 43 percent of bean seed yield reduction was attributed to interplanted maize. Maize-bean association in Malawi resulted in 51 percent bean yield reduction and 44 percent maize yield reduction (Edje and Laing, 1982). Bean seed yields improved with an increase in planting densities. Bean yields were strongly affected by maize competition.

The relationship between the yields of climbing bean cultivars and maize when intercropped was inverse. Climbing bean yield potential was associated with a longer life cycle than bush beans. It is also associated with prolonged durations of both leaf area and podfilling. The bean yield loss in associated culture was attributed to greater overlap with the dominant maize which reduced leaf area and podfilling phases (Clark and Francis, 1985). Durations of both phases were equal when bush and climbing beans were intercropped and final yield differences between them were not significant. The most competitive bean cultivars were the highest yielding in association and were tall, more vigorous, and later to mature. Likewise, the most competitive maize genotypes were also tall plant types (Davis and Garcia, 1983). Breeding beans with physiological tolerance to shade particularly after flowering and with enhanced nitrogen fixation would improve seed yield in associated culture (Davis and Garcia, 1983).

Early maturing beans maintained better yields in association with maize than medium- or late-maturing cultivars. In the medium- and late-maturing beans there was substantial yield reduction (Osiru, 1982). A suitable cultivar for maize/bean association would be one that utilizes available resources and matures early. It should be fairly erect and indeterminate with short vine to ensure maximum competition with maize during the early part of the season (Osiru, 1982). This observation supports an increased emphasis on early pod set and seed filling in bean genotypes for simultaneously planted bean-maize intercrops. Yield potential is most likely to be reached when component crops make their major resource demands at different times (Francis, 1978).

Bush beans under severe competition are very efficient in use of scarce resources. Maize-bean intercropping results in lower soil moisture than when beans are grown in pure stand (Mkandawire, 1987). Consequently, seed yields of bean in associated culture were usually lower than seed yield under monoculture. Bean yield in maize-bean association decreased mainly due to a reduction in the number of pods per plant (Gardiner and Craker, 1981). Francis et al. (1976) explained the reduction in terms of a reduction in number of racemes per plant, and lower pod and stem weights per plant.

Maize competition for resources is higher than that of beans. Yields of maize under optimum density and management conditions were often not affected when intercropped simultaneously with the common bean (Mmbaga, 1980; Mmbaga et al., 1982). Any reduction that might occur was normally substantially less than the observed bean yield (Davis and Garcia, 1983). However, bean yield might strongly be affected by maize competition (Francis et al., 1982). Fertilization with 60-70-30 for maize and 20-35-15 NPK for bean, respectively, produced a high combined yield of both maize and beans (Oliveira et al., 1983).

Maize competition also reduced bean components of yield in all four bean cultivars (Francis et al., 1982). The absence of specific maize cultivar x bean cultivar interactions indicated that bean cultivars selected with any particular maize genotype should be equally suitable for planting with any other maize genotypes (Davis and Garcia, 1983). Francis (1978) suggested that near simultaneous planting was optimal for production of the highest total yield from intercropped maize and beans. Estimates from Latin America suggested that about 60 percent of maize and 80 percent of beans were produced in associated culture (Francis, 1978).

2.1.2. Harvest Index

Harvest index is the ratio of seed weight to total plant biomass and is commonly used as an index of the proportion of assimilates allocated to a specific sink of a plant. It is currently used to evaluate cultivars' partitioning efficiency. Harvest indices of the common bean vary for different cultivars and growing conditions. Wallace et al. (1972) reported harvest indices from 53 to 67 percent among eleven cultivars of common bean. These values reflected the fact that in measurement of the harvest index of grain legumes, leaves are generally not included because they are lost before harvest. Cultivars with the highest harvest index had the lowest seed yield (Wallace and Munger, 1966).

Standardized correlated responses to selection for grain yield through the harvest index of individual F_2 plants showed that harvest index was of limited value for yield improvement (Zimmermann et al., 1984). Mmbaga (1980) obtained harvest index values ranging from 62 to 65 percent in a monoculture/intercropping experiment. In general, the lines with some ability to climb suffered less reduction in harvest index than the bush type due to competition for light from the maize (Davis et al., 1984).

2.1.3. Dry Weight Distribution

Dry weight distribution among plant organs in plants harvested sequentially suggested a movement of assimilates from leaves to stem and then to pods (Burga, 1978). Dry weight distribution in leaves, stems, and pods of beans in monoculture at 58 days after planting (DAP) was 41, 33, and 4 percent, respectively. However, in bean-maize associations, bean dry matter distribution for leaves, stem, and pods of beans was 33, 45, and 2 percent, respectively, for the same period (Edje and Laing, 1982). Bean and maize growth cycles are usually offset in time; bean growth significantly exceeded maize growth during the first 26 days (Clark and Francis, 1985). Maize dry matter (DM) significantly exceeded that of the bean after 47 days but nitrogen content did not differ consistently between the bean and maize monocrops after 33 days (Clark and Francis, 1985). The staggering of planting and hence growth cycles in the bean-maize intercrops may result in significantly more dry matter, nitrogen, and leaf area index (LAI) than either component monocrop during all or part of the growing season.

Seed filling in common bean is sustained by on-going photosynthesis, mobilization of starch from leaf tissue, and possibly the remobilization of stored root and stem assimilates (Burga, 1978; Bouslama, 1977; Lindoo and Nooden, 1976). Stored carbohydrate could serve as a buffer to support normal grain growth despite adverse weather conditions (Yoshida, 1972). Soybean seed growth rates were not closely related to rates of photosynthate production because storage carbohydrate acted as a buffer between seed growth and photosynthesis (Egli and Legget, 1976).

Yield superiority in the architype (indeterminate type II growth habit, few branches with a narrow erect profile, and a long seed filling period) is based on extended filling periods, high partitioning and remobilization of carbohydrates and nitrogen, large sink, and lower abscission rate (Izquierdo, 1981). Remobilization of reserve from storage sites optimized and stabilized yields in dry beans. Late remobilization of carbohydrate reserves can be triggered by stress conditions and thus stabilize yield (Izquierdo, 1981). Bush beans are characterized by a short but rapid filling period, high partitioning, and high remobilization (Izquierdo, 1981). Once the photosynthetic mechanism becomes impaired, bush bean pod filling is dependent on remobilization (Izquierdo, 1981). Stems and pod walls were the most important sources of remobilizable reserves (Izquierdo, 1981).

Nep-2 and Black Turtle varieties maintained a high amount of accumulated starch and nitrogen in stems at physiological maturity (Izquierdo, 1981). High root and stem starch content throughout the reproductive stage was associated with low-yielding cultivars. This accumulation of starch in stems during pod-filling indicated that beans were inefficient in their use of photosynthate or provided inadequate sink capacity for the present resources (Adams et al., 1978; Biddulph and Cory, 1965).

Some evidence suggested that yields in grain legumes are source limited (Sinclair and de Wit, 1975). Tanaka and Fujita (1979) reported that during the most active period of flowering and pod wall growth the carbohydrate content of stems was low. This indicated that the sink capacity exceeded the source capacity during the period of peak demand. Consequently, source may be a limiting factor during the flowering and pod wall growth period (before actual seed filling), resulting in flower and/or pod abortion. Tanaka and Fujita (1979) considered the abortion of excessive flowers and pods as a unique characteristic of dry beans to adjust the sink size to the source in order to keep seed size relatively stable (yield component compensation).

Starch concentration in the lower stem with few pods increased continuously from flowering but in other plant parts declined after early pod filling. Starch accumulation increased from anthesis and was maximum at the mid-seed filling stages in roots, stem, petioles, and pod wall (Izquierdo, 1981). Concentration of soluble sugars in nodules and roots declined at mid pod-fill. Nitrogen fixation decreased rapidly after peaking at early pod-fill, reaching the lowest value at mid pod-fill. The decline was accompanied by the loss of lower leaves and the presence of a high concentration of starch in the stem (Waters et al., 1980).

Bean leaves on lower nodes are the major contributors of photosynthate to roots and lower stem sections (Biddulph and Cory, 1965; Lucas et al., 1976; Wien et al., 1976). Since canopy closure reduces light penetration to the lower levels of the crop profile, the dependence of nodules on photosynthate from lower leaves could be a major factor limiting N_2 fixation (Waters et al., 1980). High plant density greatly reduced N_2 fixation of individual bean plants (Graham and Rosas, 1978). The availability of photosynthate to below-ground parts also depended on competition from more active sinks higher up the plant (Lawrie and Wheeler, 1974; Lucas et al., 1976).

Yield differences among cultivars were associated with the length of the seed filling period rather than with the rate of seed growth (Izquierdo, 1981). The seed filling duration was correlated with yield and days to maturity, suggesting that a short reproductive period might result in a reduction in yield (Tohme, 1986). Type II beans showed more than a two-fold increase in the duration of the filling period when compared with the bush bean cultivars (Izquierdo, 1981). Genetic differences in accumulation and depletion of stem reserves among bean cultivars were reported by Adams et al. (1978). They reported starch values ranging from undetectable to abundant amount in roots and stems of twenty-three dry bean cultivars. Starch amount varied with the three physiological stages (flowering, mid pod-filling, and physiological maturity) at which samples were taken. In addition, they found no clear pattern of relationship between starch accumulation in stems and roots and yield.

Prior to flowering, in experiments conducted by Waters et al. (1980), over 85 percent of the recovered C^{14} activity translocated from node four was in roots, nodules, and lower stem. However, at flowering, radioactivity translocated to the lower stem declined but correspondingly increased in nodules (Waters et al., 1980). Nodules accumulated only 3.5 percent of the radioactivity of the preflowering stage.

Westermann et al. (1985) observed that seed at physiological maturity contained 64, 73, and 84 percent of the labeled-N applied at the late vegetative, early pod development and seed filling stages, respectively. The seed contained an average of 68 percent of the total plant N and 53 percent of the total plant dry weight at physiological maturity (Westermann et al., 1985). Consequently, photosynthetic and N_2-fixation activities during seed filling could have a significant influence on the final seed N concentration and bean seed yield (Westermann et al., 1985).

2.1.4. Leaf Area

Maize reduced maximal bean leaf area index (LAI) in the bush and climbing cultivars. Reduced LAI was noted at 40 days in the bush bean but not until 54 days in the climbing bean (Clark and Francis, 1985). In the bush bean, intercropping had no effect on the duration of leaf area expansion, while in the intercropped climbing bean leaf area expansion was curtailed at forty-seven days (Clark and Francis, 1985).

Leaf area indices of the two monocrop bean cultivars were nearly identical up to 47 days, after which the bush bean declined (Clark and Francis, 1985). This reflected the shorter life cycle of the bush bean while the climbing bean continued to increase to a maximal LAI at 60 days (Clark and Francis, 1985). In Kenya, maximum leaf area indices of 3.2, 3.2, and 4.8 were obtained from Rose Coco, Mweze Moja, and Canadian Wonder, respectively (Coulson, 1985). Yamaguchi (1974) showed that leaf area index was the trait most associated with grain yield and was positively correlated with number of leaves per plant, plant height, and lodging susceptibility.

2.2. Maize Yield and Yield Components

2.2.1. Grain Yield

Maize yields are often not affected when intercropped with common beans under optimum management conditions and moderate densities (Francis, 1978a). The findings indicated that neither competitive depression nor nitrogen transfer from the legume occurred (Searle et al., 1981). Intercropping depressed legume dry matter and grain yield at 0 kg N ha^{-1} (Francis, 1978a). Maize yield reduction depends on the competitive ability of common bean cultivars used in association with maize (Davis and Garcia, 1983).

Yields of maize in the tropics are generally lower than those reported from temperate environments due to lower harvest indices (30-40 percent) as compared with 50-55 percent for temperate germ plasm (Goldsworthy, 1974; Daynard, 1969). This is possibly due to more suitable growing conditions in the temperates such as longer daylight and cooler nights for maize as compared to the tropics. Seed yield from maize may be a function of the rate and duration of dry matter accumulation by the individual kernels multiplied by the number of kernels per plant (Poneleit and Egli, 1979). Studies have shown positive association of the duration of grain dry matter accumulation with yield per unit area (Daynard and Kannenberg, 1976).

2.2.2. Land Equivalent Ratio

The concept of a land equivalent ratio (LER) has been used to obtain evidence as to whether two or more crops should be intercropped rather than planted as sole crop stands (IRRI, 1974). LER is the most frequently used index to determine the effectiveness of intercropping relative to growing crops separately (Willey, 1985). LER is defined as the total land area required under sole cropping to give the yields obtained in the intercropping mixture. It is expressed as:

$$LER = Y_{ij}/Y_{ii} + Y_{ji}/Y_{jj}$$

where Y is the yield per unit area, Y_{ii} and Y_{jj} are sole crop yields of the component crops i and j, and Y_{ij} and Y_{ji} are intercrop yields (Mead and Willey, 1980). The partial LER values, L_i and L_j, represent the ratios of the yields of crops i and j when grown as intercrops relative to sole crops. Thus

$$L_i = (Y_{ij}/Y_{ii}) \text{ and } L_j = (Y_{ji}/Y_{jj}) .$$

LER is the sum of the two partial land equivalent ratios so that

$$LER = L_i + L_j .$$

The partial LER values give an indication of the relative competitive abilities of the components of intercrop systems. The value of LER is determined by several factors including density and competitive ability of the component crops in the mixture, spatial arrangement, crop morphology and duration, and management variables that affect individual crop species (Enyi, 1973; Natarajan and Willey, 1980a; Fawusi et al., 1982). It was suggested that in density studies of cereal-legume intercrop systems, the sole crop yields used as standardization factors for estimating LER should be at the optimum densities of the crops (IRRI, 1974; Huxley and Maingu, 1978). The values of LER follow the density of the legume component rather than that of the cereal (Ofori and Stern, 1987) and possibly the trend of the competitive gap.

Differences in growth durations of component crops affect the magnitude of the LER. The LER values in crops with similar maturities are usually less than in crop combinations with contrasting maturities (Trenbath, 1976; Willey, 1979). No yield advantages were found in maize-cowpea (Haizel, 1974) and sorghum-cowpea (Andrews, 1972; Rees, 1986) intercrop systems in which components were of similar growth durations and consequently narrowed competitive gap. Enyi (1973) studied maize or sorghum intercropped with either cowpea or beans of similar growth durations and observed that productivity was less than when compared to intercropping of these cereals with 240-day pigeon pea. The estimated partial LER of maize was 0.72 with pigeon pea, 0.64 with beans, and 0.50 with cowpea. The lower partial LER values for the associations with beans and cowpea may be due to competition in the intercrop state for growth-limiting factors, because peak demands on the environment by these crops might have coincided with those of the cereals.

The availability of water also appeared to influence the LER. In maize-bean (Fisher, 1977) and sorghum-cowpea intercrop systems (Mafra et al., 1981; Rees, 1986), LER values increased with the availability of water and diminished when water was limited. However, Natarajan and Willey (1980b) noted that LER increased under limited water situations. The cereal component with relatively high growth rate, height advantage, and a more extensive rooting system is favoured in the competition with the associated legume. The yield of the legume component declined on average by about 52 percent of the sole crop yield, whereas the cereal yield was reduced by only 11 percent (Ofori and Stern, 1987).

Biological efficiency as measured by the land equivalent ratio was higher in intercrop than in monoculture, and one intercrop combination showed a 65 percent advantage over monoculture (Francis et al., 1982). Mmbaga et al. (1982) obtained LER values of 1.25 and 0.96 when maize was intercropped with bean exhibiting types I and III, respectively. Edje and Laing (1982) in Malawi observed a land equivalent ratio greater than unity while Mmbaga (1980) at East Lansing, Michigan, obtained LER values of up to 1.34 when type II was intercropped with maize. Total grain yields of maize and bean did not show any advantage for either monoculture or intercropping at higher maize densities (Francis et al., 1982).

Land equivalent ratio can be greater than 1.0 if mixtures are less affected by pests and/or diseases than sole crop stands, or if the two crops do not compete seriously for one or more environmental resources (Trenbath, 1976). Less competition could occur if the crops use different forms of a given resource that are available, if they use the same resource at different times or from different zones of the environment, or if quantities available are in excess of requirements (Trenbath, 1976).

2.3. Light Interception in the Two Cropping Systems

Light cannot be influenced directly by man as is the case with moisture and nutrients, and therefore often becomes the limiting factor. Legumes are commonly grown in the tropics under reduced solar radiation due to dense cloud cover and shading from tall intercrops (Eriksen and Whitney, 1984). Photosynthetic response of a plant is affected by the light intensity at which it is grown (Wolf and Blaser, 1972). High intensity radiation induced additional development of the palisade and spongy mesophyll regions, resulting in thicker leaves (Pearce and Lee, 1969). Intercropped beans developed thinner leaves characteristic of plants under reduced light intensity (Crookston and Hill, 1979).

Maize canopy apparently contributed to more light interception and less light reflection in the intercropped beans. Strong correlations exist between the yield of a crop and its light environment (Shibles and Weber, 1965). Considerable attention has therefore been given to optimizing crop leaf area index and to designing plants which permit maximum light penetration into the lower canopy (Wilfong et al., 1967). A photomorphogenic effect which stimulated some bean genotypes to climb was described by Kretchmer et al. (1979). The stimulus to climb may be related to the quality of light penetrating through the maize canopy (Kretchmer et al., 1979). Photosynthetic energy transmitted to the ground before attainment of full cover in a row monocrop represents a wasted resource (Clark and Francis, 1985). The utilization of this resource by an interplanted crop may increase total resource use by the intercrop (de Wit, 1960).

Shading of legumes generally caused elongated growth, reduced specific leaf weight (SLW), and increased leaf area per unit of plant weight (Beuerlein and Pendleton, 1971). Shading did not affect plant heights of cowpea and bush beans except for some petiole elongation in bush beans (Eriksen and Whitney, 1984). Number of seeds per pod was unaffected by shading in cowpea, soybean, and bush bean. Cowpea was the most shade sensitive, soybean was intermediate, and bush bean was least sensitive (Eriksen and Whitney, 1984).

Shading of beans by maize plants during the later growth stages probably reduced the supply of photosynthate for the developing seeds (Fisher, 1979) and contributed substantially to the decreased yields of bean plants in the associated culture. Shading appeared to be the main competitive effect of maize on beans (Zelitch, 1971). A reduction of photosynthetically active radiation (PAR) incident on bean canopies reduced bean yield, growth rate, LAI and net assimilation rate (Gardiner and Craker, 1981), leaf number, area, and thickness, and pod number (CIAT, 1976; Crookston and Hill, 1979). Photosynthesis per unit area of shaded leaves was decreased by an average of 38 percent (Crookston, 1975), while transpiration was not significantly affected.

Increased intracellular resistance of the shaded leaves was more important in reducing CO_2 uptake than was the increase in stomatal resistance (Crookston, 1975).

In experiments conducted by Burga (1978), shade environment reduced the CO_2 uptake rates of Seafarer and Nep-2 by 55 and 30 percent, respectively. Shade also reduced the amount of starch in stem (Burga, 1978). Knecht and O'Leary (1972) indicated that there is a decrease in the size and/or number of stomata per unit leaf area of shaded leaves, with a resultant increase in leaf resistance to CO_2 diffusion. Shading consistently resulted in thinner and frequently smaller leaves, thus reducing the volume of photosynthetic cells per leaf or per unit leaf area (Wilson and Cooper, 1960). Light interception by maize leaves was quite small until late in the life of the bean crop (Fisher, 1979). Light interception by maize rose steadily up to about 79 days from emergence and then maintained a value between 60 and 70 percent until 132 days (Fisher, 1979).

Fisher (1979) proposed that bean yield reductions under maize were due to root competition since bean plants reached their peak light interception early in the growing season before the maize canopy had developed. More than 90 percent light penetrated the mixture until about 53 days after planting (DAP) (Fisher, 1979). Light penetration to the beans declined from 90 to 67 percent at 71 DAP (Fisher, 1979). Beans reached peak interception at about 36 DAP. Maize and beans in mixtures had higher mean seed weights than in sole crop stands, though not significant (Fisher, 1979). This is a common phenomenon in mixed cropping, attributed to relaxation of competitive stress on one or more of the species during its grain filling phase where these are separated in time and competitive gap (de Wit, 1960).

The rate of dry matter production in crops depends on the efficiency of the interception of photosynthetically active radiation (PAR) (Biscoe and Gallagher, 1977; Monteith, 1977). The generally taller cereal shades the legume, and at high densities causes reduced growth and yield of the companion legume. Gardiner and Craker (1981), maintaining a constant bean density of 220,000 plants/ha, found that varying maize density from 18,000 to 55,000 plants/ha progressively reduced the amount of light available to the beans. At the low maize density (18,000 plants/ha), beans received 50 percent of the incident light, compared to 20 percent at the highest maize density (55,000 plants/ha). At the highest maize density, yield of the intercrop bean was only 30 percent that of the bean in monoculture. Light interception in maize-pigeon pea intercrop was low with the initial slow increase in leaf area index (LAI), and about 80 percent when LAI reached about three (Sirakumar and Virmani, 1980). The foliage canopy of the intercrop was more effective in capturing the light. Maize-pigeon pea intercrop attained an LAI of three in 45 days, compared to 50 days in the sole maize and 115 days in the sole pigeon pea. Sirakumar and Virmani (1980) observed that dry matter production per unit of PAR absorbed was higher in the maize-pigeon pea mixture than in the sole crops.

2.4. Water Use in the Cropping Systems

Water is the most important soil factor in semiarid and subtropical regions where inadequate rainfall may frequently limit crop production (Baker and Norman, 1975). The differences in root systems, depth of rooting, lateral root spread, and root density are factors that affect competition for water between component crops (Babalola, 1980; Haynes, 1980). The use of different parts of the soil profile by root systems of different crop species minimizes the degree of competition for water (Haynes, 1980).

The cereal is generally favoured when component crops compete for available water due to its higher growth rate and more extensive root system. The total water use by sole pigeon pea at the end of the growing period (173 DAP) was 584 mm and in the mixture was 585 mm; in sole sorghum at harvest (82 DAP) it was 434 mm. Reddy and Willey (1981) obtained a total water use of 406 mm in the mixture, compared to 303 mm in sole millet (82 DAP) and 368 mm in sole groundnut (105 DAP).

Hulugalle and Lal (1986) reported that water use efficiency (WUE) in maize-cowpea intercrop was higher than that in the sole crops when soil water was not limiting. However, under drought conditions WUE in the intercrop was lower compared to the sole maize. For the favourable moisture regimes, WUE (kg grain/mm/ha) of the intercrop was 3.6 compared to 2.1 in eight of the sole crops, and for the droughty conditions, 1.6 for the intercrop, 2.2 for the sole maize, and 0.5 for the sole cowpea.

2.5. Management Factors Influencing Productivity and Efficiency in the Two Cropping Systems

2.5.1. Component Crop Density

In a maize-bean intercrop system increasing maize density three-fold, from 18,000 to 55,000 plants/ha, caused reductions of 24 percent in leaf area index and 70 percent in seed yield of the associated bean (Gardiner and Craker, 1981). Density of the cereal component contributes a greater proportion to mixture yield, but the efficiency of the cereal-legume intercropping systems, measured in terms of LER, follows the trend of the intercrop legume component yields (Natarajan and Willey, 1981a).

Seed production of component crops in an intercropping pattern is determined by such factors as density of seeding of each component, relative competitive ability, plant height, cycles of maturity, and genotypes (Francis et al., 1982). There is a range of successful plant density levels in the maize-bean association which may be used to attain maximum grain and protein yield and net income. Research in bush bean monoculture has shown a yield plateau for densities greater than twenty plants/m^2 (CIAT, 1975), and the density needed to reach this plateau was unrelated to bean cultivar (Francis et al., 1982).

Maize density appeared to influence both maize and bean yields and yield components to a much greater degree than intercropped bean density (Francis et al., 1982). Maize is taller and shades the developing bean crop. However, a vigorous intercropped climbing bean may reduce maize yield (Francis et al., 1982). Maize yields were positively correlated with maize density and ears per plant. Bean seed yield was positively correlated with pods/m^2 and pods/plant, but not with bean density (Francis et al., 1982). Reductions in leaf area index, growth rate, and net assimilation rate of beans occurred under high maize density as compared with bean monocrop (Gardiner and Craker, 1981).

2.5.2. Plant Configuration and Spacing

Row arrangements, in contrast to arrangements of component crops within rows, improved the amount of light transmitted to the lower legume canopy. Such arrangements can enhance legume yields and efficiency in cereal legume intercrop systems (Mohta and De, 1980). In a maize-groundnut intercrop system Evans (1960) obtained LERs of 1.09 in the same row arrangement compared to 1.30 in alternate rows. In the maize-pigeon pea system, maize yield was not affected in the alternate row arrangement, but it was reduced by 20 percent when the pigeon pea was in the same row (Dalal, 1974). Consequently, arrangement of component crops in alternate rows is more beneficial than in the same rows. In contrast to these observations, Agboola and Fayemi (1971) did not observe any difference whether maize and cowpea were planted in the same or alternate rows. The use of double rather than single alternate row arrangements of component crops improved the yield, light penetration to the canopy of the legume component, and efficiency of the intercrop pattern.

2.5.3. Time of Sowing

The relative time of sowing of component crops is an important management variable manipulated in cereal-legume intercrop systems. Andrews (1972) pointed out that differential sowing improved productivity and minimized competition for growth-limiting factors in intercropping. Willey (1979) also pointed out that sowing component crops at different times ensured full utilization of growth factors because crops occupy the land throughout the growing season. In contrast to simultaneous sowing, maize sown five to fifteen days earlier than beans increased maize yields by 13-43 percent and the associated bean yields were reduced by 20-27 percent (Francis et al., 1976). On average, intercropping efficiency measured as LER was 39 percent higher when beans were sown 5-15 days before maize. Studies on maize intercropped with four contrasting bean cultivars sown 5-10 days apart suggested that near-simultaneous sowing of component crops was optimal for attaining the highest combined yields and intercropping efficiencies (Francis, 1978; Francis et al., 1982a).

In Colombia, Francis et al. (1982b) varied dates of sowing maize and indeterminate beans (types II and III) and noted that maize was more competitive than beans at all sowing dates, except when beans were sown 10 days earlier. Sowing maize 10 days before beans reduced bean yield by 69 percent and maize by only 7 percent.

Beans sown 10 days earlier reduced maize yield by 53 percent and bean yield by 21 percent. In Nigeria, Remison (1982) did not find any advantage of staggered over simultaneous sowing dates of maize and cowpea. Intercropped cowpea yield was reduced by 57 percent and maize yield by 35 percent when sown simultaneously. In Western Australia, Ofori and Stern (1987) concluded from a maize-cowpea intercrop system that staggered sowing dates of component crops at intervals of 10 or 21 days were of no advantage over sowing them simultaneously. May (1982) observed that a yield advantage of 32 percent completely disappeared when green-gram was sown one week after bulrush millet. From these studies, it may be concluded that staggered or differential sowing of component crops is of no advantage over simultaneous sowing. In staggered sowing, the earlier sown component has an initial advantage over the later sown component. Component crops are unable to compensate fully for yield loss due to earlier or later association with the other component.

2.6. Pest Interactions in the Two Cropping Systems

The environment of the bean plant is drastically changed by intercropping and therefore diseases and insects may form a major constraint for bean production. Intercrops generally suffer less disease attack than monocultural crops with the same overall density. Mixed stands contain a greater proportion of plants with resistance to some of the pathogens present (Steiner, 1984). The total plant density of intercrops is mostly higher than that of either sole crop. This induces a change of microclimate, especially where low-growing crops are interplanted between tall species (shelter effect) (Burdon, 1978).

Van Rheenen et al. (1982) observed that beans grown in association with maize showed a lower incidence of halo blight, bean common mosaic virus, anthracnose, common blight, scab, mildew, and to a lesser extent angular leaf spot. The opposite was observed with white mold (van Rheenen et al., 1982). Relative humidity in mixtures is generally increased and becomes more favourable for some fungal and bacterial diseases (Burdon, 1978). The susceptibility of the crop species, primarily the dominated ones, might also increase due to reduced insolation (Burdon, 1978). Associated culture may restrict early development of dominated crops, making them more susceptible to disease (Burdon, 1978).

Ascochyta phaseolerum was less prevalent in cowpea interplanted with maize than in cowpea growing alone. The total number of diseased plants as well as the speed of dissemination of the pathogen was less in the polyculture (Larios and Moreno, 1977). The total number of infected plants with cowpea mosaic virus (CPMV) and chlorotic cowpea mosaic virus (CCMV) was lower in polyculture than in monoculture, apparently because fewer numbers of vector chrysomelid beetles (e.g. Diabrotica cerotoma) were present in the mixed stands. A similar situation occurred in Malawi where beans trapped aphids, thus decreasing the spread of rosette disease of groundnut in mixed stands (Thresh, 1982). Pigeon pea in Haiti was completely protected from virus diseases when grown between rows of tall sorghum (Palti, 1981). On the other hand, the severity of angular leaf spot of beans caused by Isariopsis griseola was highest in bean polycultures that included maize and lowest in systems where beans were intercropped with sweet potatoes or cassava (Moreno, 1977).

Some crop associations modify the microclimate and result in increased relative humidity and shade. Consequences of the modified microclimate may favour the incidence of diseases such as angular leaf spot and wilt of the common bean. However, the shielding effect of the companion crops against airborne pathogens should more than offset the microclimatic advantage pathogens may derive from the dense foliage of mixed crops (Palti, 1981). Mixtures of different crop species buffer against disease losses by delaying the onset of the disease, reducing spore dissemination, and/or modifying microenvironmental conditions such as humidity, light, temperature, and air movement. Certain associated plants can function as repellants, antifeedants, growth disrupters, or toxicants. Some plant combinations may enhance soil fungistasis and antibiosis through indirect effects on soil organic matter content (Sumner et al., 1981). The use of interspecific mixtures and therefore a higher level of diversity of genotypes shows great possibilities for disease reduction. A parallel approach involves the use of multilines in cereal crops to achieve high genetic diversity (Browning, 1975).

Intercropping systems enable farmers to spread the risk of crop losses due to insect attack (Steiner, 1984). Farmers, through intercropping, created an unsuitable habitat for some pests and a favourable environment for predators (Steiner, 1984). Consequently, complexity of plants in associated culture led to a lower buildup of insects than when crops were grown in sole crop stands. The dispersal of both the adult and larvae stages of insects may be impeded where host and non-host are growing together. The resistant or non-host plants may offer a barrier to the dispersal of inoculum or pests (Burdon, 1978) leading to less bean damage.

Maize in maize-groundnut intercrop is attacked less frequently by the maize borer because the borer moth prefers a background with a brownish colour to a solid green background (Raros, 1973). In addition, some pests avoid their preferred crops when shaded by taller crops in association (Karel, 1982).

Intercropping does not necessarily favour only predators; there are examples where it favours pests, too. The attack on cotton by the American boll weevil was increased by relay-intercropping maize with cotton (Steiner, 1984). The foliage beetle, Ootheca mutabilis, caused significantly more damage in mixed crop cowpea than in sole crop (IITA, 1978). Pigeon pea is highly attractive to thrips, a major cowpea pest. Thrips damage to cowpea is therefore increased in the vicinity of pigeon pea (IITA, 1978). Ecologists have conducted experiments in multiple cropping systems to test the theory that increased plant diversity fosters stability of insect populations (Pimentel, 1961; Root, 1973). Examination of 198 herbivore species showed that 53 percent exhibited lower abundance in multicrops than in monoculture, 18 percent were more abundant in multicrops, 9 percent showed no difference, and 20 percent showed a variable response (Andow, 1983; Risch et al., 1983). In Nigeria, populations of flower thrips were reduced by 42 percent on cowpea/maize polyculture. However, cropping pattern had no effect on infestations of Maruca testulatis, pod-sucking bugs, and meloid beetles (Matteson et al., 1984). Early infestations of Maruca were no different in monocrops and polycultures of maize and cowpea in Nigeria, but 12 weeks after planting infestations were significantly higher in the monocrops. Similar shifts were observed with thrips (Matteson et al., 1984). In India, larval populations of Heliothis amigera were higher in sorghum-pigeon pea intercropping systems than in sole crop pigeon pea plots, which led to high grain losses in polycrops (Bhatnagar and Davies, 1981). In the Philippines, Hasse and Litsinger (1981) observed that intercropping maize with legumes did not reduce the numbers of egg masses laid by common corn borers (Ostrinnia furnaealis).

A reduced insect pest incidence in multicrops may be the result of increased parasitic and predator populations, decreased colonization and reproduction of pests, chemical repellency, masking and/or feeding inhibition from non-host plants, and prevention of pest movement and/or emigration (Matteson et al., 1984). A host plant may be protected from insect pests by the physical presence of other overlapping plants. A case in point is the camouflage of bean seedlings by standing rice stubble for beansfly (Hasse and Litsinger, 1981). Certain pests prefer a crop background of a particular colour and/or texture. Aphids and flea beetles are more attracted to sole crops with a background of bare soil than to ones with a weedy background. Aromatic odors of certain plants can disrupt host finding behavior. Grass borders repelled leafhoppers in beans and population of Plutella xylostella are repelled from cabbage-tomato intercrops (Hasse and Litsinger, 1981). Risch (1981) looked at the population dynamics of six chrysomelid beetles in monocultures and polycultures of maize-bean-squash. In polycultures containing at least maize, the number of beetles per unit was significantly lower relative to the numbers of beetles on host plants in monocultures. Beetles tended to emigrate more from polycultures than from host monocultures due to shade and barrier to beetle movement. Egunjobi (1984) studied the ecology of Pratylenchus brachyurus in traditional maize cropping systems of Nigeria. Nitrogen, phosphorus, and potassium fertilizer applications increased the numbers of the nematode more in soil under monocultural maize than in plots with maize intercropped with cowpea, groundnut, or green gram.

Intercropping can suppress the growth of weeds more than sole cropping if interference between crop components is weaker than that between crops and weeds (Yih, 1982). Intercrops were better at suppressing weeds within 30 days after sowing because of increased preemptive use of light effected by earlier canopy closure (Bantilan et al., 1974). The role of allelochemical interference between intercrop components and weeds has scarcely been explored. This type of weed control was potentially useful in monoculture cropping systems (Putnam and Duke, 1974; Fay and Duke, 1977; Lockerman and Putnam, 1979). In intercrops, there must be selectivity in the effects of toxins released by the crops; weeds must be more susceptible than crop components. Gliessman (1983) evaluated the effect of squash leaf extract on radical elongation of maize, cowpea, and cabbage seedlings. The extract had a stronger inhibitory effect on cabbage than on the other two species. Shading combined with selective allelochemical produced by the squash leaves can be an effective means of weed control in maize-cowpea polyculture (Gliessman et al., 1981; Letourneau, 1983).

Intercrops are generally more effective in reducing weed growth than the correspondent sole crops and greater soil coverage can be obtained by the foliage of the associated systems than by the sole crops. Shading showed considerable potential for reducing the spread of <u>Cyperus rotundus</u>. Weed growth in maize-groundnut (smother crop) intercrops was less than in the sole crop of groundnuts (Steiner, 1984).

2.7. Influence of Soil Nutrients in the Two Cropping Systems

The major soil nutrients for which component crops compete when in limited supply are nitrogen, phosphorus, and potassium. The cereal component, with a faster-growing or more extensive root system, generally has a competitive advantage over the associated legume (Trenbath, 1976). The inability of the legume to compete for these nutrients is attributed to lesser ramification of their root systems (Rabotnov, 1977). Competition for nutrients is important and could begin early in the growth of the component crops in cereal-legume intercropping systems (Wahua, 1983). Evans (1977) pointed out that the absorption of nitrogen is controlled by the roots of component crops. In cereal-legume intercropping, the legume component is capable of fixing atmospheric N_2 under favourable conditions and this is thought to reduce competition for N with the cereal component (Trenbath, 1976). In the absence of an effective N-fixing system, both cereal and intercrop legume compete for available soil N (Ofori and Stern, 1987). In a maize-cowpea intercrop system, Wahua (1983) observed that at 105 kg N/ha, the crops were in competition for N and that this occurred before flowering. Nitrogen uptake by intercrop cowpea was 64 kg/ha compared to 88 kg/ha in the sole crop cowpea. Nitrogen uptake of intercrop maize was reduced by 17 percent compared to sole maize. Without applied N, Chang and Shibles (1985a) and Ofori and Stern (1986) reported strong competition for soil N by intercrop maize and cowpea. This was particularly evident between 49 and 63 days when both crop species were at the reproductive stage and required substantial amounts of N. Intercrop cereal grain yields increased progressively with applied N, while seed yields of companion legumes decreased or were less affected.

Phosphorus is a major nutrient that determines, along with other constraints, the production potential of most grain legumes usually intercropped with cereals. Legumes are poorer competitors for P when intercropped with grasses or cereals due to differences in root morphology (Donald, 1963; Jackman and Mouat, 1972; Evans, 1977). Lai and Lawton (1962) evaluated root competition for P between corn and intercrop field bean using ^{32}P labeled fertilizer placed at different depths. They noted that corn was more vigorous in the uptake of P than beans as a result of its more extensive roots. Wahua (1983) observed that maize and cowpea were competing for P and the competition was more evident at flowering. In the absence of applied P, maize was more competitive than cowpea in the initial stages. However, at high rates of applied P, P uptake of intercrop maize was reduced by 30 percent, indicating competition for P from cowpea. Competition was clearly expressed in the observation that intercrop cowpea took up only 50 percent of the sole cowpea P uptake in the absence of applied P, while at a high level of P, 65 percent was taken up. Remison (1978) concluded that intercropped maize and cowpea grown at two levels of P did not compete for P because there was no significant differences in yields of the sole crops and the intercrops.

Studies by Drake et al. (1951) showed that cation exchange capacities (CEC) of roots of legumes are approximately double those of cereals. The relatively high CEC of legumes indicates that on soils with low levels of exchangeable K, the legumes would be deficient in K because larger amounts of divalent cations would be absorbed by the roots. The level of K in many soils decreases as the growing season progresses. Consequently, K uptake in competition with cereal becomes increasingly difficult for the legume (Drake et al., 1951). Natarajan and Willey (1980b) noted that sorghum was more aggressive for K than pigeon pea, and this severely affected the early growth of pigeon pea. In pigeon pea, K uptake was 28.6 kg/ha in the sole crop and 3 kg/ha in the intercrop, a reduction of 87.5 percent. Wahua (1983) observed that maize was more competitive for K than cowpea, particularly when N was high. At 50 days after planting, application of 115 kg/ha of N caused reductions of 31 percent in uptake of K in the intercrop maize, and 50 percent in the intercrop cowpea, compared to the respective sole crops.

2.8. Nitrogen Fixation and Transfer by Legume Crop Component

In fixing atmospheric N_2, legumes contribute to the N content of soil either as sole crops in rotation or as intercrops (La Rue and Patterson, 1981). In such systems, legumes may either increase the soil N status through fixation and excretion, or in the absence of an effective N-fixation system, compete for N (Trenbath, 1976).

The quantity of N_2 fixed by the legume component in cereal-legume intercropping depends on the species, morphology, density of legume in the mixture, the type of management, and the competitive abilities of the component crops.

Legumes of indeterminate growth are more efficient in terms of N_2 fixation than determinate types. Eaglesham et al. (1982) observed that in a growing season soybean fixed more nitrogen than cowpea, but soybean used a greater amount of the N_2 fixed to produce seed. Cowpea fixed less N and had a lower seed N harvest index. It thus contributes more N to the soil from its residues.

In a sorghum-soybean intercrop system, a tall variety of sorghum reduced soybean yield by 75 percent and N_2 fixation at the early pod-fill stage by 99 percent (Wahua and Miller, 1978b). Soybean received more than 90 percent of the incoming radiation with the short sorghum, compared to less than 50 percent with the tall sorghum. Ofori and Stern (1987) noted that cowpea maintained its ability to fix atmospheric N_2 when intercropped with maize, but that N_2 fixation was reduced by N fertilizer application.

Evidence in the literature suggested that the N_2 fixed by the intercrop legume may be available to the associated cereal in the current growing season (Agboola and Fayemi, 1972; Remison, 1978; Eaglesham et al., 1981; Pandey and Pendleton, 1986) or as residual N for the benefit of a succeeding cereal crop (Nair et al., 1979; Searle et al., 1981; Singh, 1983). Roots and nodules of legumes are important sources of N transfer because of their high N content

(Butler and Bathurst, 1956). Peoples et al. (1983) reported that N from roots and nodules of cowpea were 13 percent of the total plant N. In cowpea, Minchin et al. (1978) noted N from these sources to be only 6 percent of the total plant N. This N quantity may be inadequate to produce any substantial N benefit for a subsequent crop.

The degree to which N from an intercrop legume may benefit a cereal crop depends on the quantity and concentration of the legume N, microbial degradation (mineralization) of the legume residues, utilization of these residues, and the amount of N_2 fixed by the legume (Henzell and Vallis, 1977; Herridge, 1982). The rate of mineralization of organic N, determined by microbial activity, is primarily influenced by the prevailing moisture and temperature regimes (Ladd and Amato, 1984). Henzell and Vallis (1977) estimated that under tropical conditions 30 percent of the N in legume residues could be mineralized and taken up by grass after 24 weeks.

The transfer of N was confirmed by the significant dilution of N^{15} in the intercrop maize compared to sole maize at 25 kg N/ha. They concluded that cowpea and associated maize were competing for applied N and that the N_2 fixed by cowpea ended up in the seed and was harvested from the system. These findings were consistent with those reported by Danso et al. (1987) using faba beans and barley.

Nitrogen harvested from crops as seed is the largest source of N loss from any cropping system. Assuming N concentration of 1-3 percent in cereal grain and 3-6 percent in legume seed, a cereal yield of 3,000 kg/ha of grain removes 30-90 kg/ha of N from the soil, and 800 kg/ha of legume seed removes 24-48 kg/ha N (Ofori and Stern, 1987). Another source of N loss is by volatilization. The important pathways of gaseous N losses from cropping systems are through denitrification, the reduction of NO_3 to N_2O and N_2 by microorganisms, and volatilization of NH_3. Hauck (1971) concluded that N losses via denitrification could be of the order of 10-30 percent of the N applied, and that this commonly occurs in soils which are wet for prolonged periods.

Chalk and Smith (1983) showed that N losses through NH_3 volatilization are usually small and that these were generally less than 2 percent of the total N applied. However, on a calcareous soil, Smith and Chalk (1980) measured significant losses of N_2 (10 percent) and N_2O (6 percent) of applied NH_3. Nitrogen losses increased with rising pH. Jewitt (1942) found NH_3 losses equivalent to 0, 13, and 87 percent of N when ammonium sulfate was applied to soils of pH 7.0, 8.6, and 10.5, respectively. Assuming mean N applied to be 300 kg/ha, the N loss via volatilization was 16.7 percent of N applied from urea, 11.4 percent from ammonium sulfate, and 5 percent from ammonium nitrate. Singh et al. (1978) found in a 180 cm soil profile that maize intercropped with mung bean reduced NO_3 loss by leaching by 60 percent and by 41 percent when maize was intercropped with blackgram, compared with sole crop maize.

2.9. Plant Nutrient Concentration

The objective of leaf analysis of crops is to establish critical nutrient concentrations above which no additional yield increase is expected. Tyner (1946) was one of the first to define critical concentrations. He defined it as the concentration above which the response to further fertilization of that nutrient is doubtful. The differences between nutrient uptake by sole-cropped plants and those in the mixture indicate the degree of competition and not necessarily seed yields of each component (Wahua, 1983). Total protein yield was higher for intercrop system over all density combinations (Francis et al., 1982).

Average protein content of mature bean seed is 22.3 percent for navy beans (Leveille, 1978). Kelly and Bliss (1975) used four bean strains differing in seed protein quality and quantity with protein content ranging from 21.5 to 31.9 percent. Bean seed nitrogen concentration at physiological maturity was 3.3, 3.21, 3.27, and 3.31 percent N for C-20, Seafarer, Cran-028, and Michigan improved cranberry (MIC), respectively (Mariga, 1987). Bush bean nitrogen content under warm season was 2.62, 2.70, 2.79, and 2.98 percent N for 100, 70, 45, and 27 percent sun, respectively, while 3.28, 2.85, 3.16, and 3.34 percent N were obtained under cool season for the same light regimes, respectively (Eriksen and Whitney, 1984). Seed nitrogen yields under warm season were 71, 90, 77, and 63 kg/ha N for 100, 70, 45, and 27 percent sun while under cool season seed N-yields were 44, 58, 51, 35 kg/ha N for the given light regimes, respectively (Eriksen and Whitney, 1984).

Micronutrient concentration for C-20 navy bean at physiological maturity was 14.5, 71.8, 27.9, 9.0, and 8.1 ppm Mn, Fe, Zn, Cu, and B, respectively. Seafarer nutrient concentration was 13.9. 63.0, 24.9, 8.5, and 6.8 ppm for Mn, Fe, Zn, Cu, and B, respectively (Mariga, 1987). Micronutrient concentrations for Cran-028 were 11.9, 69.8, 34.1, 10.5, and 10.3 ppm for Mn, Fe, Zn, Cu, and B, respectively, while MIC nutrient concentrations were 11.2, 48.6, 30.1, 10.3, and 9.7 ppm for Mn, Fe, Zn, Cu, and B, respectively (Mariga, 1987).

Nutritional content of whole maize grain per 100 grams of edible portion was 9.3 and 73.7 percent for protein and carbohydrates, respectively, while kidney bean protein and carbohydrates were 21.7 and 60.9 percent respectively (FAO, 1968). Mmbaga (1980) obtained 25-27 percent protein in San Fernando bean while maize hybrid 5802 in association with San Fernando produced 7.7 to 9.6 percent protein at East Lansing, Michigan. Maize grain protein concentrations (N x 6.25) ranged from 6 to 10 percent depending on fertility levels (Rendig and Broadbent, 1979). The nitrogen concentrations in both sole and intercropped maize in the two experiments were similar. Hence, the larger seed nitrogen yields of the sole maize compared with those of the intercrop maize were due to differences in grain yield, and indicative of competition between maize and cowpea for nitrogen when intercropped (Ofori and Stern, 1987; Wahua, 1983). Nitrogen yield of maize grain increased significantly with each rise in maize density (Ofori and Stern, 1987). Grain percent N of maize in monoculture was 1.2 while maize in association with cowpea had 1.1 percent N. Nitrogen yield (kg N ha^{-1}) was 107 and 63 for sole and mixed cropping, respectively (Ofori and Stern, 1987).

Beauchamp et al. (1976), using selected inbred lines of maize, obtained grain percent N values ranging from 1.90 to 2.10 percent in 1970, while in 1971 the same inbred lines had grain percent N ranging from 1.37 to 1.81 percent. Tyner (1946) and Dumenil (1961) observed a significant relationship between maize yield and N, P, and K concentrations in the ear leaf. Maize and cowpea compete for N, P, K, and Ca. The competition stress showed up clearly around the time of anthesis for each crop; 50 DAP for maize and 40 DAP for cowpea. Maize nutrient accumulation for crops grown in monoculture did not differ appreciably from those of plants in the mixture with cowpea (Wahua, 1983). Nutrient uptake (kg ha^{-1}) of maize was 185, 3.97, 176, and 157 for N, P, K, and Ca, respectively, in monoculture. Maize in association with cowpea had nutrient uptake of 163, 3.89, 156, and 142 kg ha^{-1} for N, P, K, and Ca, respectively (Wahua, 1983). Average elemental composition of maize ear leaf in a monocultural system was 3.39, 0.31, 2.15, 0.59, and 0.30 percent for N, P, K, Ca, and Mg, respectively (Dahl et al., 1982). Maize ear leaf micronutrient concentration was 40, 65, 13, 3, and 150 ppm for Zn, Mn, Cu, B, and Fe, respectively (Dahl et al., 1982).

CHAPTER 3

MATERIALS AND METHODS

Two cultivars of beans, Domino (upright, small, black seeded, indeterminate type II with short vines) and Carioca (climbing, small, brown and tan speckled seed, indeterminate type III) (Singh, 1982), were evaluated at three densities in association with maize hybrid 422 (a short season cultivar) on the Michigan State University Agronomy Farm at East Lansing, Michigan. Treatment combinations included monocultural maize, Domino, and Carioca; and Domino in association with maize at 10, 15, and 20 bean plants/m2 (equivalent to 100,000, 150,000, and 200,000 plants/ha, respectively). Carioca was also grown in association with maize at 10, 15, and 20 plants/m^2. A total of nine treatment combinations were tested in 1984, 1985, and 1986, representing first, second, and third growing seasons, respectively. The experiment was planted in a randomized complete block design with four replications on a Capac fine loamy soil (mixed mesic, Hapludolfs) 0-3 percent slope.

Bean rows in monoculture were 4 m long, 0.5 m wide, and 0.1 m spacing within the row, representing 20 plants/m^2 (200,000 plants/ha). A 3 m long section of the central four rows of the eleven row plot was harvested for seed yield, leaving a 0.5 m border on each end of the four rows (6 m^2). The fifth central row was used for sampling dry matter. Five bean rows grown in association with six maize rows were 4 m long, 1 m wide, and 0.1, 0.07, and 0.05 m spacing within the row, representing 10, 15, and 20 plants/m^2, respectively. A 3 m long section of the central two rows of beans in association with maize was harvested for seed yield, leaving one bean row on each side of the plot and 0.5 m from each end of the two central rows as border rows (6 m^2). Dry matter data of bean in associated culture was sampled from the third central row. Monocultural and associated culture rows of maize were 4 m long, 1 m wide, and 0.5 m spacing within the row (two plants/hill), representing 4 plants/m^2 (40,000 plants/ha). These maize rows planted in association with beans were 0.5 m distant from the bean rows. Three central rows of maize (consisting of seven plant hills each) were harvested for grain yield while the fourth central row was sampled for leaf nutrient concentration of maize, leaving one row of maize on each side of the plot and one plant hill at each end of the three central rows as guard rows (10.5 m^2).

Fertilizer application rates of 30, 45, 45 kg/ha NPK, respectively, were applied at planting to both crop species. Maize plots received an additional 120 kg N/ha as a top dress application when maize was 0.6 m high. A mixture of metolachlor (2.3 kg a.i./ha) and chloramben (2.3 kg a.i/ha) herbicides was applied and incorporated before planting as recommended practice for maize-bean mixtures. Several traits were observed, measured, and recorded during the course of the experimental period. A caliper was used to measure stem diameter of the five plants sampled during physiological maturity. Plant height, effective pods/m^2, seeds/pod, and nodes/plant were recorded at physiological maturity. Hundred seed weight and seed yield were measured and recorded at harvesting. Biomass yield was recorded at mid-pod filling and total biomass was measured at harvesting to calculate harvest index (HI). Bean dry weight, total non-structural carbohydrate (TNC), mineral nutrient concentration, light penetration, and leaf area were also observed and recorded as detailed below.

3.1. Dry Weight

Five competitive bean plants (uniform competition) were uprooted in each plot biweekly starting at 50 percent flowering and continuing to physiological maturity. Fifty percent flowering was the time when 50 percent of the plants had at least one open flower. Physiological maturity referred to the stage when not less than 95 percent of the pods turned from green to tan, yellow, or brown colour and the plant had reached maximum dry matter accumulation. Each plot sample was partitioned into roots, stems and petioles, leaves and pods (pods only at mid-pod filling and at physiological maturity). The samples were dried in an oven at 80°C for 72 hours. Dry weights were recorded and plant tissues were ground in a standard motor driven Wiley laboratory mill to pass through a 40 mm mesh screen. Ground samples were stored in plastic storage bags (zip-loc type) for determination of starch.

3.2. Total Non-Structural Carbohydrate (TNC) Analysis

Oven-dried bean root, stem, and leaf tissues sampled from plants at mid-pod filling in 1984, 1985, and 1986 were analyzed for sugar and starch concentrations. Duplicates of 100 mg samples were placed in 100 ml beakers. A blank sample was included for every 24 samples. About 30 ml of 80 percent ethanol was added to each beaker for sugar extraction. Beakers were heated in a steam bath for one hour and then left to cool for about 20 minutes. The ethanol solution was poured through Whatman No. 2 filter paper into a 125 ml Ehrlenmeyer flask. The filtrate volume was raised to the 100 ml mark with distilled water and mixed well by shaking. The residue was washed from the filter paper into the appropriate beakers and evaporated in a 60°C oven until dry.

Beakers containing tissue residue were cooled and kept in an ice bath throughout the starch extraction procedure. For each beaker, 10 ml of cold (0°C) 30 percent perchloric acid was added to a beaker containing the dry residue. A glass rod was used to stir until a paste was formed. Beakers were mixed by swirling every 5 minutes for 40 minutes. Samples were filtered through Whatman No. 2 filter paper into a 125 ml Ehrlenmeyer flask. Beakers were rinsed and filtered into appropriate flasks. The volume in each flask was raised to the 100 ml mark by adding distilled water and mixed well by shaking.

Glucose (from Sigma 510-A kit) was used to make working standard solutions from 0-100 mg/L for bean sugar analysis

(Appendix L). The stock standard concentration was 1,000 mg/L glucose. A set of glucose standards was prepared for each rack of 24 samples. Cornstarch was used to make the starch standard solutions from 0-100 mg/L for bean starch analysis (Appendix M). The starch stock standard was prepared by weighing 1 g of cornstarch and adding 1 ml ethanol (95 percent) plus 100 ml sodium acetate buffer (0.1 M, pH 4.2). The mixture of cornstarch, ethanol, and sodium acetate buffer was heated on a hot plate just to boiling. The mixture was cooled in a water bath and transferred to a 200 ml volumetric flask. Sodium acetate buffer was added to bring the final volume to 200 ml. The stock standard contained 5,000 mg/L starch (0.5 percent starch). Volume of stock standards was dispensed accordingly into clean, labeled test tubes and distilled water was added to bring the volume to 4 ml.

One ml of sugar and starch sample and 1 ml of glucose and starch standards each were pipetted into a test tube and 1 ml of 5 percent phenol solution was added to each tube and then mixed by vortexing. Five ml of concentrated (96 percent) H_2SO_4 were quickly added to produce mixing and uniform heat distribution. The test tubes were vortexed and left to stand for 10 minutes. The test tubes were vortexed again before being placed into a water bath (25-30°C) for 20 minutes for colour development and stability.

Absorbance of glucose and starch standards and sample solutions were read at 490 um absorbance using a Lambda 4B UV/VIS spectrophotometer C688-0001. The absorbances of the standards were plotted against their known concentrations by using the NCSS programme. The standard curves were linear and the regression equation and correlation values were obtained (Appendix N). Bean carbohydrate concentrations were obtained by multiplying the absorbance of bean sample by the regression equation values (Y = .1485 + 100.9877 x ABS) to obtain mg/L sample. Percent sugar or starch concentration of bean was obtained by the following equation:

Percent sugar/starch concentration of bean

$$= \underset{\text{sample weight}}{\frac{1.0\ \text{g}}{0.1\ \text{g}}} \times \underset{\text{sample solution}}{\frac{100\ \text{ml final volume}}{1.0\ \text{ml}}} \times \frac{\text{mg/L sample}}{10{,}000\ \text{mg}} \quad (10{,}000\ \text{mg} = 1\%)$$

Sugar and starch concentrations were converted to gm/kg by multiplying percent sugar/starch by 10 (1% = 10 gm/kg). Total non-structural carbohydrate (TNC) was obtained by adding sugar and starch concentrations.

3.3. Mineral Nutrient Concentration

Determination of the total spectrum of mineral nutrient concentration was conducted for leaves and seeds of bean and maize. Young, fully expanded bean leaves were picked from a 3 m long section of the central two or four rows of each plot (one trifoliate leaf from each plant) for associated and monocultural plots, respectively, at first flowering, making a total of thirty leaves per plot. Likewise, a total of fifteen maize leaves were sampled just above the ear from each plot at tasselling for the determination of mineral nutrients. These samples were dried for 72 hours to a constant weight in an oven at 80°C. Leaves and seeds of maize and beans were ground in a standard motor driven Wiley laboratory mill to pass a 40 mm mesh sieve and were stored in plastic storage bags (zip-loc type) for the determination of total mineral nutrients.

Five hundred milligrams of ground samples from each plot were weighed on an analytical balance and were placed in clean numbered crucibles and were covered immediately. The crucibles were dry-ashed in a muffle furnace for five hours at 500°C. The furnace was preheated for one hour to stabilize at 500°C. Samples were left to cool and 25 ml of digestion solution (3N HNO_3 in 1000 ppm LiCl 12.22 gm LiCl + 375 ml Nitric acid and volume was raised to 2 litres by adding distilled H_2O) were added to each crucible and were left for one hour for the digestion to be completed. The solution was filtered into labeled vials which were then capped with linerless caps. Mineral nutrient concentrations of both crop species were determined by the use of a D.C. plasma emission spectrophotometer. High and low standards were included as checks for every 20 samples.

For the determination of nitrogen (protein), 250 mg of ground seed and leaf samples were weighed on an analytical balance and were placed in Kjeldahl digestion flasks. Three ml of concentrated H_2SO_4 and one Kjeldahl tablet (catalyst--a 100:10:1 mixture of

K_2SO_4, $CuSo_4 \cdot 5H_2O$, and Selenium, were added to each flask. The flasks were set on the block digestor. The micro Kjeldahl procedure (Bremner and Mulvaney, 1982) was used to digest samples for three hours or until colourless at 375°C. After digestion, samples were cooled for 20 minutes and diluted to 100 ml volume with distilled water and representative amount of digested solution was poured into labeled vials (20 ml) and covered. Total seed and leaf N of bean and maize was determined by the quickchem system automated ion analyzer (Lachat). Percent protein of bean and maize in each plot was obtained by multiplying percent N by 6.25.

3.4. Light Penetration and Leaf Area

Light penetration was estimated by using the ozalid paper technique of Friend (1961). Ten sheets of ozalid paper were stapled together and then cut into booklets of 2 x 2 cm. The booklets were placed in black-painted petri dishes with the light sensitive side facing the sun. The booklets were attached to the cover by plastic tape. Light reached the booklet through a 0.5 cm diameter unpainted window on the cover. The petri dishes were sealed with plastic tape to protect the booklets from weather damage. The petri dishes were placed at the top and bottom of bean canopy in each plot in the two-cropping systems between 7 and 8 pm and were collected after 24 hours.

The exposed booklets were placed in wire baskets and the baskets were suspended in an air-tight plastic container containing concentrated ammonium hydroxide. The booklets were suspended in the air-tight plastic container for at least three hours. A count of the number of bleached papers gave an estimate of the amount of light penetration in each plot. To convert the number of papers bleached to percent relative light interception, ozalid papers were exposed for varying lengths of time to direct sunlight and calculations were based on direct sunlight. Light intensity was directly measured with a light meter (Lambda Instruments model LI-188 with a quantum sensor).

Leaves sampled for dry matter weight at mid-pod filling were also used for measuring the leaf area. Five trifoliate leaves were picked alternately from the main stem of each of the five plants and their areas and weights were measured and recorded. Leaf area was measured with a portable leaf area meter (Lambda Instruments model LI-300). The leaves were dried and leaf area index was determined by:

$$\text{Leaf Area Index (LAI)} = \frac{\text{Leaf area/m}^2\text{) x Total Dry Weight (gm)}}{\text{Specific Dry Weight (gm) x m}^2\text{ of Ground Area}}$$

In order to isolate interactions, the Michigan State University Stat 4 package (factor factorial) was used for analysis of variance for all the traits during the experimental period.

CHAPTER 4

RESULTS

4.1. Bean Performance in the Two Cropping Systems

Analyses of variance for bean yields and yield-related traits in associated culture are shown in Appendix A, Tables A1-A3. Effect of seasons was highly significant for biomass, plant height, pods/m^2, stem thickness, leaf area index, hundred seed weight, seed yield, relative light interception, nodes per plant, bean seed protein, nitrogen, phosphorus, and potassium yield (Appendix A, Tables A1-A3). Biomass, pods/m^2, bean seed phosphorus yield, and seed yield in associated culture for the 1984 growing season were significantly higher than in the 1986 cropping season (except one treatment; Table 1). Furthermore, leaf area index in the first growing season was significantly larger than the leaf size obtained in the second season.

Highly significant cultivar differences were observed in plant height, pods/m^2, stem diameter, hundred seed weight, seeds per pod, and bean seed potassium yield (Appendix A, Tables A1-A3). Significant ($p < 0.05$) cultivar differences were also observed for nodes per plant and seed yield in associated culture (Appendix A, Tables A1-A3). Domino had significantly more seeds per pod generally than Carioca. However, the hundred seed weight of Carioca was significantly greater than for Domino. Bean seed yield, bean seed protein, phosphorus and potassium yields, pods/m^2,

Table 1. Effect of Year, Bean Cultivar, and Bean Density on Bean Yield and Yield-Related Traits in the Associated Culture.

		Intercropped Bean Densities (10^3 pl/ha)					
		100		150		200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca
Stem Diameter (cm)	1984	0.7^{a}	0.5^{c}	0.6^{b}	0.5^{c}	0.5^{c}	0.5^{c}
	1985	0.6^{b}	0.4^{d}	0.5^{c}	0.4^{d}	0.4^{d}	0.4^{d}
	1986	0.5^{c}	0.5^{c}	0.5^{c}	0.4^{d}	0.5^{c}	0.4^{d}
Column Mean		0.6	0.5	0.5	0.4	0.5	0.4
LSD (0.05) 0.06						CV (%)	8.8
Nodes/Plant	1984	15^{a}	14^{ab}	14^{ab}	14^{ab}	12^{cd}	13^{bc}
	1986	12^{cd}	13^{bc}	11^{d}	13^{bc}	12^{cd}	12^{cd}
Column Mean		13	13	12	13	12	12
LSD (0.05) 1.3						CV (%)	7.0
Plant Height (cm)	1984	74^{bc}	98^{a}	68^{cd}	100^{a}	67^{cd}	88^{ab}
	1985	36^{g}	56de	40^{fg}	56de	40^{fg}	55de
	1986	48^{e-g}	96^{a}	47^{e-g}	79^{bc}	51^{ef}	77^{bc}
Column Mean		53	83	52	78	53	73
LSD (0.05) 15						CV (%)	16.5

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 1 (cont'd.).

Trait	Year	100 Domino	100 Carioca	150 Domino	150 Carioca	200 Domino	200 Carioca
		Intercropped Bean Densities (10^3 pl/ha)					
Relative Light Interception (%)	1984	35	25	30	35	35	35
	1985*	20	20	25	25	25	20
	1986	20	20	25	25	25	25
Column Mean		25	22	27	28	28	27
						CV (%)	34.7
$Pods/m^2$	1984	140^{bc}	125^{cd}	190^{a}	130^{cd}	170^{ab}	140^{bc}
	1985	107^{c-f}	77^{f-h}	130^{cd}	97^{d-g}	170^{ab}	115^{c-e}
	1986	62^{h}	67^{gh}	82^{e-h}	89^{e-h}	115^{c-e}	80^{f-h}
Column Mean		103	90	134	105	152	112
LSD (0.05) 35						CV (%)	21.0
Seeds/Pod	1984	7^{a}	6^{b}	7^{a}	6^{b}	7^{a}	6^{b}
	1986	7^{a}	6^{b}	7^{a}	6^{b}	6^{b}	6^{b}
Column Mean		7	6	7	6	6	6
LSD (0.05) 0.5						CV (%)	5.4

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 1 (cont'd.).

Trait	Year	Intercropped Bean Densities (10^3 pl/ha) 100 Domino	100 Carioca	150 Domino	150 Carioca	200 Domino	200 Carioca
Leaf Area Index	1984	2.3^{b-d}	2.2^{b-d}	2.6^{b}	2.5^{bc}	2.4^{bc}	3.3^{a}
	1985	1.3^{g}	1.4^{fg}	1.4^{fg}	1.5^{e-g}	1.5^{e-g}	1.4^{fg}
	1986	1.8^{d-g}	2.1^{b-d}	2.0^{c-e}	1.9^{d-f}	2.2^{b-d}	2.1^{b-d}
Column Mean		1.8	1.9	2.0	2.0	2.0	2.3
LSD (0.05) 0.5						CV (%)	18.8
Biomass (g/m^2)	1984	232^{bc}	210^{b-f}	281^{ab}	228^{bc}	221^{b-d}	308^{a}
	1985	141^{f-i}	88^{hi}	175^{c-g}	150^{d-h}	214^{b-e}	149^{e-h}
	1986	95^{hi}	96^{hi}	89^{hi}	113^{g-i}	134^{g-i}	77^{i}
Column Mean		156	131	182	164	190	178
LSD (0.05) 72						CV (%)	30.4
Seed Yield (kg/ha)	1984	953^{b-e}	1047^{a-c}	1122^{ab}	992^{b-d}	1122^{ab}	1216^{a}
	1985	762^{f-j}	653^{ij}	860^{d-g}	647^{ij}	922^{c-f}	645^{ij}
	1986	623^{j}	603^{j}	698^{g-j}	689^{h-j}	827^{d-h}	800^{e-i}
Column Mean		779	768	893	776	957	887
LSD (0.05) 171						CV (%)	14.2

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 1 (cont'd.).

		Intercropped Bean Densities (10^3 pl/ha)					
		100		150		200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca
Harvest Index (%)	1984	53^{e}	57^{a-c}	54^{de}	56^{b-d}	55^{c-e}	59^{a}
	1986	58^{ab}	57^{a-c}	57^{a-c}	57^{a-c}	55^{c-e}	57^{a-c}
Column Mean		55	57	55	56	55	58
LSD (0.05) 3						CV (%)	4.0
Hundred Seed Weight (gm)	1984	18^{c}	25^{a}	18^{c}	24^{a}	18^{c}	24^{a}
	1985	18^{c}	21^{b}	18^{c}	20^{b}	18^{c}	20^{b}
	1986	20^{b}	25^{a}	20^{b}	25^{a}	20^{b}	24^{a}
Column Mean		19	24	19	23	19	23
LSD (0.05) 2						CV (%)	5.5
Protein (kg/ha)	1984	251^{bc}	297^{ab}			314^{a}	313^{a}
	1985	215^{cd}	171^{d}			256^{bc}	183^{d}
	1986	192^{d}	167^{d}			247^{bc}	220^{cd}
Column Mean		219	212			272	239
LSD (0.05) 55						CV (%)	16.2

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 1 (cont'd.).

Trait	Year	Intercropped Bean Densities (10^3 pl/ha) 100 Domino	100 Carioca	150 Domino	150 Carioca	200 Domino	200 Carioca
Nitrogen (kg/ha)	1984*	40	47			50	50
	1985	34	27			40	29
	1986	30	27			39	35
Column Mean		35	34			43	38
						CV (%)	16.8
Phosphorus (kg/ha)	1984	5^{b}	5^{b}			5^{b}	6^{a}
	1985	4^{c}	3^{d}			5^{b}	4^{c}
	1986	3^{d}	2^{e}			4^{c}	3^{d}
Column Mean		4	3			5	4
LSD (0.05) 1						CV (%)	17.8
Potassium (kg/ha)	1984	13^{b}	12^{bc}			15^{a}	16^{a}
	1985	11^{cd}	9^{e}			13^{b}	9^{e}
	1986	9^{e}	7^{f}			11^{cd}	10^{de}
Column Mean		11	9			13	12
LSD (0.05) 2						CV (%)	13.4

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

and biomass increased with bean density but not significantly so in some treatments (Table 1). Bean roots, stems, leaves, and pod dry weight generally increased with increasing bean density. Maximum stem and leaf dry weight was achieved at around mid-pod filling and declined toward physiological maturity (Table 2 and Figures 1 and 2). However, root dry weight did not peak at any physiological stage. Root dry weight within each density remained similar throughout the three physiological stages (Table 2 and Figure 3).

Bean density levels significantly ($p < 0.01$) increased stem diameter and seed yield (Appendix A, Tables A1-A3). Domino (100,000 plants/ha), during the first season, had significantly larger stem diameter than for the last two seasons. Seed yield of Carioca at 200,000 plants/ha in the first season was significantly higher than for the last two seasons. Similarly, density increased biomass and leaf area index of Carioca, and reduced nodes per plant of Domino significantly ($p < 0.05$) in the first season (Table 1). Domino, at 200,000 plants/ha, had significantly fewer nodes per plant than at a lower plant density in the 1984 cropping season. On the other hand, Carioca had a significant increase in leaf area index and biomass when it was planted at 200,000 plants/ha than when it was planted at lower bean densities during the first season.

A significant year x cultivar interaction ($p < 0.05$) was observed for plant height, harvest index, bean seed protein, phosphorus, and potassium yield (Appendix A, Tables A1-A3). A similar

Table 2. Effect of Bean Density on Dry Weight of Bean Cultivars in the Two Cropping Patterns.

Density (10^3 pl/ha)	Trait	Three Year Average Dry Weight (gm/m^2) First Flowering	Mid-Pod Filling	Physiological Maturity
Intercropped				
100	Domino Roots	7^{d-f}	6^{e-g}	7^{d-f}
150		8^{c-e}	8^{c-e}	8^{c-e}
200		9^{b-d}	9^{b-d}	9^{b-d}
Monoculture				
200		19^{a}	20^{a}	19^{a}
Intercropped				
100	Carioca Roots	4^{gh}	4^{gh}	3^{h}
150		4^{gh}	4^{gh}	4^{gh}
200		5^{f-h}	5^{f-h}	5^{f-h}
Monoculture				
200		10^{bc}	11^{b}	9^{b-d}
LSD (0.05) 2.3				CV 22%
Intercropped				
100	Domino Stem	37^{f}	42^{ef}	33^{f}
150		44^{ef}	47^{ef}	44^{ef}
200		50^{ef}	49^{ef}	48^{ef}
Monoculture				
200		90^{cd}	119^{a}	100^{bc}
Intercropped				
100	Carioca Stem	36^{f}	39^{ef}	35^{f}
150		39^{ef}	47^{ef}	40^{ef}
200		46^{ef}	56^{e}	42^{ef}
Monoculture				
200		80^{d}	115^{ab}	109^{ab}
LSD (0.05) 17.7				CV 30%

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 2 (cont'd.).

Density (10^3 pl/ha)	Trait	Three Year Average Dry Weight (gm/m^2) First Flowering	Mid-Pod Filling	Physiological Maturity
Intercropped				
100	Domino Leaves	46^{d-f}	45^{d-f}	35^{f}
150		53^{c-e}	53^{c-e}	46^{d-f}
200		58^{cd}	55^{cd}	54^{c-e}
Monoculture				
200		107^{b}	125^{a}	105^{b}
Intercropped				
100	Carioca Leaves	43^{d-f}	44^{d-f}	39^{ef}
150		51^{c-e}	54^{c-e}	45^{d-f}
200		58^{cd}	64^{c}	48^{d-f}
Monoculture				
200		110^{ab}	125^{a}	113^{ab}
LSD (0.05) 15.4				CV 26%
Intercropped				
100	Domino Pods		63^{ef}	109^{c-f}
150			73^{d-f}	132^{b-d}
200			77^{d-f}	147^{bc}
Monoculture				
200			176^{b}	366^{a}
Intercropped				
100	Carioca Pods		45^{f}	106^{c-f}
150			58^{f}	125^{b-e}
200			53^{f}	125^{b-e}
Monoculture				
200			150^{bc}	388^{a}
LSD (0.05) 65				CV 34%

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

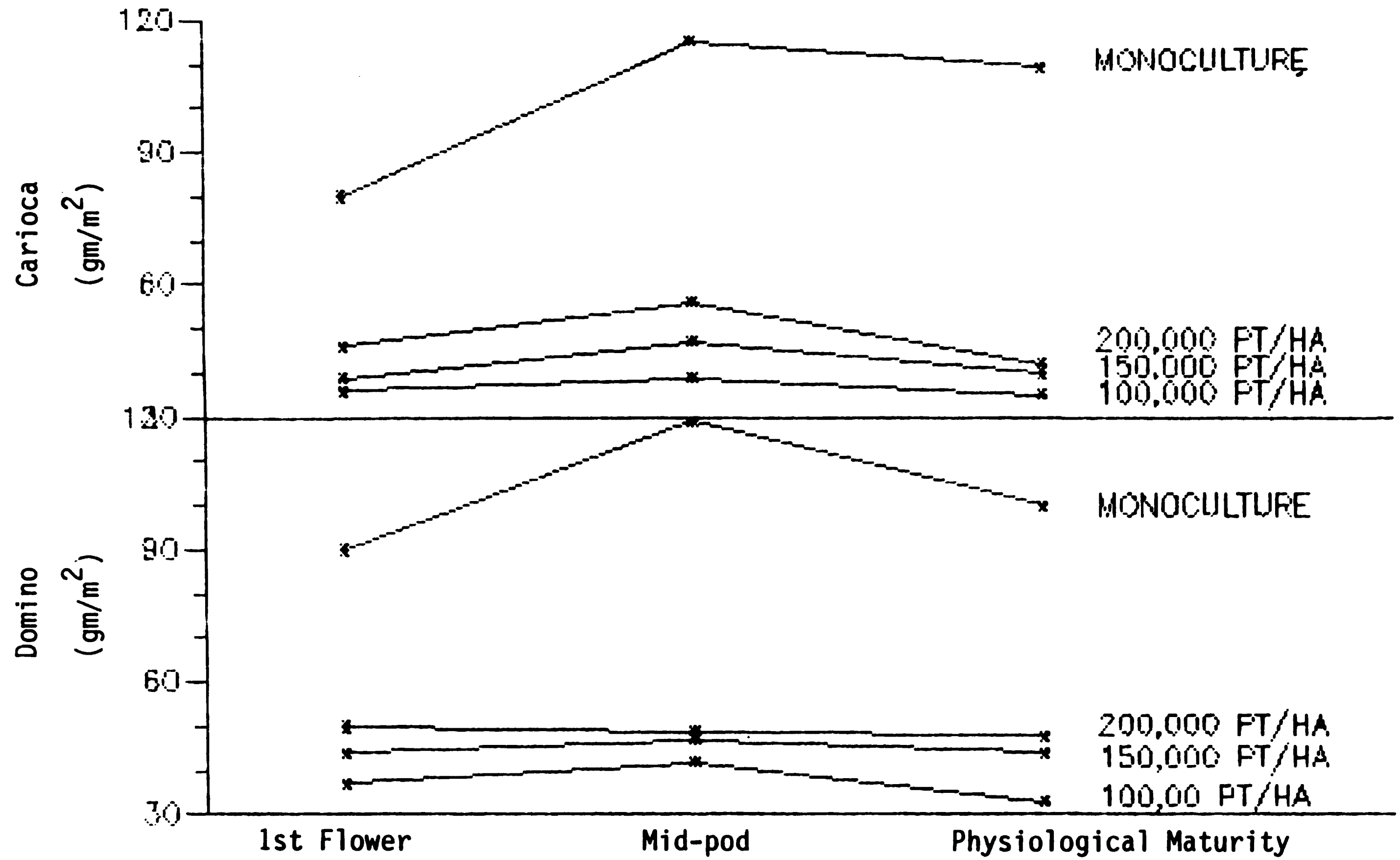

Figure 1. Stem Dry Weight of Bean at Different Reproductive Stages

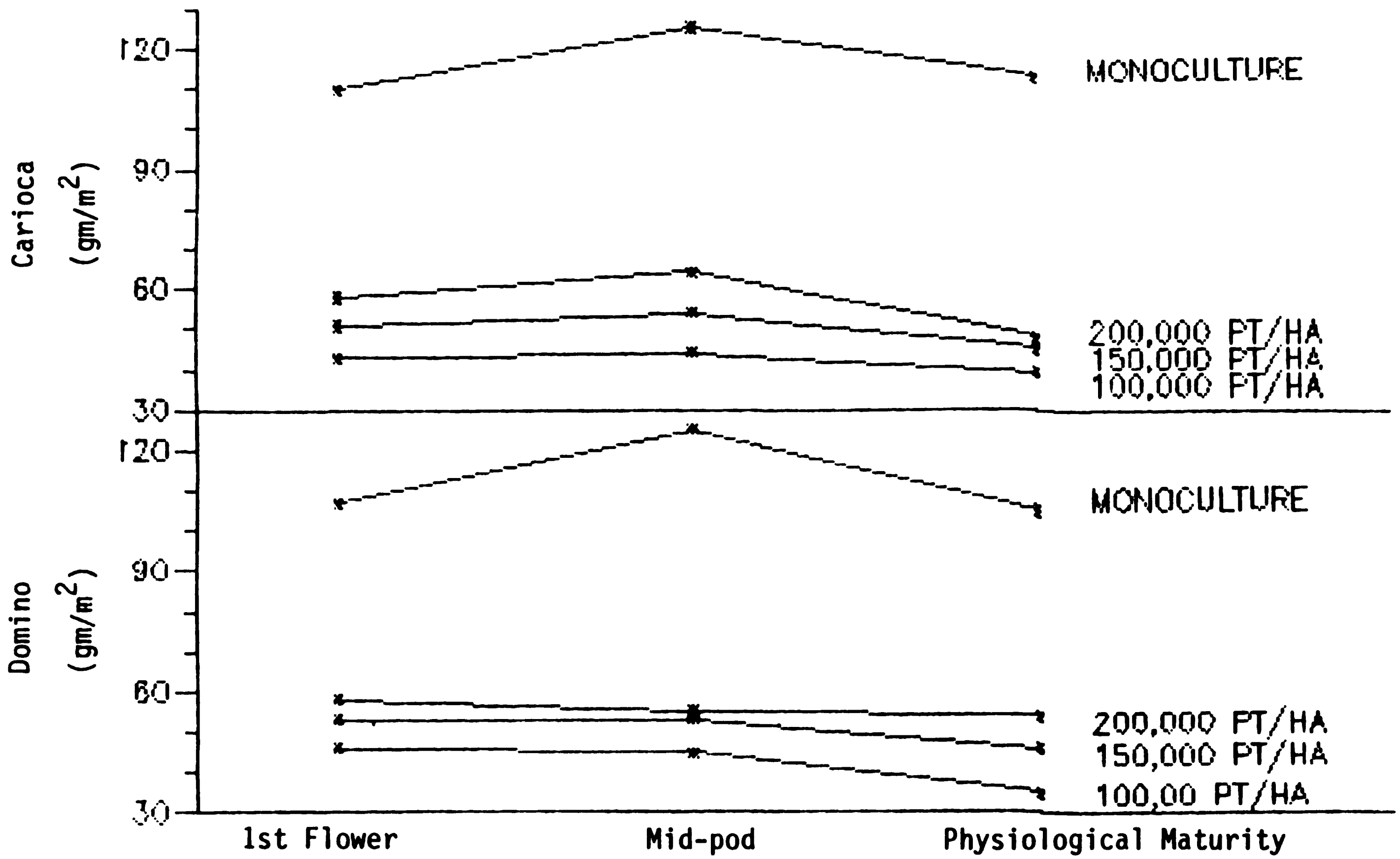

Figure 2. Leaf Dry Weight of Bean at Different Reproductive Stages

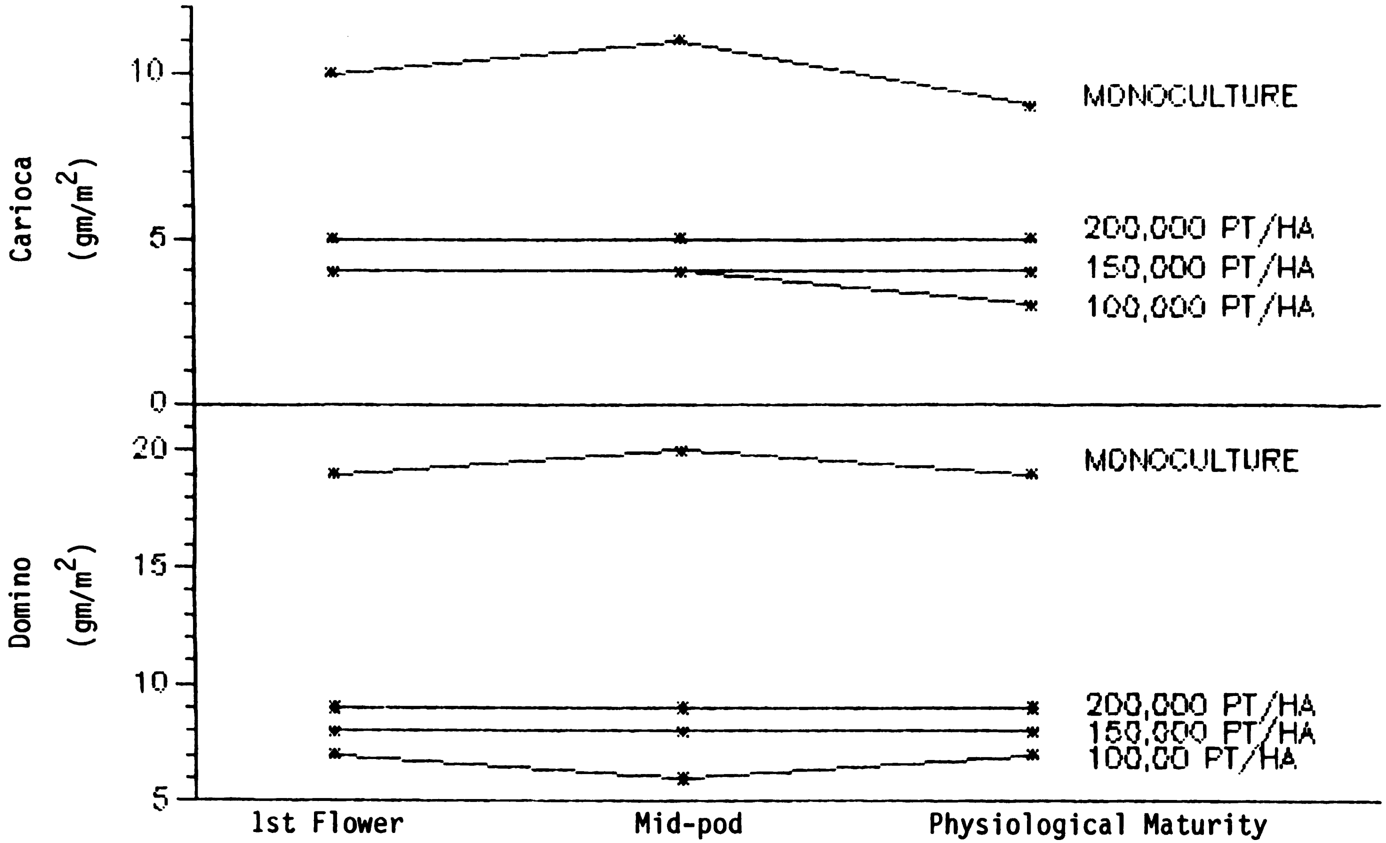

Figure 3. Root Dry Weight of Bean at Different Reproductive Stages

year x cultivar interaction was noted for hundred seed weight, seed yield, and nodes per plant at the 1 percent probability level. Carioca plant height in the 1984 growing season (first growing season) was significantly ($p < 0.05$) taller than its height in the second growing season. Domino vine length was significantly shorter than Carioca in all growing seasons (Table 1). Bean cultivar performance in the first season was significantly higher in seed yield, bean seed phosphorus, and potassium yield as compared with observed performances in the third growing season. Hundred seed weight of Carioca in the second season was significantly lower than its weight in the first and third cropping seasons. Carioca's seed protein yield in the first season was significantly higher than any corresponding value in the second and third seasons (Table 1).

A significant year x cultivar x density interaction was observed for biomass, stem thickness, leaf area index, and nodes per plant at the 5 percent probability level (Appendix A, Tables A1-A2). Carioca planted at 200,000 plants/ha had a significantly higher biomass in the first season over its biomass and Domino's biomass in the second and third cropping seasons (Table 1). Similarly, the leaf area index of Carioca (200,000 plants/ha) in 1984 was significantly larger than its leaf area index in the second and third growing seasons (Table 1). Domino's leaf area index (LAI) for the entire experimental period was significantly smaller than Carioca LAI at 200,000 plants/ha in the

1984 cropping season. Domino had significantly more nodes per plant at 100,000 plants/ha in 1984 than it had and Carioca had in the 1986 growing season. The stem thickness of Domino in 1984 at 100,000 plants/ha was significantly larger than its stem thickness and the stem thickness of Carioca obtained during the entire experimental period (Table 1). Results of beans planted simultaneously with maize indicated non-significant year x density and cultivar x density interactions for bean yield and yield-related traits (Appendix A, Tables A1-A3).

Bean traits measured under monoculture compared with traits measured under associated culture showed that the monocultural seed yield, biomass, relative light interception, pods/m^2, leaf area index, bean seed protein, nitrogen, phosphorus and potassium yields, bean roots, stems, leaves, and pod dry weights of each cultivar were significantly ($p < 0.05$) greater (Tables 2 and 3). The stem thickness of Domino under monoculture was either not significant or significantly thicker than the stem thickness of Domino grown in association with maize. Stem thickness of Carioca under monoculture was not significantly different from stem thickness in association for the first and second growing seasons. However, the stem thickness of Carioca under monoculture in the 1986 cropping season was significantly thicker than Carioca's stem thickness in associated culture.

Table 3. Effect of Year, Bean Cultivar, and Bean Density on Bean Yield and Yield-Related Traits in the Two Cropping Patterns.

		Sole Bean Stand 200,000 pl/ha		Intercropped Bean Densities (10^3 pl/ha)					
				100		150		200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca	Domino	Carioca
Stem Diameter (cm)	1984	0.7^{a}	0.5^{c}	0.7^{a}	0.5^{c}	0.6^{b}	0.5^{c}	0.5^{c}	0.5^{c}
	1985	0.6^{b}	0.4^{d}	0.6^{b}	0.4^{d}	0.5^{c}	0.4^{d}	0.4^{d}	0.4^{d}
	1986	0.7^{a}	0.6^{b}	0.5^{c}	0.5^{c}	0.5^{c}	0.4^{d}	0.5^{c}	0.4^{d}
Column Mean		0.7	0.5	0.6	0.5	0.5	0.4	0.5	0.4
LSD (0.05) 0.6								CV (%)	8.7
Nodes/Plant	1984	15^{a}	14^{ab}	15^{a}	14^{ab}	14^{ab}	14^{ab}	12^{cd}	13^{bc}
	1986	14^{ab}	14^{ab}	12^{cd}	13^{bc}	11^{d}	13^{bc}	12^{cd}	12^{cd}
Column Mean		14	14	13	13	12	13	12	12
LSD (0.05) 1.3								CV (%)	6.8
Plant Height (cm)	1984	64^{e-g}	98^{a}	74^{c-e}	98^{a}	68^{d-f}	100^{a}	67^{d-f}	88^{a-c}
	1985	39^{ik}	56^{f-h}	36^{i-k}	56^{f-h}	40^{i-k}	56^{f-h}	40^{i-k}	55^{f-h}
	1986	54^{f-i}	83^{bc}	48^{h-k}	96^{ab}	47^{h-k}	79^{cd}	51^{g-j}	77^{c-e}
Column Mean		52	79	53	83	52	78	53	73
LSD (0.05) 14.6								CV (%)	15.8

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 3 (cont'd.).

Trait	Year	Sole Bean Stand 200,000 pl/ha Domino	Sole Bean Stand 200,000 pl/ha Carioca	Intercropped Bean Densities (10^3 pl/ha) 100 Domino	100 Carioca	150 Domino	150 Carioca	200 Domino	200 Carioca
Relative Light Interception (%)	1984	60^{a}	55^{a}	35^{b}	25^{bc}	30^{bc}	35^{b}	35^{b}	35^{b}
	1985	55^{a}	55^{a}	20^{c}	20^{c}	25^{bc}	25^{bc}	25^{bc}	20^{c}
	1986	55^{a}	50^{a}	20^{c}	25^{bc}	25^{bc}	25^{bc}	25^{bc}	25^{bc}
Column Mean		57	53	25	23	27	28	28	27
LSD (0.05) 12.9								CV (%)	27.3
$Pods/m^2$	1984	360^{ab}	390^{a}	140^{d-f}	125^{e-h}	190^{d}	130^{e-g}	170^{de}	140^{d-f}
	1985	270^{c}	190^{d}	107^{f-j}	77^{h-j}	130^{e-g}	97^{f-j}	170^{de}	115^{f-i}
	1986	285^{c}	310^{bc}	62^{j}	67^{ij}	82^{g-j}	89^{f-j}	115^{f-i}	80^{g-j}
Column Mean		305	297	103	90	134	105	152	112
LSD (0.05) 52								CV (%)	22.7
Seeds/Pod	1984	7^{a}	7^{a}	7^{a}	6^{b}	7^{a}	6^{b}	7^{a}	6^{b}
	1986	7^{a}	7^{a}	7^{a}	6^{b}	7^{a}	6^{b}	6^{b}	6^{b}
Column Mean		7	7	7	6	7	6	6	6
LSD (0.05) 0.5								CV (%)	5.1

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 3 (cont'd.).

Trait	Year	Sole Bean Stand 200,000 pl/ha		Intercropped Bean Densities (10^3 pl/ha) 100		150		200	
		Domino	Carioca	Domino	Carioca	Domino	Carioca	Domino	Carioca
Leaf Area Index	1984	4.2^{a}	4.3^{a}	2.3^{d-f}	2.2^{d-g}	2.6^{c-e}	2.5^{d-f}	2.4^{d-f}	3.3^{bc}
	1985	2.3^{d-f}	1.8^{f-i}	1.3^{i}	1.4^{hi}	1.4^{hi}	1.5^{g-i}	1.5^{g-i}	1.4^{hi}
	1986	3.4^{b}	2.9^{b-d}	1.8^{f-i}	2.1^{d-h}	2.0^{d-i}	1.9^{e-i}	2.2^{d-g}	2.1^{d-h}
Column Mean		3.3	3.0	1.8	1.9	2.0	2.0	2.0	2.3
LSD (0.05)	0.7							CV (%)	21.5
Biomass (g/m^2)	1984	637^{a}	604^{a}	232^{b-f}	210^{c-g}	281^{b-d}	228^{c-f}	221^{c-f}	308^{bc}
	1985	337^{b}	262^{b-d}	141^{f-h}	88^{h}	175^{d-h}	150^{e-h}	214^{c-g}	149^{e-h}
	1986	252^{bc}	264^{b-d}	95^{h}	96^{h}	89^{h}	113^{gh}	134^{f-h}	77^{h}
Column Mean		409	377	156	131	182	164	190	178
LSD (0.05)	107							CV (%)	33.4
Seed Yield (kg/ha)	1984	3271^{a}	3483^{a}	953^{f-h}	1047^{e-g}	1122^{d-f}	992^{e-h}	1122^{d-f}	1216^{de}
	1985	1562^{c}	1357^{cd}	762^{h-k}	653^{jk}	860^{g-j}	647^{jk}	922^{f-i}	645^{jk}
	1986	2456^{b}	2384^{b}	623^{jk}	603^{k}	698^{i-k}	689^{i-k}	827^{g-k}	800^{h-k}
Column Mean		2430	2408	779	768	893	776	957	887
LSD (0.05)	240							CV (%)	13.8

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 3 (cont'd.).

Trait	Year	Sole Bean Stand 200,000 pl/ha Domino	Sole Bean Stand 200,000 pl/ha Carioca	Intercropped Bean Densities (10^3 pl/ha) 100 Domino	100 Carioca	150 Domino	150 Carioca	200 Domino	200 Carioca
Harvest Index (%)	1984	59^{cd}	65^{a}	53^{g}	57^{c-f}	54^{fg}	56^{d-g}	55^{e-g}	59^{cd}
	1986	60^{bc}	63^{ab}	58^{c-e}	57^{c-f}	57^{c-f}	57^{c-f}	55^{e-g}	57^{c-f}
Column Mean		60	64	55	57	55	56	55	58
LSD (0.05) 3.4								CV (%)	4.1
Hundred Seed Weight (gm)	1984	19^{de}	24^{a}	18^{e}	25^{a}	18^{e}	24^{a}	18^{e}	24^{a}
	1985	18^{e}	22^{b}	18^{e}	21^{bc}	18^{e}	20^{cd}	18^{e}	20^{cd}
	1986	20^{cd}	24^{a}	20^{cd}	25^{a}	20^{cd}	25^{a}	20^{cd}	24^{a}
Column Mean		19	23	19	24	19	23	19	22
LSD (0.05) 1.6								CV (%)	5.3
Protein (kg/ha)	1984	870^{a}	939^{a}	251^{e-g}	297^{de}			314^{de}	313^{de}
	1985	437^{c}	357^{d}	215^{f-h}	171^{h}			256^{ef}	183^{gh}
	1986	680^{b}	630^{b}	192^{f-h}	167^{h}			247^{e-g}	220^{f-h}
Column Mean		662	642	219	212			272	239
LSD (0.05) 72								CV (%)	13.5

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 3 (cont'd.).

		Sole Bean Stand 200,000 pl/ha		Intercropped Bean Densities (10^3 pl/ha)					
				100		150		200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca	Domino	Carioca
Nitrogen (kg/ha)	1984	139^{a}	150^{a}	40^{e-g}	47^{d-f}			50^{de}	50^{de}
	1985	70^{e}	57^{d}	34^{gh}	27^{h}			40^{e-g}	29^{gh}
	1986	109^{b}	101^{b}	30^{gh}	27^{h}			39^{e-g}	35^{f-h}
Column Mean		106	103	35	34			43	38
LSD (0.05)	11.7							CV (%)	13.8
Phosphorus (kg/ha)	1984	15^{b}	17^{a}	5^{gh}	5^{gh}			5^{gh}	6^{fg}
	1985	8^{de}	7^{ef}	4^{hi}	3^{ij}			5^{gh}	4^{hi}
	1986	11^{c}	9^{d}	3^{ij}	2^{j}			4^{hi}	3^{ij}
Column Mean		11	11	4	3			5	4
LSD (0.05)	1.3							CV (%)	14.3
Potassium (kg/ha)	1984	44^{a}	46^{a}	13^{e-g}	12^{f-h}			15^{df}	16^{de}
	1985	21^{c}	17^{d}	11^{gh}	9^{hi}			13^{e-g}	9^{hi}
	1986	31^{b}	28^{b}	9^{hi}	7^{i}			11^{gh}	10^{g-i}
Column Mean		32	30	11	9			13	12
LSD (0.05)	3.7							CV (%)	14.6

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

4.2. Bean Carbohydrate Concentration

Year effects were significant for all carbohydrate traits except leaf starch concentration (Appendix A, Table A4). Root and stem starch, sugar, and TNC concentrations were significantly higher in the second growing season than in the first and third cropping seasons (with a few exceptions; Table 4). On the other hand, leaf sugar and TNC concentrations were significantly reduced in the first season as compared to the second season (except a few treatments), possibly due to increased sink capacity in the first year. Differential effects of cultivars on bean root sugar, stem starch, sugar and stem TNC, and leaf starch, sugar, and TNC concentrations were not significant (Appendix A, Table A4).

A significant density effect occurred for root starch, sugar, TNC, stem starch ($p < 0.01$), stem TNC, leaf sugar, and leaf TNC ($p < 0.05$) concentrations (Appendix A, Table A4). Year x density interactions in bean carbohydrate concentration were not significant. However, cultivar x density interaction was significantly expressed in root sugar, stem starch, TNC ($p < 0.01$), root TNC, and stem sugar ($p < 0.05$) concentrations (Appendix A, Table A4). Furthermore, significant year x cultivar x density interactions were observed for root sugar, TNC, and stem starch ($p < 0.01$) concentrations (Appendix A, Table A4). Carioca (200,000 plants/ha) root sugar and TNC and stem starch concentrations in the second growing season were significantly higher than all the corresponding values in the first and third seasons (Table 4).

Table 4. Effect of Year, Bean Cultivar, and Bean Density on Bean Carbohydrate Concentration during Mid-Pod Filling in the Associated Culture.

Trait	Year	Associated Culture (10^3 pl/ha)			
		100		200	
		Domino	Carioca	Domino	Carioca
Root Starch (gm/kg)	1984	33[cd]	31[d]	42[cd]	36[cd]
	1985	72[a]	31[d]	77[a]	57[b]
	1986	38[cd]	35[cd]	44[c]	36[cd]
Column Mean		48	32	54	43
LSD (0.05) 12				CV (%)	19.7
Root Sugar (gm/kg)	1984	45[c-e]	41[de]	47[cd]	46[cd]
	1985	62[ab]	45[c-e]	54[bc]	71[a]
	1986	30[fg]	25[g]	36[ef]	31[fg]
Column Mean		46	37	46	49
LSD (0.05) 10				CV (%)	14.2
Root TNC (gm/kg)	1984	79[bc]	73[b-d]	89[b]	82[bc]
	1985	134[a]	76[b-d]	131[a]	128[a]
	1986	68[cd]	60[d]	80[bc]	67[cd]
Column Mean		94	70	100	92
LSD (0.05) 17				CV (%)	13.4
Stem Starch (gm/kg)	1984	41[c-e]	35[de]	35[de]	48[bc]
	1985	55[b]	45[b-d]	51[bc]	82[a]
	1986	36[de]	30[e]	41[c-e]	36[de]
Column Mean		44	37	42	55
LSD (0.05) 12				CV (%)	18.8
Stem Sugar (gm/kg)	1984	72[bc]	62[cd]	50[d]	79[bc]
	1985	108[a]	106[a]	105[a]	116[a]
	1986	74[bc]	66[b]	83[b]	80[bc]
Column Mean		85	78	79	92
LSD (0.05) 20				CV (%)	16.4

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 4 (cont'd.).

		Associated Culture (10^3 pl/ha)			
		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca
Stem TNC (gm/kg)	1984	113[de]	97[ef]	86[f]	127[cd]
	1985	164[b]	151[bc]	156[b]	198[a]
	1986	110[d-f]	96[ef]	124[d]	116[de]
Column Mean		129	115	122	147
LSD (0.05)	25			CV (%)	13.7
Leaf Starch (gm/kg)	1984	22	25	26	24
	1985	23	26	25	24
	1986	24	26	25	26
Column Mean		23	26	25	25
				CV (%)	12.7
Leaf Sugar (gm/kg)	1984*	25	25	29	31
	1985	40	37	35	43
	1986	36	32	40	41
Column Mean		34	31	35	38
				CV (%)	17.4
Leaf TNC (gm/kg)	1984*	47	50	55	55
	1985	63	63	60	67
	1986	60	58	65	67
Column Mean		57	57	60	63
				CV (%)	10.5

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

A year x cultivar interaction was observed for root starch ($p < 0.01$), root TNC, and stem starch ($p < 0.05$) concentrations (Appendix A, Table A4). Carioca, at 200,000 plants/ha, had significantly higher stem starch concentration in the second growing season than the Domino and Carioca stem starch concentrations in the first and third growing seasons (Table 4). Root starch concentration in Domino in the second season was significantly higher than in Carioca during the same season and Domino and Carioca values in the first and third seasons. Similarly, the root TNC concentration for Domino during the second growing season was significantly higher than for Carioca and Domino in the first and third cropping seasons and for Carioca (100,000 plants/ha) in the second season.

A comparison of the cropping patterns indicated that the two systems did not differ significantly with respect to their effects on leaf carbohydrate concentrations (Table 5). No distinct trend was observed between the two cropping systems in regard to root and stem carbohydrate concentrations. Root starch concentration in Domino, in maize-bean association, at both densities during the second cropping season was significantly higher than in all other combinations except monocultural Domino (Table 5). Root sugar concentration of Carioca (200,000 plants/ha) during the second growing season was similar to monocultural Domino root sugar concentration but was significantly higher than any treatment combination in the two cropping patterns (Table 5).

Table 5. Effect of Year, Bean Cultivar, and Bean Density on Bean Carbohydrate Concentration during Mid-Pod Filling in the Two Cropping Patterns.

		Sole Bean Stand		Associated Culture (10^3 pl/ha)			
		200,000 pl/ha		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca
Root Starch (gm/kg)	1984	51^{bc}	42^{cd}	33^{d}	31^{d}	42^{cd}	36^{d}
	1985	82^{a}	50^{bc}	72^{a}	31^{d}	77^{a}	57^{b}
	1986	44^{b-d}	37^{cd}	38^{cd}	35^{d}	44^{b-d}	36^{d}
Column Mean		59	43	48	32	54	43
LSD (0.05)	14					CV (%)	21.2
Root Sugar (gm/kg)	1984	52^{d-f}	52^{d-f}	45^{e-g}	41^{gh}	47^{e-g}	46^{e-g}
	1985	63^{ab}	59^{b-d}	62^{bc}	45^{f-h}	54^{c-e}	71^{a}
	1986	36^{hi}	29^{ij}	30^{ij}	25^{j}	36^{hi}	31^{ij}
Column Mean		50	47	46	37	46	49
LSD (0.05)	9					CV (%)	13.7
Root TNC (gm/kg)	1984	102^{cd}	94^{c-e}	79^{e-g}	73^{f-h}	89^{d-f}	82^{e-g}
	1985	146^{a}	109^{c}	134^{ab}	76^{f-h}	131^{ab}	128^{b}
	1986	80^{e-g}	66^{gh}	68^{gh}	60^{h}	80^{e-g}	67^{gh}
Column Mean		109	90	94	70	100	92
LSD (0.05)	17					CV (%)	13
Stem Starch (gm/kg)	1984	46^{b-f}	40^{d-g}	41^{c-g}	35^{fg}	35^{e-g}	48^{b-e}
	1985	72^{a}	54^{bc}	55^{b}	45^{b-f}	51^{b-d}	82^{a}
	1986	40^{d-g}	35^{fg}	36^{e-g}	30^{g}	41^{c-g}	36^{e-g}
Column Mean		53	43	44	37	42	55
LSD (0.05)	13					CV (%)	20
Stem Sugar (gm/kg)	1984	67^{d-f}	90^{bc}	72^{c-e}	62^{ef}	50^{f}	79^{c-e}
	1985	113^{a}	113^{a}	108^{ab}	106^{ab}	105^{ab}	116^{a}
	1986	71^{c-e}	79^{c-e}	74^{c-e}	66^{d-f}	83^{cd}	80^{c-e}
Column Mean		84	94	85	78	79	92
LSD (0.05)	20					CV (%)	16.8

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 5 (cont'd.).

Trait	Year	Sole Bean Stand 200,000 pl/ha Domino	Sole Bean Stand 200,000 pl/ha Carioca	Associated Culture (10^3 pl/ha) 100 Domino	Associated Culture (10^3 pl/ha) 100 Carioca	Associated Culture (10^3 pl/ha) 200 Domino	Associated Culture (10^3 pl/ha) 200 Carioca
Stem TNC	1984	113^{fg}	130^{d-f}	113^{f-h}	97^{gh}	86^{h}	127^{ef}
(gm/kg)	1985	185^{ab}	167^{bc}	164^{bc}	151^{c-e}	156^{cd}	198^{a}
	1986	109^{f-h}	114^{fg}	110^{f-h}	96^{gh}	124^{ef}	116^{fg}
Column Mean		136	137	129	115	122	147
LSD (0.05)	27					CV (%)	14.5
Leaf	1984	27	27	22	25	26	24
Starch	1985	25	24	23	26	25	24
(gm/kg)	1986	25	25	24	26	25	26
Column Mean		26	25	23	26	25	25
						CV (%)	11.9
Leaf	1984	32	31	25	25	29	31
Sugar	1985	39	35	40	37	35	43
(gm/kg)	1986	31	33	36	32	40	41
Column Mean		34	33	34	31	35	38
						CV (%)	16.1
Leaf TNC	1984	59	59	47	50	55	55
(gm/kg)	1985	64	60	63	63	60	67
	1986	56	58	60	58	65	67
Column Mean		60	59	57	57	60	63
						CV (%)	10.4

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Root TNC concentration of Domino under monoculture was not significantly different from its root TNC value in associated culture at both densities in the second season but was significantly higher than the other treatment combinations (Table 5). The two associated density levels did not generally differ markedly in root total non-structural carbohydrates within each growing season (Table 5).

Stem starch in Carioca at the higher density during the second year was significantly higher than the corresponding values in the two cropping patterns except stem starch concentration of Domino under monoculture (Table 5). Stem sugar concentration for both cultivars under monoculture was not significantly different from their stem sugar concentration in associated culture during the 1985 season. However, stem sugar concentration in the second season was significantly higher than the stem sugar values of the remaining seasons (Table 5). Stem TNC of Carioca at the high density during the second year was not significantly different from Domino stem TNC concentration under monoculture. However, it was significantly higher than the rest of the treatment combinations in the two cropping patterns (Table 5). The two levels of density combinations did not differ significantly (with few exceptions) in stem TNC within each growing season (Table 5).

4.3. Bean Mineral Nutrients

4.3.1. Bean Seed Mineral Nutrient Concentration

The analyses of variance for seed nutrient concentrations of bean in association with maize are presented in Appendix A, Table A5. Cultivars differed significantly ($p < 0.05$) for boron and potassium concentrations (Appendix A, Table A5). Only boron showed a significant ($p < 0.05$) year x cultivar interaction (Appendix A, Table A5). Boron concentration in Carioca was significantly higher than Domino's boron values during the first season. However, Domino's potassium concentration was significantly higher than the Carioca potassium values in the third season (Table 6). Significant cultivar differences were also observed for iron and copper concentrations at the 1 percent probability level. Iron concentration of Domino was significantly higher than in Carioca in 1984. Similarly, copper concentration of Domino was significantly higher than Carioca copper concentration in 1986. The results in Appendix A, Table A5 indicated that the effect of density on seed nutrient content was not significant. No significant year x density, cultivar x density, and year x cultivar x density interactions were observed for bean seed nutrient concentration.

A comparison of seed nutrient contents in monoculture with those contents in associated culture indicated that protein, nitrogen, phosphorus, magnesium, boron, molybdenum, and zinc concentrations did not vary significantly (Table 7). However,

Table 6. Effect of Year, Bean Cultivar, and Bean Density on Seed Nutrient Concentration of Bean in the Associated Culture.

		Bean Density (10^3 pl/ha)			
		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca
Protein (gm/kg)	1984	260	280	280	260
	1985	280	260	280	280
	1986	310	280	300	270
Column Mean		283	273	287	270
				CV (%)	9
Nitrogen (gm/kg)	1984	42	45	45	41
	1985	45	42	44	45
	1986	49	44	48	44
Column Mean		45	44	46	43
				CV (%)	9
Phosphorus (gm/kg)	1984	5	4	5	5
	1985*	5	5	5	6
	1986	5	4	5	4
Column Mean		5	4	5	5
				CV (%)	12.2
Potassium (gm/kg)	1984	14[a]	12[c]	13[b]	13[b]
	1985	14[a]	14[a]	14[a]	14[a]
	1986	14[a]	12[c]	14[a]	13[b]
Column Mean		14	13	14	13
LSD (0.05) 1				CV (%)	6.5

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 6 (cont'd.).

Trait	Year	100 Domino	100 Carioca	200 Domino	200 Carioca
		Bean Density (10^3 pl/ha)			
Calcium (gm/kg)	1984	2	2	2	1
	1985	1	2	2	2
	1986*	1	1	1	1
Column Mean		1	2	2	1
				CV (%)	16.1
Magnesium (gm/kg)	1984	2	2	2	2
	1985	2	2	2	2
	1986	2	2	2	2
Column Mean		2	2	2	2
				CV (%)	5.7
Boron (mg/kg)	1984	10^c	11^b	10^c	11^b
	1985	10^c	10^c	9^d	9^d
	1986	11^b	11^b	11^b	12^a
Column Mean		10	11	10	11
LSD (0.05) 1				CV (%)	7.3
Copper (mg/kg)	1984	12^{bc}	11^{cd}	12^{bc}	12^{bc}
	1985	14^a	12^{bc}	14^a	13^{ab}
	1986	11^{cd}	8^e	10^d	8^e
Column Mean		12	10	12	11
LSD (0.05) 2				CV (%)	13.8

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 6 (cont'd.).

Trait	Year	Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Iron (mg/kg)	1984	80[a]	71[cd]	79[ab]	70[cd]
	1985	71[cd]	64[d]	68[cd]	69[cd]
	1986	72[bc]	68[cd]	74[a-c]	68[cd]
Column Mean		74	68	74	69
LSD (0.05) 8				CV (%)	8.0
Molybdenum (mg/kg)	1984*	6	5	6	6
	1985	4	4	4	4
	1986	3	3	4	4
Column Mean		4	4	5	5
				CV (%)	19.1
Manganese (mg/kg)	1984	13	12	13	13
	1985*	10	10	10	10
	1986	14	13	13	12
Column Mean		12	12	12	12
				CV (%)	9.1
Zinc (mg/kg)	1984	34	35	34	37
	1985	32	36	32	40
	1986	34	33	32	35
Column Mean		33	35	33	37
				CV (%)	13.8

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 7. Effect of Year, Bean Cultivar, and Bean Density on Seed Nutrient Concentration of Bean in the Two Cropping Patterns.

		Sole Bean Stand		Bean Density (10^3 pl/ha)			
		200		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca
Protein (gm/kg)	1984	270	270	260	280	280	260
	1985	280	270	280	260	280	280
	1986	280	260	310	280	300	270
Column Mean		277	267	283	273	287	270
						CV (%)	8.9
Nitrogen (gm/kg)	1984	42	43	42	45	45	41
	1985	45	43	45	42	44	45
	1986	44	42	49	44	48	44
Column Mean		44	43	45	44	46	43
						CV (%)	8.9
Phosphorus (gm/kg)	1984	5	5	5	4	5	5
	1985	5	6	5	5	5	6
	1986	4	4	5	4	5	4
Column Mean		5	5	5	4	5	5
						CV (%)	11.3
Potassium (gm/kg)	1984	13[b]	13[b]	14[a]	12[c]	13[b]	13[b]
	1985	14[a]	13[b]	14[a]	14[a]	14[a]	14[a]
	1986	13[b]	12[c]	14[a]	12[c]	14[a]	13[b]
Column Mean		13	13	14	13	14	13
LSD (0.05) 1						CV (%)	5.9

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 7 (cont'd.).

Trait	Year	Sole Bean Stand 200 Domino	Sole Bean Stand 200 Carioca	Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Calcium (gm/kg)	1984	1^{b}	1^{b}	2^{a}	2^{a}	2^{a}	1^{b}
	1985	2^{a}	2^{a}	1^{b}	2^{a}	2^{a}	2^{a}
	1986	2^{a}	2^{a}	1^{b}	1^{b}	1^{b}	1^{b}
Column Mean		2	2	1	2	2	1
LSD (0.05)	0.4					CV (%)	15.4
Magnesium (gm/kg)	1984	2	2	2	2	2	2
	1985	2	2	2	2	2	2
	1986	2	2	2	2	2	2
Column Mean		2	2	2	2	2	2
						CV (%)	5.9
Boron (mg/kg)	1984	10	11	10	11	10	11
	1985	10	9	10	10	9	9
	1986	10	10	11	11	11	12
Column Mean		10	10	10	11	10	11
						CV (%)	7.9
Copper (mg/kg)	1984	11^{b-d}	10^{c-e}	12^{a-c}	11^{b-d}	12^{a-c}	12^{a-c}
	1985	13^{ab}	12^{a-c}	14^{a}	12^{a-c}	14^{a}	13^{ab}
	1986	12^{a-c}	8^{e}	11^{b-d}	8^{e}	10^{c-e}	8^{e}
Column Mean		12	10	12	10	12	11
LSD (0.05)	2.5					CV (%)	15.5

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 7 (cont'd.).

		Sole Bean Stand		Bean Density (10^3 pl/ha)			
		200		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca
Iron (mg/kg)	1984	73^{ab}	63^{b-e}	80^{a}	71^{ab}	79^{a}	70^{a-c}
	1985	51^{e}	57^{c-e}	71^{ab}	64^{b-e}	68^{a-d}	69^{a-c}
	1986	73^{ab}	55^{de}	72^{ab}	68^{a-d}	74^{ab}	68^{a-d}
Column Mean		66	58	74	68	74	69
LSD (0.05)	13.8					CV (%)	14.3
Molybdenum (mg/kg)	1984	5	4	6	5	6	6
	1985	4	4	4	4	4	4
	1986	3	4	3	3	4	4
Column Mean		4	4	4	4	5	5
						CV (%)	17.8
Manganese (mg/kg)	1984	12^{bc}	12^{bc}	13^{ab}	12^{bc}	13^{ab}	13^{ab}
	1985	10^{de}	9^{e}	10^{de}	10^{de}	10^{de}	10^{de}
	1986	12^{bc}	11^{cd}	14^{a}	13^{ab}	13^{ab}	12^{bc}
Column Mean		11	11	12	12	12	12
LSD (0.05)	1.3					CV (%)	8
Zinc (mg/kg)	1984	32	32	34	35	34	37
	1985	34	34	32	36	32	40
	1986	36	28	34	33	32	35
Column Mean		34	31	33	35	33	37
						CV (%)	13.3

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

mixed results were obtained in each season for potassium, calcium, copper, iron, and manganese concentrations (Table 7). Copper, Fe, and Mn concentrations of the two cultivars in monoculture were not significantly different from their corresponding concentrations in associated culture in each season (with few exceptions). Potassium concentration of Domino in association with maize (except one treatment) for the three seasons was similar to Domino's under monoculture and Carioca's potassium values under associated culture in the second season but was significantly higher (with one exception) than all the remaining values.

4.3.2. Bean Leaf Mineral Nutrient Concentration

Bean leaf nutrient concentration results in associated culture are presented in Appendix A, Table A6. Seasonal effect was highly significant ($p < 0.01$) for phosphorus, potassium, calcium, magnesium, boron, copper, molybdenum, manganese, and zinc concentrations. Calcium and manganese concentrations were significantly lower in 1985 than their corresponding concentrations in 1984 and 1986. Magnesium concentration, on the other hand, was significantly higher while copper concentration was significantly lower in the first season than in the last two seasons. Significant seasonal effect was also observed for protein and nitrogen concentration at the 5 percent probability level (Appendix A, Table A6). On the other hand, cultivar effect on phosphorus and potassium concentration was significant at the 5 percent probability level and boron, molybdenum, and zinc at the 1 percent probability level

(Appendix A, Table A6). Phosphorus and potassium concentrations of Carioca (100,000 plants/ha) were significantly higher in the second season while its Zn concentration was significantly higher in the first season than Domino's values within the same season (Table 8).

A significant ($p < 0.05$) year x cultivar interaction was observed for boron concentration while the year x cultivar interaction was highly significant for protein, nitrogen, and molybdenum concentration (Appendix A, Table A6). Protein and N concentrations in Carioca were significantly increased in 1985 over corresponding Domino's trait values during the same season. Similarly, B and Mo concentrations of Carioca were significantly higher in 1986 than Domino concentrations within the same season. Effect of bean density on bean leaf nutrients was not significant. Similarly, year x density interaction was not significant for the bean leaf nutrient concentration. Furthermore, no significant effect was observed for cultivar x density or year x cultivar x density interactions in bean leaf nutrient levels (Appendix A, Table A6).

A comparison of bean leaf nutrient concentrations under monoculture with the leaf nutrient concentrations of bean in associated culture is presented in Table 9. Leaf protein, nitrogen, phosphorus, potassium, calcium, magnesium, and copper of bean under monoculture were not significantly different from their leaf nutrient concentrations of bean in associated culture (Table 9). Bean leaf boron concentrations of the two cropping patterns did not differ significantly in the 1984 and 1985 growing seasons.

Table 8. Leaf Nutrient Concentration of Bean as Affected by Year, Bean Cultivar, and Bean Density in the Associated Culture.

		Bean Density (10^3 pl/ha)			
		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca
Protein (gm/kg)	1984	270^{c-e}	290^{b-d}	270^{c-e}	290^{b-d}
	1985	240^{e}	320^{ab}	250^{de}	310^{a-c}
	1986	340^{a}	260^{de}	340^{a}	310^{a-c}
Column Mean		283	290	287	303
LSD (0.05) 50				CV (%)	12.3
Nitrogen (gm/kg)	1984	43^{b-d}	47^{a-c}	44^{b-d}	47^{a-c}
	1985	39^{d}	52^{a}	40^{c}	50^{ab}
	1986	54^{a}	42^{cd}	54^{a}	50^{ab}
Column Mean		45	47	46	49
LSD (0.05) 8				CV (%)	12.3
Phosphorus (gm/kg)	1984	4^{c}	4^{c}	4^{c}	4^{c}
	1985	5^{b}	6^{a}	5^{b}	5^{b}
	1986	5^{b}	6^{a}	6^{a}	6^{a}
Column Mean		5	5	5	5
LSD (0.05) 0.9				CV (%)	12.5
Potassium (gm/kg)	1984	17^{cd}	17^{cd}	16^{d}	17^{cd}
	1985	24^{b}	31^{a}	21^{b-d}	23^{bc}
	1986	21^{b-d}	27^{ab}	22^{b-d}	26^{ab}
Column Mean		21	25	20	22
LSD (0.05) 7				CV (%)	21.4

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 8 (cont'd.).

Trait	Year	Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Calcium (gm/kg)	1984	35	39	33	38
	1985*	19	20	19	19
	1986	38	40	36	40
Column Mean		31	33	29	32
				CV (%)	26.4
Magnesium (gm/kg)	1984*	13	13	13	12
	1985	6	7	7	7
	1986	8	9	9	10
Column Mean		9	10	10	10
				CV (%)	9.9
Boron (mg/kg)	1984	36[c]	38[c]	35[c]	37[c]
	1985	37[c]	41[c]	37[c]	38[c]
	1986	58[b]	68[a]	57[b]	69[a]
Column Mean		44	49	43	48
LSD (0.05)	8			CV (%)	12.2
Copper (mg/kg)	1984*	10	11	10	11
	1985	19	20	17	16
	1986	17	16	17	17
Column Mean		15	16	15	15
				CV (%)	21.2

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 8 (cont'd.).

Trait	Year	Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Iron (mg/kg)	1984	502	699	581	580
	1985	366	368	343	359
	1986	319	603	426	567
Column Mean		396	557	450	502
				CV (%)	19.5
Molybdenum (mg/kg)	1984	11^b	11^b	11^b	11^b
	1985	7^d	7^d	7^d	7^d
	1986	10^c	13^a	10^c	11^b
Column Mean		9	10	9	10
LSD (0.05) 1				CV (%)	8.1
Manganese (mg/kg)	1984	126	161	94	126
	1985*	29	33	31	30
	1986	110	119	107	113
Column Mean		88	104	77	90
				CV (%)	27.3
Zinc (mg/kg)	1984	39^f	53^{a-c}	40^f	45^{d-f}
	1985	42^{ef}	48^{b-e}	40^f	42^{ef}
	1986	46^{c-f}	55^{ab}	51^{a-d}	58^a
Column Mean		42	52	44	48
LSD (0.05) 8				CV (%)	12.4

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 9. Leaf Nutrient Concentration of Bean as Affected by Year, Bean Cultivar, and Bean Density in the Two Cropping Patterns.

		Sole Bean Stand 200		Bean Density (10^3 pl/ha) 100		Bean Density (10^3 pl/ha) 200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca
Protein (gm/kg)	1984	310	280	270	290	270	290
	1985	240	280	240	320	250	310
	1986	350	310	340	260	340	310
Column Mean		300	290	283	290	287	303
						CV (%)	11.8
Nitrogen (gm/kg)	1984	50	45	43	47	44	47
	1985	39	44	39	52	40	50
	1986	57	49	54	42	54	50
Column Mean		49	46	45	47	46	49
						CV (%)	11.8
Phosphorus (gm/kg)	1984	4	5	4	4	4	4
	1985	5	5	5	6	5	5
	1986	6	6	5	6	6	6
Column Mean		5	5	5	5	5	5
						CV (%)	12.2
Potassium (gm/kg)	1984	17	17	17	17	16	17
	1985	23	23	24	31	21	23
	1986	21	23	21	27	22	26
Column Mean		20	21	21	25	20	22
						CV (%)	21.3

Table 9 (cont'd.).

Trait	Year	Sole Bean Stand 200 Domino	Sole Bean Stand 200 Carioca	Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Calcium (gm/kg)	1984	36	40	35	39	33	38
	1985	19	18	19	20	19	19
	1986	36	44	38	40	36	40
Column Mean		30	34	31	33	29	32
						CV (%)	24.7
Magnesium (gm/kg)	1984	12	13	13	13	13	12
	1985	7	7	6	7	7	7
	1986	10	10	8	9	9	10
Column Mean		10	10	9	10	10	10
						CV (%)	10.2
Boron (mg/kg)	1984	35[d]	39[d]	36[d]	38[d]	35[d]	37[d]
	1985	35[d]	35[d]	37[d]	41[d]	37[d]	38[d]
	1986	50[c]	51[bc]	58[b]	68[a]	57[bc]	69[a]
Column Mean		40	42	44	49	43	48
LSD (0.05)	7					CV (%)	11.3
Copper (mg/kg)	1984	14	13	10	11	10	11
	1985	16	17	19	20	17	16
	1986	14	14	17	16	17	17
Column Mean		15	15	15	16	15	15
						CV (%)	22.9

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 9 (cont'd.).

		Sole Bean Stand 200		Bean Density (10^3 pl/ha) 100		200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca
Iron (mg/kg)	1984	486^{c-e}	728^{a}	502^{cd}	699^{ab}	581^{bc}	580^{bc}
	1985	397^{d-g}	381^{d-g}	366^{e-g}	368^{e-g}	343^{fh}	359^{fg}
	1986	231^{h}	274^{gh}	319^{f-h}	603^{bc}	426^{d-f}	567^{c}
Column Mean		371	461	396	557	450	502
LSD (0.05)	123					CV (%)	19.1
Molybdenum (mg/kg)	1984	11^{b}	11^{b}	11^{b}	11^{b}	11^{b}	11^{b}
	1985	7^{e}	7^{e}	7^{e}	7^{e}	7^{e}	7^{e}
	1986	9^{d}	11^{b}	10^{c}	13^{a}	10^{c}	11^{b}
Column Mean		9	10	9	10	9	10
LSD (0.05)	1					CV (%)	8.1
Manganese (mg/kg)	1984	127^{b}	122^{bc}	126^{b}	161^{a}	94^{cd}	126^{b}
	1985	28^{e}	29^{e}	29^{e}	33^{e}	31^{e}	30^{e}
	1986	100^{b-d}	69^{d}	110^{bc}	119^{bc}	107^{bc}	113^{bc}
Column Mean		85	73	88	104	77	90
LSD (0.05)	31					CV (%)	25.2
Zinc (mg/kg)	1984	42^{d-f}	59^{a}	39^{ef}	53^{a-c}	40^{ef}	45^{c-e}
	1985	42^{d-f}	45^{c-e}	42^{d-f}	48^{b-e}	40^{ef}	42^{d-f}
	1986	52^{a-c}	48^{b-e}	46^{b-e}	55^{ab}	51^{a-d}	58^{a}
Column Mean		45	51	42	52	44	48
LSD (0.05)	9					CV (%)	13.2

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

However, bean leaf boron of Carioca grown in association with maize was significantly ($p < 0.05$) higher than the monocultural values in the 1986 growing season. Bean leaf boron concentration of Domino grown in association with maize was either significantly ($p < 0.05$) higher or remained similar to the monocultural boron concentration in the 1986 growing season (Table 9). Similarly, leaf zinc concentration of Domino grown in associated culture did not vary significantly from its monocultural value within each growing season. Zinc in Carioca under monoculture was either not significant or significantly higher than zinc concentration in associated culture (Table 9).

Leaf manganese of Domino in monoculture was not significantly different from leaf manganese concentration in associated culture for the 1985 and 1986 growing seasons. On the contrary, Domino leaf manganese planted at 200,000 plants/ha was significantly lower than leaf manganese concentration in Domino in monoculture in the 1984 cropping season. Leaf manganese of Carioca in monoculture was either significantly ($p < 0.05$) lower or not significantly different from leaf manganese of Carioca in associated culture for the 1984 and 1986 cropping seasons (Table 9).

Bean cultivars grown with maize had similar molybdenum concentrations as their monocultural counterparts for the 1984 and 1985 growing seasons. However, the concentration of molybdenum in monoculture for the 1986 cropping season was either not significant or significantly lower than the molybdenum concentration in the intercropping system (Table 9). Leaf iron concentration of Domino in monoculture was not significantly different from the concentration of iron in the associated culture for the 1984 and 1985 cropping seasons. On the contrary, leaf iron concentration of Carioca in monoculture was significantly ($p < 0.05$) higher than iron concentration of Carioca (200,000 plants/ha) grown in association with maize during the 1984 cropping season. Leaf iron concentration of Carioca in the 1986 season was significantly higher in the intercropped system than in monoculture (Table 9).

4.4. Maize Performance in the Two Cropping Systems

Results of maize yield and yield-related traits in association with bean cultivars are presented in Appendix A, Tables A7 and A8. Effect of bean cultivars on maize traits was not significant. No year x cultivar interactions were observed in maize traits except grain potassium yield, which differed significantly at the 5 percent probability level (Appendix A, Tables A7 and A8). Maize grain potassium yield was significantly higher during the third growing season than any other season when maize was grown in association with Domino (Table 10).

Significant bean density ($p < 0.01$), year x density ($p < 0.05$), and year x cultivar x density ($p < 0.05$) interactions were observed only for maize plant height (Appendix A, Tables A7 and A8). Plant height of maize intercropped with Carioca (100,000 plants/ha) was significantly shorter in the 1985 growing season than the maize-Domino association within the same season and bean

Table 10. Effect of Year, Bean Cultivar, and Bean Density on Maize Yield and Yield-Related Traits in the Associated Culture.

		Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha)					
		100		150		200	
Trait	Year	Domino	Carioca	Domino	Carioca	Domino	Carioca
Maize Height (cm)	1984	203^{a-c}	202^{a-d}	200^{b-d}	197^{cd}	197^{cd}	199^{cd}
	1985	160^{e}	148^{f}	151^{f}	158^{e}	145^{f}	145^{f}
	1986	206^{ab}	207^{a}	199^{cd}	198^{cd}	196^{d}	200^{b-d}
Column Mean		190	186	183	184	179	181
LSD (0.05) 7						CV (%)	2.7
Protein Yield (kg/ha)	1984	492	505			540	537
	1985	525	512			532	494
	1986*	755	795			698	761
Column Mean		591	604			590	597
						CV (%)	13.3
Nitrogen Yield (kg/ha)	1984	79	81			86	86
	1985	84	82			85	79
	1986*	121	127			111	122
Column Mean		95	97			94	96
						CV (%)	13.3

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 10 (cont'd.).

Trait	Year	Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	150 Domino	150 Carioca	200 Domino	200 Carioca
Phosphorus Yield (kg/ha)	1984	32	35			36	36
	1985*	27	25			27	25
	1986	36	33			31	32
Column Mean		32	31			31	31
						CV (%)	11.1
Potassium Yield (kg/ha)	1984	25ef	27de			26de	28cd
	1985	23fg	21gh			23fg	20h
	1986	35a	31b			32b	30bc
Column Mean		28	26			27	26
LSD (0.05) 3						CV (%)	8.9
Hundred Seed Weight (gm)	1984	30	33	33	31	33	31
	1985	32	32	34	32	31	32
	1986	32	32	31	32	30	32
Column Mean		31	32	33	32	31	32
						CV (%)	7.7

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 10 (cont'd.).

Trait	Year	Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	150 Domino	150 Carioca	200 Domino	200 Carioca
Land Equivalent Ratio (LER)	1984	1.19	1.21	1.29	1.23	1.28	1.31
	1985	1.22	1.21	1.32	1.28	1.35	1.15
	1986	1.20	1.23	1.17	1.21	1.23	1.28
Column Mean		1.20	1.22	1.26	1.24	1.29	1.25
						CV (%)	7.0
Maize Grain Yield (kg/ha)	1984	5310	5429	5631	5565	5605	5675
	1985	5201	4972	5416	5489	5330	4718
	1986*	7452	7683	7023	7259	7018	7443
Column Mean		5988	6028	6023	6104	5984	5945
						CV (%)	8.6

Note: Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

density level. Significant ($p < 0.01$) seasonal effect was observed on maize plant height, maize grain yield, grain protein, nitrogen, phosphorus, and potassium yield (Appendix A, Tables A7 and A8). Grain yield, grain protein, and nitrogen yield of maize in associated culture in the 1986 cropping season was higher than in 1984 and 1985. Maize associated with beans during the 1985 growing season yielded less grain phosphorus and potassium than the 1984 and 1986 yield for these elements.

A comparison of monoculture with the associated culture maize performance is shown in Table 11. Hundred seed weight of maize in monoculture was not significantly different from that of the intercrop weight. Maize in sole crop stand was significantly taller than maize in associated culture during the 1985 growing season. Maize grain protein and nitrogen yield differences in associated culture in 1984 and 1986 were not significant with the exception of the maize-Domino combination at 200,000 plants/ha which yielded significantly lower than the monocultural maize (Table 11). Furthermore, protein and nitrogen yields of maize under monoculture in the 1985 growing season were significantly higher than the counterpart in associated culture at the 5 percent probability level. Similarly, grain phosphorus and potassium yields of maize in monoculture in 1985 were significantly ($p < 0.05$) higher than grain phosphorus and potassium yields of maize in association with beans (Table 11).

Table 11. Effect of Year, Bean Cultivar, and Bean Density on Maize Yield and Yield-Related Traits in the Two Cropping Patterns.

Trait	Year	Sole Maize Stand (40,000 pl/ha)	Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha)					
			100		150		200	
			Domino	Carioca	Domino	Carioca	Domino	Carioca
Maize Height (cm)	1984	201^{a-c}	203^{a-c}	202^{a-c}	200^{a-c}	197^{c}	197^{c}	199^{bc}
	1985	176^{d}	160^{e}	148^{g}	151^{fg}	158^{ef}	145^{g}	145^{g}
	1986	207^{a}	206^{ab}	207^{a}	199^{bc}	198^{c}	196^{c}	200^{a-c}
Column Mean		195	190	186	183	184	179	181
LSD (0.05) 7.5							CV (%)	2.9
Protein Yield (kg/ha)	1984	547^{c}	492^{c}	505^{c}			540^{c}	537^{c}
	1985	753^{ab}	525^{c}	512^{c}			532^{c}	494^{c}
	1986	802^{a}	755^{ab}	795^{ab}			698^{b}	761^{ab}
Column Mean		701	591	604			590	597
LSD (0.05) 101.9							CV (%)	11.6
Nitrogen Yield (kg/ha)	1984	87^{c}	79^{c}	81^{c}			86^{c}	86^{c}
	1985	121^{ab}	84^{c}	82^{c}			85^{c}	79^{c}
	1986	128^{a}	121^{ab}	127^{ab}			111^{b}	122^{ab}
Column Mean		112	95	97			94	96
LSD (0.05) 16.3							CV (%)	11.6

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 11 (cont'd.).

Trait	Year	Sole Maize Stand (40,000 pl/ha)	Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha)					
			100		150		200	
			Domino	Carioca	Domino	Carioca	Domino	Carioca
Phosphorus	1984	39^{a}	32^{b-d}	35^{a-c}			36^{ab}	36^{ab}
Yield	1985	40^{a}	27^{df}	25^{f}			27^{ef}	25^{f}
(kg/ha)	1986	36^{a-c}	36^{a-c}	33^{bc}			31^{c-e}	32^{b-d}
Column Mean		38	32	31			31	31
LSD (0.05) 4.9							CV (%)	10.6
Potassium	1984	30^{c-e}	25^{g-i}	27^{f-h}			26^{f-h}	28^{e-g}
Yield	1985	33^{a-c}	23^{ij}	21^{j}			23^{h-j}	20^{j}
(kg/ha)	1986	35^{a}	35^{a}	31^{b-d}			32^{a-d}	30^{c-e}
Column Mean		33	28	26			27	26
LSD (0.05) 3.4							CV (%)	8.6
Hundred	1984	33	30	33	33	31	33	31
Seed	1985	34	32	32	34	32	31	32
Weight (gm)	1986	34	32	32	31	32	30	32
Column Mean		34	31	32	33	32	31	32
							CV (%)	7.3

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 11 (cont'd.).

Trait	Year	Sole Maize Stand (40,000 pl/ha)	Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	150 Domino	150 Carioca	200 Domino	200 Carioca
Land	1984	1.00^{f}	1.19^{de}	1.21^{c-e}	1.29^{a-d}	1.23^{b-e}	1.28^{a-d}	1.31^{a-c}
Equivalent	1985	1.00^{f}	1.22^{b-e}	1.21^{c-e}	1.32^{ab}	1.28^{a-d}	1.35^{a}	1.15^{e}
Ratio (LER)	1986	1.00^{f}	1.20^{de}	1.23^{b-e}	1.17^{e}	1.21^{c-e}	1.23^{b-e}	1.28^{a-d}
Column Mean		1.00	1.20	1.22	1.26	1.24	1.29	1.25
LSD (0.05) 0.11							CV (%)	6.7
Maize	1984	5991^{c}	5310^{c-e}	5429^{c-e}	5631^{cd}	5565^{cd}	5605^{cd}	5675^{cd}
Grain	1985	7113^{b}	5201de	4972de	5416^{c-e}	5489^{cd}	5330^{c-e}	4718^{e}
Yield (kg/ha)	1986	7915^{a}	7452^{ab}	7683^{ab}	7023^{b}	7259^{ab}	7018^{b}	7443^{ab}
Column Mean		7006	5988	6028	6023	6104	5984	5945
LSD (0.05) 737							CV (%)	8.5

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

On the other hand, phosphorus and potassium yields of maize in monoculture were either not significant or significantly higher than maize yield in associated culture for the 1984 and 1986 growing seasons. Land equivalent ratio (LER), which ranged between 1.15 and 1.35 in associated culture, was significantly higher than the LER under monoculture throughout the experimental period. Grain yield of maize in monoculture in the 1984 cropping season was not significantly different from that of the associated culture maize (Table 11). However, the grain yield of maize in sole crop stand in 1985 significantly out-yielded the corresponding yield value in associated culture at the 5 percent probability level. Other observations indicated that maize in association with Domino at 150,000 and 200,000 plants/ha yielded significantly lower grain than the grain yields of maize under monoculture during the 1986 cropping season (Table 11).

4.5. Maize Mineral Nutrient Concentration

4.5.1. Maize Grain Mineral Nutrient Concentration

Results of grain nutrient concentration of maize in association with bean cultivars are shown in Appendix A, Table A9. Bean density significantly ($p < 0.05$) affected grain copper concentration of maize. Grain copper concentration of maize was generally lower when maize was intercropped with beans at 200,000 plants/ha than when it was associated with 100,000 bean plants per hectare (Table 12). Furthermore, grain copper concentration of maize in association with Domino (100,000 plants/ha) was significantly

Table 12. Grain Nutrient Concentration of Maize as Affected by Year, Bean Cultivar, and Bean Density in the Associated Culture.

		Intercropped Maize (40,000 pl/ha) with: Bean Density (10^3 pl/ha)			
		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca
Protein (gm/kg)	1984*	90	90	100	90
	1985	100	100	100	100
	1986	100	100	100	100
Column Mean		97	97	100	97
				CV (%)	7.4
Nitrogen (gm/kg)	1984*	15	15	15	15
	1985	16	16	16	17
	1986	16	17	16	16
Column Mean		16	16	16	16
				CV (%)	7.4
Phosphorus (gm/kg)	1984	6	6	6	6
	1985	5	5	5	5
	1986*	5	4	4	4
Column Mean		5	5	5	5
				CV (%)	7.6
Potassium (gm/kg)	1984	5^a	5^a	5^a	5^a
	1985	4^b	4^b	4^b	4^b
	1986	5^a	4^b	5^a	4^b
Column Mean		5	4	5	4
LSD (0.05)	0.4			CV (%)	6.6

Note: Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 12 (cont'd.).

Trait	Year	Intercropped Maize (40,000 pl/ha) with: Bean Density (10^3 pl/ha)			
		100		200	
		Domino	Carioca	Domino	Carioca
Calcium (gm/kg)	1984	0.2	0.2	0.1	0.2
	1985	0.2	0.2	0.2	0.2
	1986	0.2	0.2	0.2	0.2
Column Mean		0.2	0.2	0.2	0.2
				CV (%)	16.0
Magnesium (gm/kg)	1984	2	2	2	2
	1985	2	2	2	2
	1986	2	2	2	2
Column Mean		2	2	2	2
				CV (%)	8.8
Boron (mg/kg)	1984	2.3	2.4	2.5	2.5
	1985	2.6	2.5	2.6	2.7
	1986	2.5	2.3	2.4	2.4
Column Mean		2.5	2.4	2.5	2.5
				CV (%)	15.0
Copper (mg/kg)	1984	4.2[a-d]	4.9[a]	3.5[d]	4.3[a-d]
	1985	4.0[a-d]	4.5[a-c]	3.8[cd]	3.8[cd]
	1986	4.7[ab]	3.5[d]	3.8[cd]	3.9[cd]
Column Mean		4.3	4.3	3.7	4.0
LSD (0.05)	0.9			CV (%)	16.2

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 12 (cont'd.).

		Intercropped Maize (40,000 pl/ha) with: Bean Density (10^3 pl/ha)			
		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca
Iron (mg/kg)	1984	27	30	29	30
	1985	27	28	25	25
	1986	33	27	30	31
Column Mean		29	28	28	29
				CV (%)	11.1
Molybdenum (mg/kg)	1984	0.3	0.3	0.4	0.3
	1985	0.5	0.4	0.4	0.5
	1986	0.3	0.3	0.3	0.4
Column Mean		0.4	0.3	0.4	0.4
				CV (%)	23.7
Manganese (mg/kg)	1984	7	7	7	8
	1985*	5	5	4	4
	1986	6	5	6	6
Column Mean		6	6	6	6
				CV (%)	13.2
Zinc (mg/kg)	1984	32^{bc}	37^{a}	33^{ab}	37^{a}
	1985	31^{b-d}	27^{de}	28^{c-e}	29^{b-e}
	1986	32^{bc}	26^{e}	30^{b-e}	28^{c-e}
Column Mean		32	30	30	31
LSD (0.05) 5				CV (%)	11.0

Note: Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

higher than grain copper values of maize in association with Carioca at the same density level in the third season (Table 12). Significant seasonal effects were noted for grain protein, nitrogen, phosphorus, potassium, magnesium, iron, manganese, and zinc concentrations of maize at the 1 percent and calcium concentration at the 5 percent probability level (Appendix A, Table A9). Grain protein and nitrogen concentrations of maize were generally lower in the first growing season than in the last two cropping seasons. On the other hand, grain phosphorus concentration of maize was significantly lower during the third growing season as compared with the first two seasons (Table 12).

Grain potassium and manganese concentrations of maize were significantly lower during the second cropping season as compared to the first season (Table 12). Grain potassium concentration of maize in association with Domino was significantly higher than grain potassium values of maize in association with Carioca during the third cropping season (Table 12). Bean cultivars did not affect grain nutrient concentration of maize in associated culture. Similarly, year x density, cultivar x density, and year x cultivar x density interactions were not significant in grain nutrient concentration of maize (Appendix A, Table A9). The comparison of monoculture and associated culture nutrient concentrations indicated that the two cropping systems did not differ significantly in grain nutrient concentration of maize (Table 13).

Table 13. Grain Nutrient Concentration of Maize as Affected by Year, Bean Cultivar, and Bean Density in the Two Cropping Patterns.

			Intercropped Maize (40,000 pl/ha) with: Bean Density (10^3 pl/ha)			
		Sole Maize Stand	100		200	
Trait	Year	(40,000 pl/ha)	Domino	Carioca	Domino	Carioca
Protein (gm/kg)	1984	90	90	90	100	90
	1985	110	100	100	100	100
	1986	100	100	100	100	100
Column Mean		100	97	97	100	97
					CV (%)	7.1
Nitrogen (gm/kg)	1984	14	15	15	15	15
	1985	17	16	16	16	17
	1986	16	16	17	16	16
Column Mean		16	16	16	16	16
					CV (%)	7.1
Phosphorus (gm/kg)	1984	6	6	6	6	6
	1985	6	5	5	5	5
	1986	5	5	4	4	4
Column Mean		6	5	5	5	5
					CV (%)	7.4
Potassium (gm/kg)	1984	5	5	5	5	5
	1985	5	4	4	4	4
	1986	4	5	4	5	4
Column Mean		5	5	4	5	4
					CV (%)	6.3

Table 13 (cont'd.).

Trait	Year	Sole Maize Stand (40,000 pl/ha)	Intercropped Maize (40,000 pl/ha) with: Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Calcium (gm/kg)	1984	0.2	0.2	0.2	0.1	0.2
	1985	0.2	0.2	0.2	0.2	0.2
	1986	0.2	0.2	0.2	0.2	0.2
Column Mean		0.2	0.2	0.2	0.2	0.2
					CV (%)	14.2
Magnesium (gm/kg)	1984	2	2	2	2	2
	1985	2	2	2	2	2
	1986	2	2	2	2	2
Column Mean		2	2	2	2	2
					CV (%)	8.6
Boron (mg/kg)	1984	2.6	2.3	2.4	2.5	2.5
	1985	2.7	2.6	2.5	2.6	2.7
	1986	2.3	2.5	2.3	2.4	2.4
Column Mean		2.5	2.5	2.4	2.5	2.5
					CV (%)	14.5
Copper (mg/kg)	1984	4.4	4.2	4.9	3.5	4.3
	1985	3.8	4.0	4.5	3.8	3.8
	1986	3.8	4.7	3.5	3.9	3.8
Column Mean		4.0	4.3	4.3	3.7	4.0
					CV (%)	15.2

Table 13 (cont'd.).

Trait	Year	Sole Maize Stand (40,000 pl/ha)	Intercropped Maize (40,000 pl/ha) with: Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Iron (mg/kg)	1984	32	27	30	29	30
	1985	26	27	28	25	25
	1986	31	33	27	30	31
Column Mean		30	29	28	28	29
					CV (%)	10.3
Molybdenum (mg/kg)	1984	0.2	0.3	0.3	0.4	0.3
	1985	0.5	0.5	0.4	0.4	0.5
	1986	0.3	0.3	0.3	0.3	0.4
Column Mean		0.3	0.4	0.3	0.4	0.4
					CV (%)	10.3
Manganese (mg/kg)	1984	7	7	7	7	8
	1985	5	5	5	4	4
	1986	6	6	5	6	6
Column Mean		6	6	6	6	6
					CV (%)	12.7
Zinc (mg/kg)	1984	33	32	37	33	37
	1985	32	31	27	28	29
	1986	28	32	26	30	28
Column Mean		31	32	30	30	31
					CV (%)	10.7

4.5.2. Maize Leaf Mineral Nutrient Concentration

Results of leaf nutrient concentration of maize in association with bean cultivars are presented in Appendix A, Table A10. Leaf manganese concentration of maize was the only nutrient which was significantly affected by bean cultivars at the 1 percent probability level (Appendix A, Table A10). Manganese concentration of maize leaf produced in association with Carioca was significantly increased over maize intercropped with Domino (with one exception) during the third cropping season (Table 14).

Highly significant seasonal effects were observed for leaf phosphorus, potassium, calcium, magnesium, boron, copper, iron, molybdenum, manganese, and zinc concentrations of maize and for nitrogen concentration at the 5 percent probability level (Appendix A, Table A10). Leaf phosphorus, calcium, magnesium, copper, iron, molybdenum, manganese, and zinc concentrations of maize were significantly lower during the second growing season than in the third cropping season (Table 14).

A significant effect of bean density on leaf nutrient concentrations was noted for calcium and boron concentrations of maize at the 5 percent probability level (Appendix A, Table A10). Calcium and boron concentrations of maize were generally higher at 100,000 bean plants/ha than at 200,000 plants/ha. Cultivar x density interaction was significant ($p < 0.05$) for leaf phosphorus and boron concentrations of maize. Maize associated with 100,000 Carioca plants/ha had significantly higher leaf phosphorus and

Table 14. Leaf Nutrient Concentration of Maize as Affected by Year, Bean Cultivar, and Bean Density in the Associated Culture.

		Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha)			
		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca
Nitrogen (gm/kg)	1984	23	26	28	23
	1985	30	32	28	28
	1986	34	34	27	29
Column Mean		29	31	28	27
				CV (%)	21.5
Phosphorus (gm/kg)	1984	4^c	5^b	4^c	4^c
	1985	4^c	4^c	4^c	4^c
	1986	5^b	6^a	5^b	5^b
Column Mean		4	5	4	4
LSD (0.05)	0.6			CV (%)	10.5
Potassium (gm/kg)	1984	23	25	22	22
	1985	20	22	21	22
	1986	24	27	25	25
Column Mean		22	25	23	23
				CV (%)	13.8
Calcium (gm/kg)	1984	8	8	7	7
	1985*	7	6	6	7
	1986	8	10	8	8
Column Mean		8	8	7	7
				CV (%)	12.8

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 14 (cont'd.).

Trait	Year	Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Magnesium (gm/kg)	1984	5	5	5	5
	1985*	5	4	4	4
	1986	5	5	5	5
Column Mean		5	5	5	5
				CV (%)	14.3
Boron (mg/kg)	1984	12^{ab}	13^{a}	12^{ab}	11^{bc}
	1985	12^{ab}	12^{ab}	11^{bc}	11^{bc}
	1986	9^{d}	11^{bc}	10^{cd}	9^{d}
Column Mean		11	12	11	10
LSD (0.05)	2			CV (%)	11.5
Copper (mg/kg)	1984	16	16	14	15
	1985*	12	14	13	13
	1986	17	20	18	19
Column Mean		15	17	15	16
				CV (%)	11.6
Iron (mg/kg)	1984	130	140	128	124
	1985*	105	109	101	108
	1986	141	161	146	145
Column Mean		125	137	125	126
				CV (%)	9.0

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

Table 14 (cont'd.).

		Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha)			
		100		200	
Trait	Year	Domino	Carioca	Domino	Carioca
Molybdenum (mg/kg)	1984	5.2	5.4	4.8	5.1
	1985*	4.4	4.1	4.1	4.5
	1986	6.1	6.9	6.3	6.2
Column Mean		5.2	5.5	5.1	5.3
				CV (%)	11.3
Manganese (mg/kg)	1984	41^{cd}	48^{c}	39^{d}	40^{cd}
	1985	17^{e}	20^{e}	18^{e}	20^{e}
	1986	63^{b}	74^{a}	60^{b}	66^{ab}
Column Mean		40	47	39	42
LSD (0.05) 9				CV (%)	14.5
Zinc (mg/kg)	1984	60	62	57	57
	1985*	44	47	46	50
	1986	72	79	73	69
Column Mean		59	63	59	59
				CV (%)	14.9

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level. Year marked with an asterisk (*) is significantly ($p < 0.05$) different from other years.

boron concentrations than at 200,000 Carioca plants/ha during the first and third growing seasons (Table 14). Year x cultivar, year x density, and year x cultivar x density interactions for the concentration of maize leaf nutrient were not significant (Appendix A, Table A10).

The comparison of leaf nutrient concentration of maize in associated culture and monoculture systems indicated that leaf nitrogen, potassium, calcium, magnesium, copper, and zinc concentrations of maize did not differ significantly (Table 15). However, significant differences were observed in leaf phosphorus, boron, iron, molybdenum, and manganese concentrations of maize at the 5 percent probability level. Leaf phosphorus concentration of maize in monoculture was significantly lower than the concentration in maize leaves produced in association with Carioca at 100,000 plants/ha in the third cropping season (Table 15). Similarly, boron concentration of maize leaf in association with Carioca at the lower density in the first growing season was significantly higher than leaf boron concentration of maize under monoculture (Table 15).

On the other hand, leaf iron and molybdenum concentrations of maize in the monoculture were either not significant or significantly higher as compared with corresponding values in associated culture. Leaf manganese concentration of maize in the monoculture and in associated culture were not significant in the first two growing seasons, while in the third cropping season, manganese

Table 15. Leaf Nutrient Concentration of Maize as Affected by Year, Bean Cultivar, and Bean Density in the Two Cropping Patterns.

			Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha)			
		Sole Maize Stand	100		200	
Trait	Year	(40,000 pl/ha)	Domino	Carioca	Domino	Carioca
Nitrogen (gm/kg)	1984	29	23	26	28	23
	1985	26	30	32	28	28
	1986	32	34	34	27	29
Column Mean		29	29	31	28	27
					CV (%)	23.1
Phosphorus (gm/kg)	1984	5^b	4^c	5^b	4^c	4^c
	1985	4^c	4^c	4^c	4^c	4^c
	1986	5^b	5^b	6^a	5^b	5^b
Column Mean		5	4	5	4	4
LSD (0.05)	0.6				CV (%)	9.6
Potassium (gm/kg)	1984	25	23	25	22	22
	1985	19	20	22	21	22
	1986	28	24	27	25	25
Column Mean		24	22	25	23	23
					CV (%)	12.9
Calcium (gm/kg)	1984	8	8	8	7	7
	1985	8	7	6	6	7
	1986	9	8	10	8	8
Column Mean		8	8	8	7	7
					CV (%)	13.6

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 15 (cont'd.).

Trait	Year	Sole Maize Stand (40,000 pl/ha)	Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Magnesium (gm/kg)	1984	5	5	5	5	5
	1985	5	5	4	4	4
	1986	5	5	5	5	5
Column Mean		5	5	5	5	5
					CV (%)	14.5
Boron (mg/kg)	1984	11^{bc}	12^{ab}	13^{a}	12^{ab}	11^{bc}
	1985	10^{cd}	12^{ab}	12^{ab}	11^{bc}	11^{bc}
	1986	10^{cd}	9^{d}	11^{bc}	10^{cd}	9^{d}
Column Mean		10	11	12	11	10
LSD (0.05)	2				CV (%)	11.3
Copper (mg/kg)	1984	16	16	16	14	15
	1985	13	12	14	13	13
	1986	20	17	20	18	19
Column Mean		16	15	17	15	16
					CV (%)	12.9
Iron (mg/kg)	1984	144^{b-d}	130^{d-f}	140^{c-e}	128^{e-g}	124^{f-h}
	1985	113^{g-i}	105^{i}	109^{hi}	101^{i}	108^{i}
	1986	159^{ab}	141^{c-e}	161^{a}	146^{a-c}	145^{b-d}
Column Mean		139	125	137	125	126
LSD (0.05)	15				CV (%)	8.4

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

Table 15 (cont'd.).

Trait	Year	Sole Maize Stand (40,000 pl/ha)	Maize (40,000 pl/ha) Intercropped with: Bean Density (10^3 pl/ha) 100 Domino	100 Carioca	200 Domino	200 Carioca
Molybdenum (mg/kg)	1984	5.9^{b-d}	5.2^{c-f}	5.4^{b-e}	4.8^{e-g}	5.1^{d-f}
	1985	4.4^{e-g}	4.4^{e-g}	4.1^{g}	4.1^{g}	4.5^{e-g}
	1986	6.9^{a}	6.1^{a-c}	6.9^{a}	6.3^{ab}	6.2^{ab}
Column Mean		5.7	5.2	5.5	5.1	5.3
LSD (0.05)	0.9				CV (%)	12.1
Manganese (mg/kg)	1984	47^{d}	41^{d}	48^{d}	39^{d}	40^{d}
	1985	15^{e}	17^{e}	20^{e}	18^{e}	20^{e}
	1986	73^{ab}	63^{bc}	74^{a}	60^{c}	66^{a-c}
Column Mean		45	40	47	39	42
LSD (0.05)	10				CV (%)	16.3
Zinc (mg/kg)	1984	68	60	62	57	57
	1985	48	44	47	46	50
	1986	78	72	79	73	69
Column Mean		65	59	63	59	59
					CV (%)	14.1

Note: Numbers with the same letter(s) are not significantly different from each other at the 0.05 level.

concentration of maize leaves produced in monoculture was either not significant or significantly higher than in the intercropping systems (Table 15).

CHAPTER 5

DISCUSSION

5.1. Bean Performance in the Two Cropping Systems

In Carioca, nodes per plant, stem thickness, and plant height appeared to decrease with increasing plant density. On the other hand, pods/m^2, leaf area index, biomass, and seed yield increased with increasing plant density although seed yield was not significantly affected (Table 16.1), as reported by Edje and Laing (1982) and Mmbaga et al. (1982). Seeds per pod and hundred seed weight did not differ significantly despite varying bean densities, indicating that shading due to maize and bean density did not affect the performance of these two yield components. Beans were able to compensate for these yield components.

Similarly, stem thickness and nodes per plant in Domino decreased as the bean density increased, indicating that plant competition for light and moisture was greater at higher bean densities as compared to lower ones (Table 16.2). Furthermore, shading might cause development of thinner and smaller leaves compared to monocultural leaves, thus reducing the volume of photosynthetic cells per leaf (Wilson and Cooper, 1960). Shading of beans by maize plants during later growth probably reduced the supply of photosynthate for the developing seed (Fisher, 1979). However, plant height, seeds per pod, harvest index, and hundred seed weight in Domino were not greatly affected by maize shading

Table 16.1. Comparison of Carioca Traits in Monoculture and in Associated Culture.

	Cropping Systems						
	Monocultural Carioca	Intercropped Carioca Densities (10^3 pl/ha)					
Traits	200	100	% of Monoculture	150	% of Monoculture	200	% of Monoculture
Stem Thickness (cm)	0.51	0.48	(94)	0.45	(88)	0.42	(82)
Nodes/Plant	14	14	(100)	13	(93)	13	(93)
Plant Height (cm)	79	83	(105)	79	(100)	73	(92)
Relative Light Interception (%)	53	23	(43)	28	(53)	27	(51)
Pods/m^2	297	90	(30)	105	(35)	112	(38)
Seeds/Pod	6.8	6.3	(93)	6.0	(88)	6.3	(93)
Leaf Area Index	3.0	1.9	(63)	2.0	(67)	2.3	(77)
Biomass (g/m^2)	376	131	(35)	164	(44)	178	(47)
Seed Yield (kg/ha)	2408	768	(32)	776	(32)	887	(37)
Harvest Index (%)	64	57	(89)	56	(87)	58	(91)
Hundred Seed Weight (gm)	23	24	(104)	23	(100)	23	(100)

Table 16.1 (cont'd.).

	Cropping Systems						
	Monocultural Carioca	Intercropped Carioca Densities (10^3 pl/ha)					
Traits	200	100	% of Monoculture	150	% of Monoculture	200	% of Monoculture
Root Dry Weight (gm/m^2)	10	4	(40)	4	(40)	5	(50)
Stem Dry Weight (gm/m^2)	101	37	(37)	42	(41)	48	(47)
Leaves Dry Weight (gm/m^2)	116	42	(36)	50	(43)	57	(49)
Pods Dry Weight (gm/m^2)	269	75	(28)	91	(34)	89	(33)
Protein (kg/ha)	642	212	(33)			239	(37)
Nitrogen (kg/ha)	103	34	(33)			38	(37)
Phosphorus (kg/ha)	11	3	(27)			4	(36)
Potassium (kg/ha)	30	9	(30)			12	(40)

Table 16.2. Comparison of Domino Traits in Monoculture and in Associated Culture.

	Cropping Systems						
	Monocultural Domino	Intercropped Domino Densities (10^3 pl/ha)					
Traits	200	100	% of Monoculture	150	% of Monoculture	200	% of Monoculture
Stem Thickness (cm)	0.67	0.59	(88)	0.52	(78)	0.49	(73)
Nodes/Plant	14	13	(93)	13	(93)	12	(86)
Plant Height (cm)	53	53	(100)	52	(98)	53	(100)
Relative Light Interception (%)	57	25	(44)	27	(47)	27	(47)
Pods/m^2	305	103	(34)	134	(44)	152	(50)
Seeds/Pod	6.9	6.8	(98)	6.9	(100)	6.7	(97)
Leaf Area Index	3.3	1.8	(54)	2.0	(61)	2.0	(61)
Biomass (g/m^2)	409	156	(38)	182	(44)	190	(46)
Seed Yield (kg/ha)	2430	779	(32)	893	(37)	957	(39)
Harvest Index (%)	60	56	(93)	56	(93)	55	(92)
Hundred Seed Weight (gm)	19	18	(95)	19	(100)	19	(100)

Table 16.2 (cont'd.).

	Cropping Systems						
	Monocultural Domino	Intercropped Domino Densities (10^3 pl/ha)					
Traits	200	100	% of Monoculture	150	% of Monoculture	200	% of Monoculture
Root Dry Weight (gm/m^2)	19.3	7	(36)	8	(41)	9	(47)
Stem Dry Weight (gm/m^2)	103	38	(37)	45	(44)	49	(47)
Leaves Dry Weight (gm/m^2)	113	42	(37)	51	(45)	56	(49)
Pods Dry Weight (gm/m^2)	271	86	(32)	102	(38)	112	(41)
Protein (kg/ha)	662	219	(33)			272	(41)
Nitrogen (kg/ha)	106	35	(33)			43	(40)
Phosphorus (kg/ha)	11	4	(36)			5	(45)
Potassium (kg/ha)	32	11	(34)			13	(41)

and density levels, indicating that these traits were stable even under the less favourable growing conditions and were similar to their monocultural values. Eriksen and Whitney (1984) observed that shading decreased pods per plant, but did not affect plant height and seeds/pod of bush beans significantly. As in Carioca, pods/m^2, biomass and seed yield in Domino, and to a certain extent, leaf area index, increased with increasing bean plant density. This observation indicated that the optimum values of these traits depended greatly on the bean density, being highest at the highest bean density although it might not be significantly different.

Bean stem and leaf dry weights at three bean density combinations with intercropping reached their highest accumulation level during the mid-pod filling phase and declined as physiological maturity was approached (Figures 1 and 2), indicating an assimilate remobilization from these plant parts to the developing pod and seed. Leaf senescence might also contribute to the decline of stem and leaf dry weight at physiological maturity. Since photosynthate transport from the leaves was reduced at this phase of plant development due possibly to aging leaves, the consequence was reduced leaf area index for optimum photosynthesis.

However, weight of roots of both cultivars at different densities under intercropping was similar throughout the reproductive stages (Table 2; Figure 3), indicating that remobilization of dry matter from roots did not play a major role in seed filling and development. It might be more efficient if the plant translocates assimilates from leaves and stems to the developing pods and seeds rather than transfers stored assimilates from roots to the seed. The plant might need more energy to transfer root assimilates to the reproductive organs. Furthermore, it might also be possible that there was limited demand for more assimilates from the roots, indicating that the bean plant in associated culture might have only a few pods and seed and therefore the assimilates from stem and leaves were probably adequate to meet the demands for seed filling. However, bean reproductive organs under monoculture were significantly higher than those in associated culture. Consequently, root assimilates were transferred to pods and seeds and thus root dry weight of both cultivars declined towards physiological maturity.

Burga (1978) indicated a movement of assimilates from leaves to stem and then to the pods. Edje and Laing (1982) observed that in bean-maize association bean dry matter distribution for leaves, stems, and pods was 33, 45, and 2 percent, respectively, while monocultural dry matter distribution was 41, 33, and 4 percent, respectively at 58 DAP. Adams et al. (1978) indicated that the inability of remobilization of starch from roots and stems could result in low rates of seed filling and consequently low seed yield. Roots accumulated 45 percent of the translocated C^{14} throughout the life of the node four leaf (Waters et al., 1980). About 80 percent of the C^{14} activity exported from node eight at flowering was in the middle and upper stem sections, but during pod-filling over 85 percent moved into the pods and less than 1 percent to the nodulated root system (Waters et al., 1980).

Seed yields of bean in associated culture ranged from 29 to 34 percent and 28 to 35 percent of their monocultural yields for Domino and Carioca, respectively, for the 1984 growing season. However, seed yield of Domino for the second cropping season ranged from 49 to 59 percent while seed yield of Carioca was only 48 percent of their seed yield under monoculture at different bean densities. In the third growing season, seed yield of both cultivars grown in association with maize ranged from 25 to 34 percent of their seed yield under monoculture. Francis et al. (1982b) noted that simultaneous sowing resulted in a 51 and 31 percent yield reduction for beans and maize, respectively.

Seed yields of bean in associated culture in the second and third cropping seasons were less than a metric ton, possibly due to moisture shortage in 1985 and common blight outbreak in the 1986 growing season. The unfavourable growing conditions in 1985 occurred just after the bean flowering stage and caused flower and pod abortion and greatly reduced seed yield to one-half or even to one-third the yield of the 1984 cropping season. Lack of moisture in the 1985 growing season also drastically reduced leaf area index (40-50 percent), biomass (40-50 percent), and pods/m^2 as compared to the 1984 season, resulting in reduced bean seed yield. Common blight infestation on beans in the 1986 season had a similar effect on bean seed yield. Moisture stress during the 1985 cropping season slightly affected the uptake of bean leaf manganese, calcium, and magnesium though it was not significantly different from the other growing seasons (except for manganese). Since magnesium is a component of the chlorophyll molecule, the photosynthesis rate might be reduced because of a reduced chlorophyll per unit area, leading to lower assimilates for seed filling. A similar trend for magnesium was observed in the third growing season (Table 9). Leaf molybdenum in the second season was significantly lower than in other cropping seasons, indicating that bean root nodule ability to fix atmospheric nitrogen was probably adversely affected because molybdenum plays an essential role in N fixation. Nevertheless, macro and micronutrients were sufficient for normal growth and development and therefore could not be responsible for the low yields produced in the second and third seasons.

Bean seed protein, N, P, and K yields in monoculture during the first and third growing seasons were three-fold higher than their yields in associated culture, possibly due to high yield components associated with the monocultural system. Seed yield of bean was positively and significantly correlated (0.339,* 0.785,** 0.886,** 0.902**) with seeds per pod, leaf area index, biomass, and pods/m^2, respectively, indicating that these traits probably

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*Indicates significance at the .05 level.

**Indicates significance at the .01 level.

contributed to the final seed yield. Bean seed yield was negatively, though not significantly, correlated (-0.220) with seed protein concentration. As expected, biomass was negatively and significantly correlated (-0.263*), with bean percent protein, whereas biomass was positively and significantly correlated (0.306,* 0.842,** 0.842**) with seeds per pod, LAI, and pods/m^2, respectively. Hundred seed weight was positively but not significantly correlated (0.135, 0.033) with seed yield and biomass, respectively, indicating that the final seed yield was not closely related to this yield component.

As pointed out earlier, leaf area index of the 1985 and 1986 cropping seasons was significantly less (with few exceptions) than in the first (1984) growing season (Table 3). Maize shading and perhaps other competitive interactions resulted in reduced bean leaf area index by 39 to 46 percent for Domino (type II) and by 23 to 37 percent for Carioca (type III) as compared to their monocultural values. Reduced leaf size might have intercepted less light for photosynthesis, thus indicating that assimilates were limited for seed filling and development, and consequently resulted in reduced seed yield.

Clark and Francis (1985) observed 31 and 22 percent leaf area index reduction by maize associated with bush and climbing cultivars, respectively. They obtained leaf area indices of 3.1 and 3.9 for intercropped and monocropped bush beans, respectively, while LAI of climbing beans was 3.6 and 4.1 for mixture and monocultural beans, respectively. However, the highest LAI obtained from maize/Domino was 2.6 compared with monocultural value of 4.2 while Carioca-maize highest bean LAI was 3.3 and monocultural value was 4.3. Leaf area index of less than 3 might signal a marked reduction of leaf surface area for light interception and photosynthesis sufficient to result in a low bean seed yield. A leaf area index range of 3 to 4 appears to be ideal for adequate photosynthesis. However, LAI values greater than 4 could possibly create shading atmosphere which might reduce the amount of intercepted light for photosynthesis. Gardiner and Craker (1981) obtained LAI ranging from 3.70 to 4.49 for intercropping and monocultural beans, respectively.

Biomass was also reduced during the last two cropping seasons, indicating that bean dry matter accumulation was limited for proper plant growth and development and a reduced biomass yield was reflected by a reduced seed yield for the last two growing seasons (Table 3). Figures 4-8 show the relationship between bean seed yield and bean biomass yield, pod/m^2, and LAI; relation between biomass and pod/m^2, and LAI over three densities. As the biomass yield increased, so did the seed yield, indicating that optimum biomass production during the vegetative stage would be a prerequisite for improved pods/plant, seeds/pod, seed size, and ultimately increased seed yield. Consequently, seed yield of bean in associated culture decreased possibly due to reduced leaf area index, reduced light interception, biomass yield, and pods/plant.

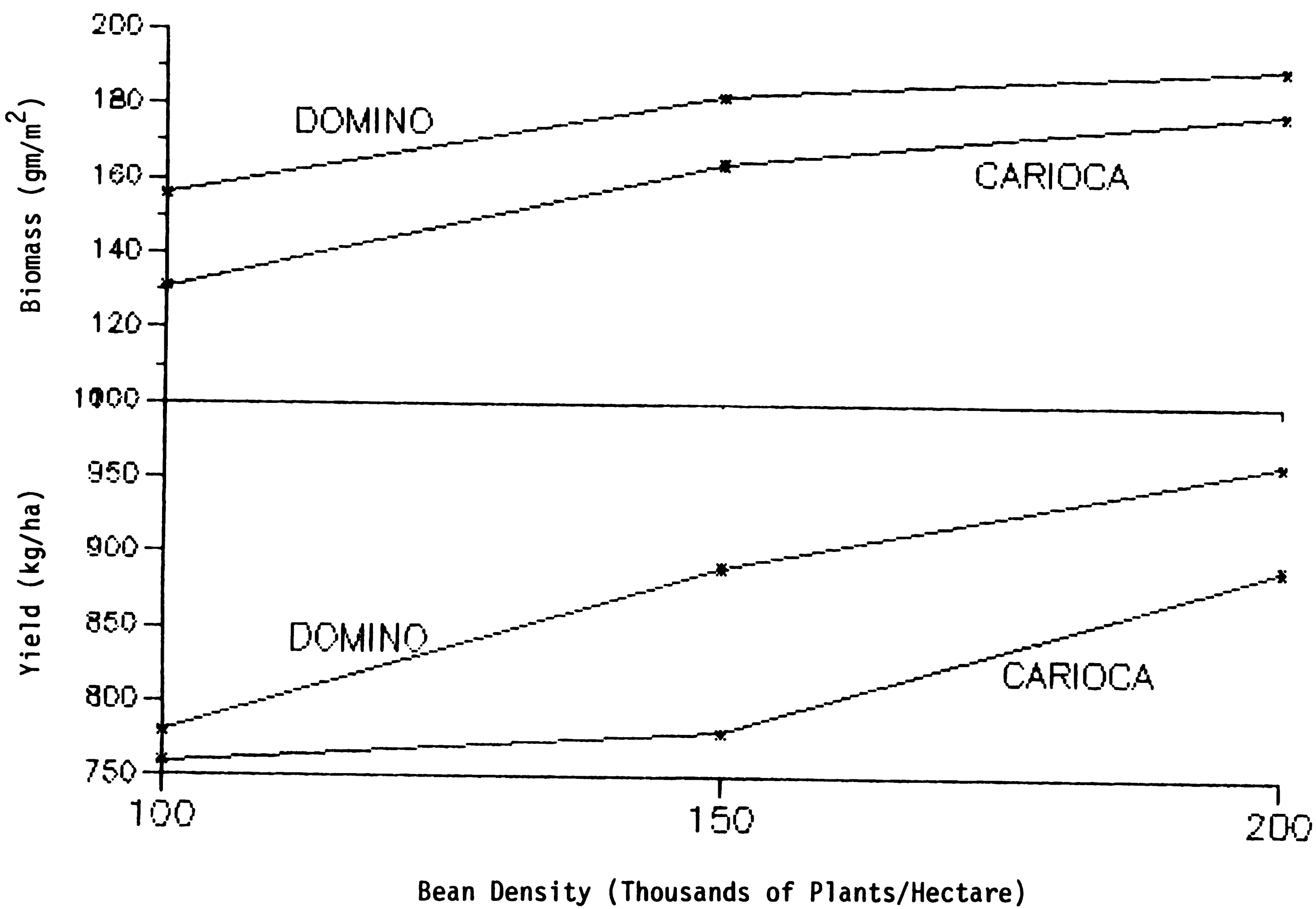


Figure 4. Yield and Biomass of Bean at Different Densities

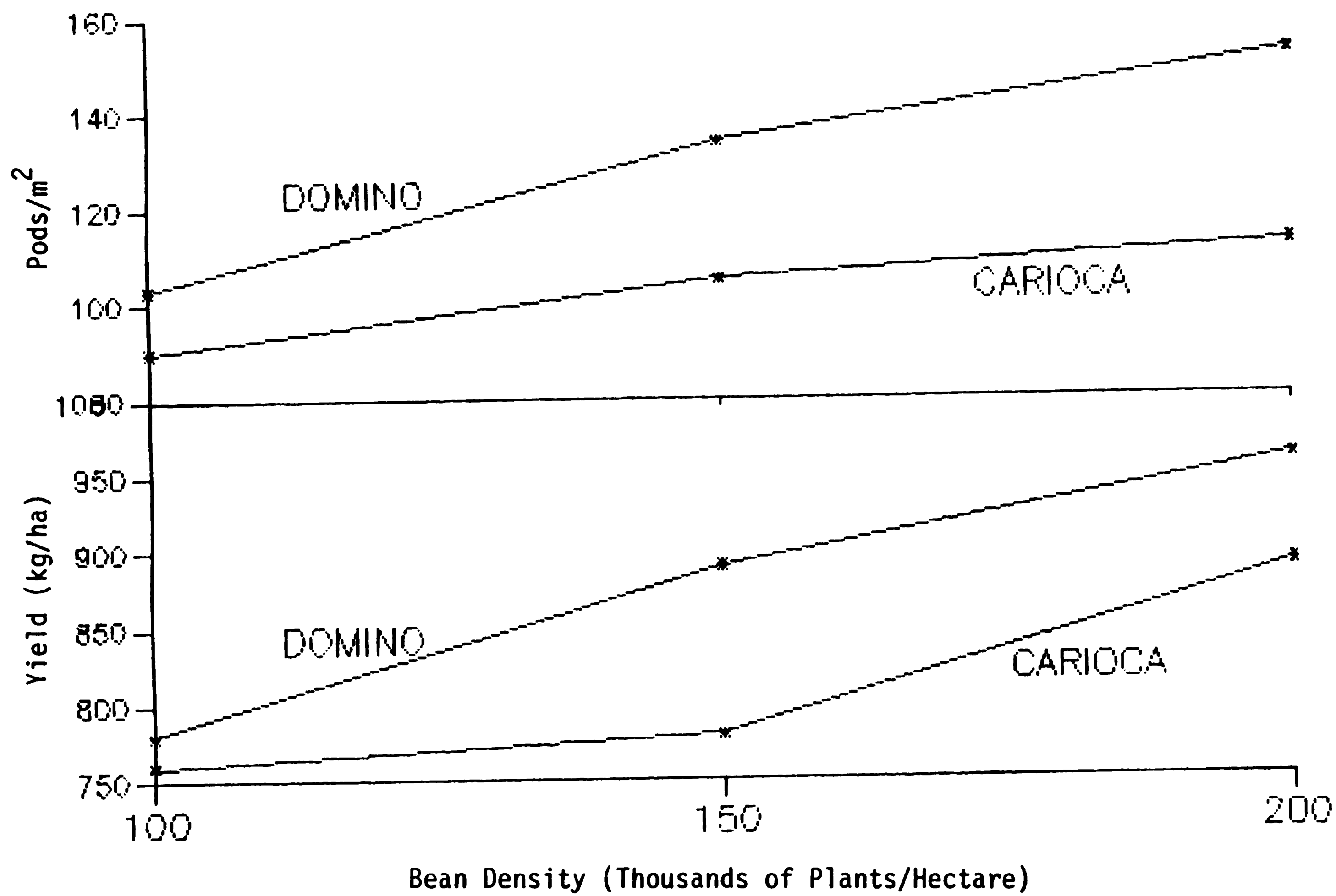


Figure 5. Yield and Pods of Bean at Different Densities

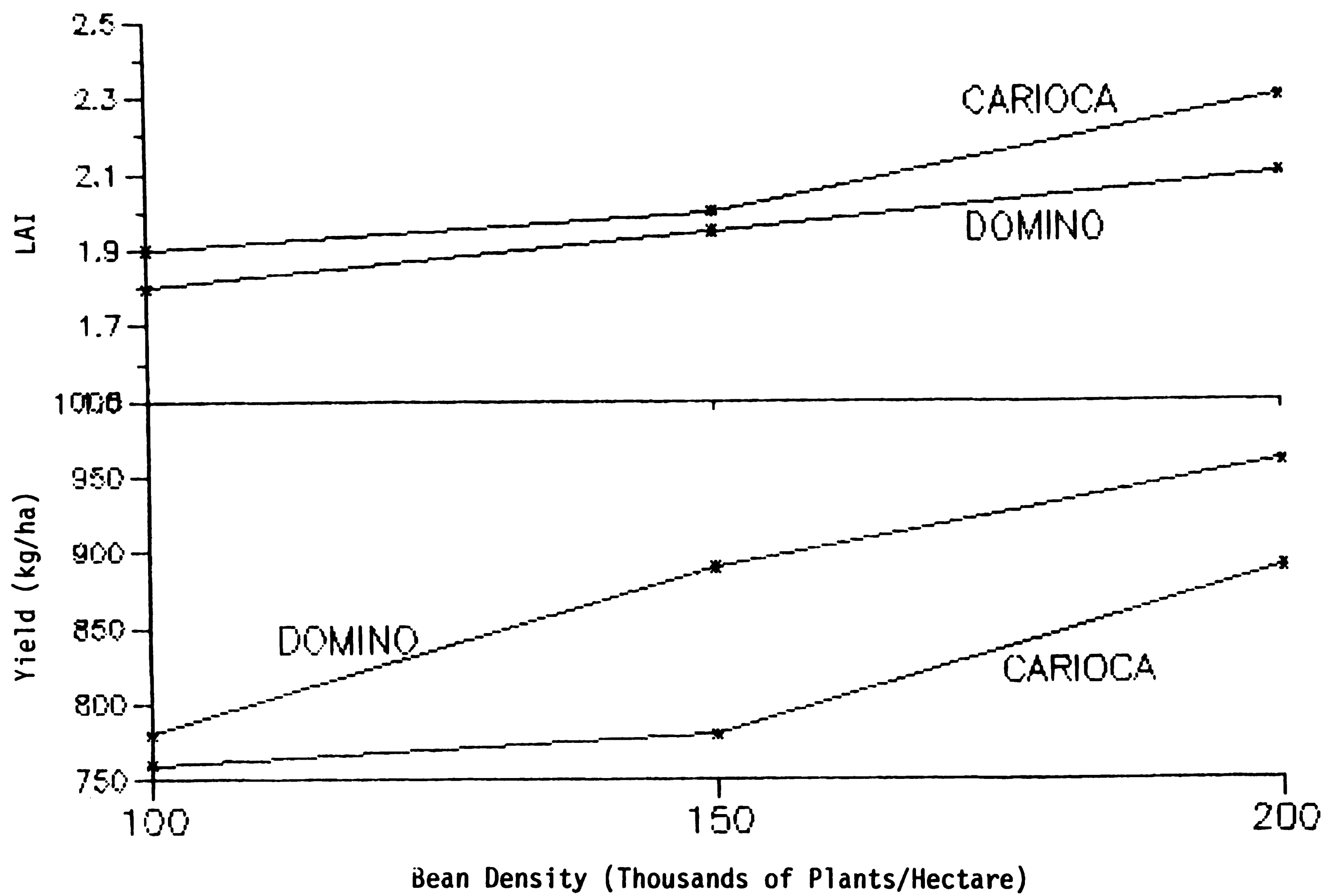


Figure 6. Yield and Leaf Area Index of Bean at Different Densities

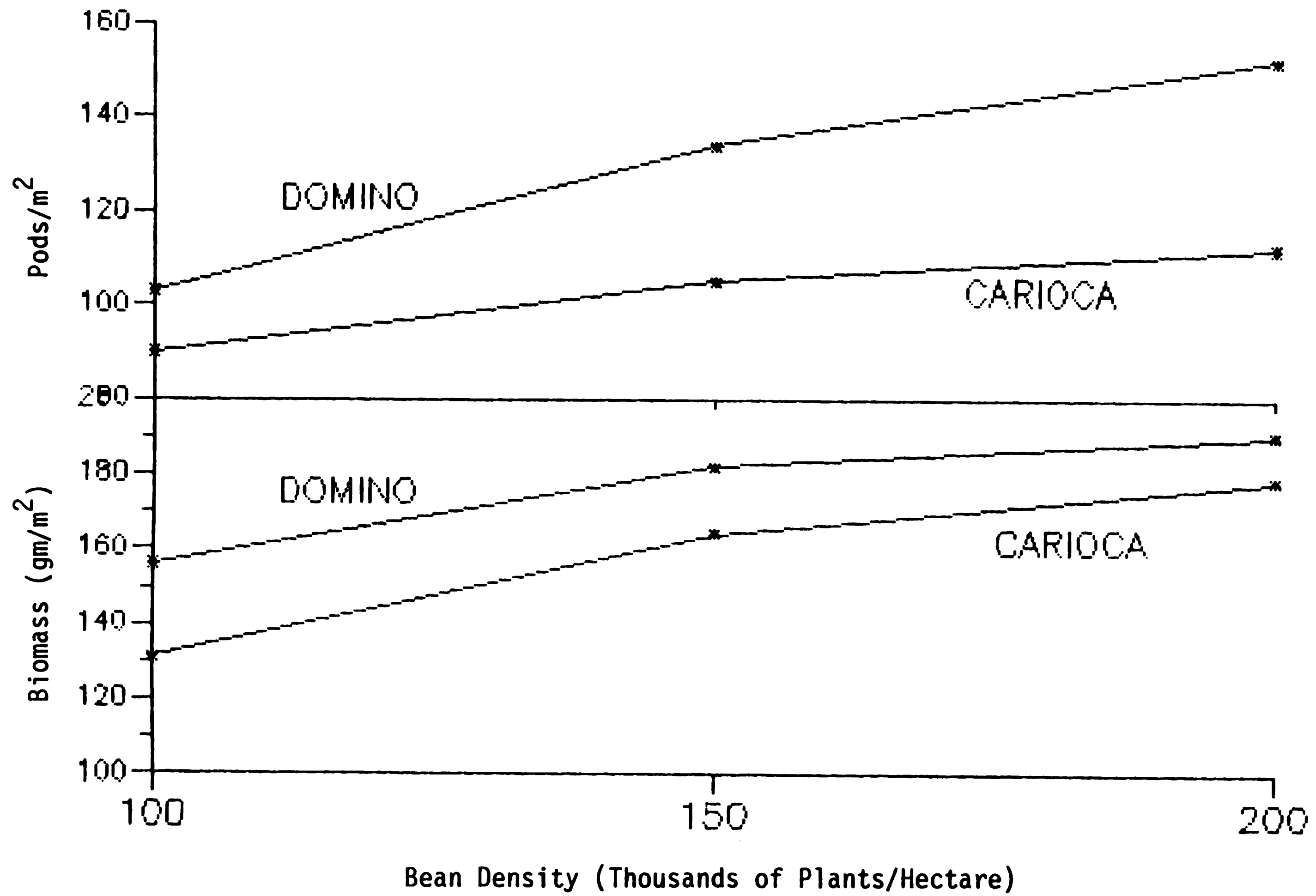


Figure 7. Biomass and Pods of Bean at Different Densities

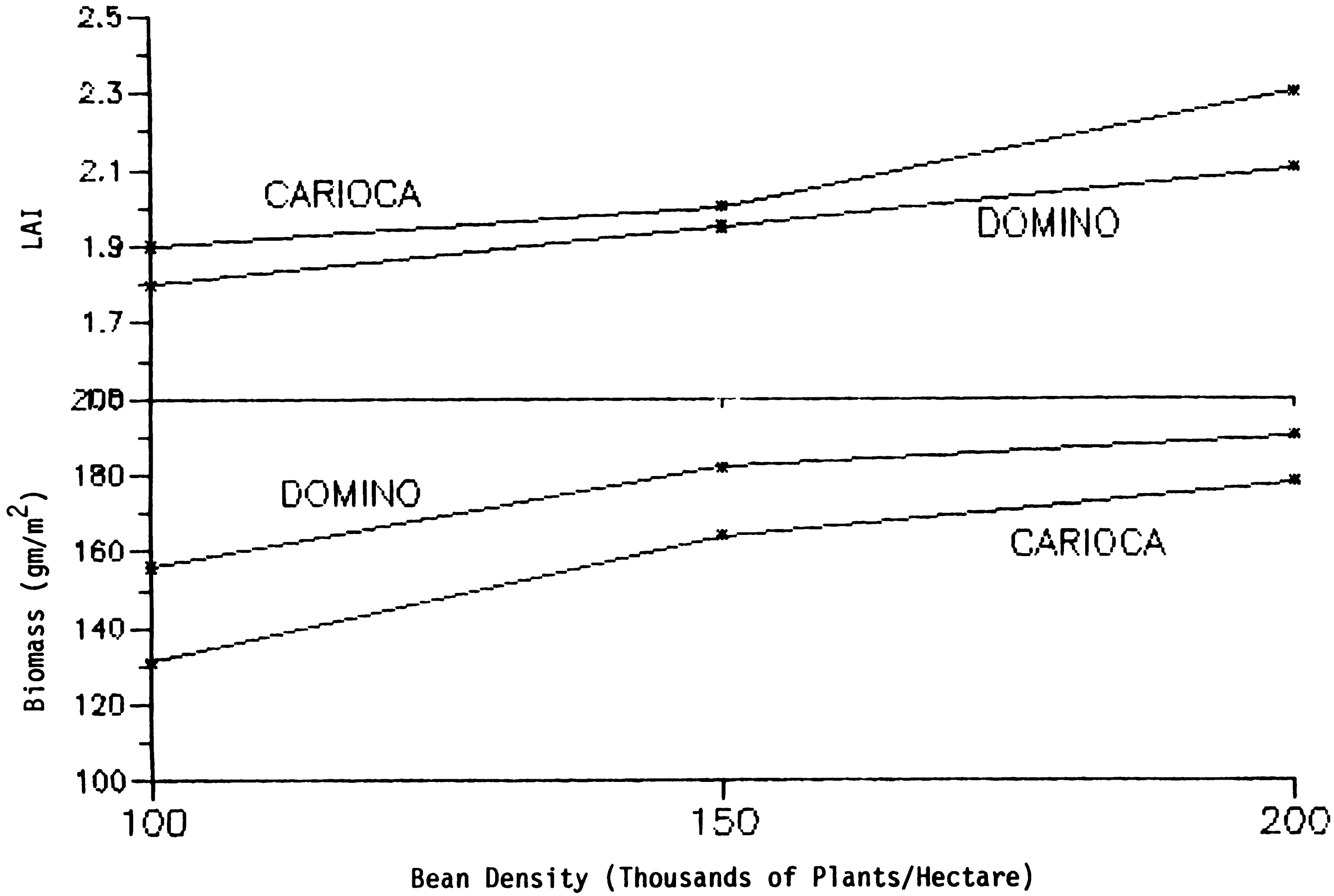


Figure 8. Biomass and Leaf Area Index of Bean at Different Densities

The relative light interception for Domino in association was between 44 and 47 percent of its light interception in monoculture (Table 16.2). The relative light interception of Carioca ranged from 43 to 53 percent of the light readings under monoculture (Table 16.1). This observation indicated that limited light might have resulted in a reduced rate of photosynthesis. Limited light led to reduced seed yield, possibly due to limited assimilates for plant growth, development, and seed filling. Consequently, beans in association with maize had a lower number of pods/plant, biomass yield, and economic seed yield. Similarly, roots, stems, and leaf dry matter accumulation for the two bean cultivars were between 36 and 50 percent of their monocultural dry weight (Tables 16.1 and 16.2), indicating that the environment created by the presence of maize as a companion crop greatly reduced the expression of these traits.

The reduction in mean dry matter produced by beans in association with maize was probably due to reduced light interception resulting from maize shading and probably due to competition for available soil moisture. The shading of bean plants by maize could have limited the amount of light that was available for intercropped bean, resulting in a reduced rate of photosynthesis and consequently reduced seed yield. Fisher (1979) observed that beans intercropped with maize never intercepted more than 30 percent of the light. Therefore, limited assimilates affected plant size and yield-related traits.

Harvest index (HI) of intercropped beans ranged from 53 to 59 percent while HI of monocultural bean was between 59 and 65 percent. However, HI range did not reflect a predictable trend. In most cases, highest HI corresponded with high seed yield. In a few observations, high yielding treatment combinations (953 kg/ha) showed the lowest HI (53 percent) while seed yield of 623 kg/ha had a HI of 58 percent. This observation indicated that HI might not be a reliable selection index for identifying new breeding lines, a view shared by Zimmermann et al. (1984). A negative correlation between grain yield and harvest index was reported by Laing et al. (1980). Clark and Francis (1985) obtained a HI for bush beans ranging from 52 to 56 percent in associated and monocultural systems, respectively. Harvest index for climbing beans ranged from 58 to 62 percent for intercropping and monocultural systems, respectively (Clark and Francis, 1985).

5.2. Bean Carbohydrate Concentration

Bean root, stem, and leaf carbohydrates in the second (1985) season were generally higher than the 1984 and 1985 seasons. The results in 1985 could possibly be a consequence of the reduced pod number/plant induced by the severe drought which occurred after flowering. Seed yields of Domino and Carioca grown in monoculture in 1985 were 1,562 and 1,357 kg/ha, respectively, compared to 3,271 and 3,483 kg/ha, respectively, for 1984 and 2,456 and 2,384 kg/ha, respectively, for 1986. The reduced reproductive sink in 1985 may have led to a higher carbohydrate accumulation in root and stem tissues as compared with the other two seasons. Leaf carbohydrate concentrations in the monoculture and intercropping systems were not significantly different and were lower than root and stem concentrations. This observation indicated that leaves rarely stored the synthesized carbohydrate but instead they constantly translocated newly synthesized products to stem, pods, seeds, and roots for storage.

Root TNC in Domino for the two cropping systems in 1985 was significantly higher (except one treatment) than for Carioca within the same season, indicating that Domino may be more tolerant to severe rainfall shortage, possibly due to a stronger and deeper root system than Carioca. Root dry weight of Domino in monoculture (Table 2) was two-fold the dry weight of Carioca under monoculture. Consequently, it is postulated that Domino was able to obtain moisture from deeper in the soil profile for increased photosynthesis and therefore produced significantly higher root TNC than Carioca within the same season. Furthermore, seed yield of Domino was slightly higher than for Carioca (Table 3), although the yield difference was not significant. Domino's higher yield provided further evidence that it might be a more useful cultivar in drought-prone areas than Carioca. However, consumers, particularly in Eastern Africa, might not prefer the seed size, colour, and flavour of Domino.

Correlation analysis for three seasons indicated that bean seed yield was positively but not significantly correlated with root carbohydrate. Stem and leaf carbohydrates were non-significantly and negatively correlated with bean seed yield. The correlation results indicated that there was an increased pod number/plant (1984) which remobilized and depleted stored root and stem carbohydrates (sink capacity exceeded the source capacity) for seed filling, resulting in increased seed yield. On the other hand, there was a reduced sink capacity in 1985 due to moisture shortage which resulted in high stored carbohydrate in stem and roots. It appeared that pod abortion was more sensitive to drought stress in 1985 than photosynthesis. As a result, root and stem tissues accumulated high amounts of carbohydrate because sink capacity was a limiting factor, resulting in reduced seed yield. In both cases, seed yield might be poorly correlated with root and stem carbohydrates.

High pod number/plant accompanied by high rates of carbohydrate storage and remobilization from root and stem tissues for seed filling might strike a balance and increase seed yield. Increased availability of carbohydrate within the plant tissues would be required for increased seed yield. Sinclair and de Wit (1976) observed that soybeans are self-destructive since they need to translocate large amounts of nitrogen from vegetative tissues during seed-fill to promote protein formation and seed growth. They further noted that increased nitrogen supply lengthens the period of seed development and results in substantial soybean yield increases. Screening and selecting bean cultivars with high translocatable root and stem TNC might be a step in the right direction in the immediate future in order to increase bean seed yield in the two cropping systems.

5.3. Performance of Maize in the Two Cropping Systems

Neither environmental effects, bean cultivars, nor bean densities affected hundred maize kernel weight, indicating that maize was competitive and efficient in obtaining the essential resources for proper growth and development. Since bean cultivars were approaching physiological maturity, were shorter, less vigorous, and with less root distribution than maize, maize grain size in monocultural maize was not significantly different from grain size of the intercrop maize. This observation indicated that the competitive ability of maize for both above and below ground resources was superior to that of the bean cultivars.

On the other hand, resources were probably not limiting for growth and development of the maize. Consequently, maize yields in monoculture for the first and the third growing seasons were not significantly different from maize yield in association (with the exception of two maize/Domino combinations which were significantly lower than maize yield under monoculture). Furthermore, grain yield of maize was not significantly affected by bean cultivars and bean densities, probably because the two crop species had different growth durations and therefore wide competitive gap. Thus, each crop reached a peak demand for resources at different times, indicating that maize obtained adequate resources for kernel filling and development at the time when beans were approaching physiological maturity, an observation supported by Enyi (1973).

However, moisture stress of the 1985 cropping season affected maize yield in association with beans, presumably due to lack of adequate soil moisture for normal growth and development of maize plants. Maize yield in associated culture was significantly lower than yield of sole maize stand, probably due to a lower monocultural maize plant stand for the available soil moisture (40,000 plants/ha) as compared to that of associated culture (140,000, 190,000, and 240,000 plants/ha) of beans and maize combined. Nutrient concentration in both cropping systems was adequate for grain filling and normal plant development and therefore could not have contributed to lower grain yield of maize in association. Bean cultivars were shorter than maize and therefore would not interfere with light interception of maize leaf. Consequently, limited soil moisture and bean density pressure probably contributed to reduced maize yield in the intercrop system during the second (1985) growing season as compared to the 1984 and 1986 growing seasons (Table 11).

Maize yield during the 1984 cropping season was 25-30 percent lower than the maize yield of the 1986 growing season, probably due to continuous rainfall during the tasselling stage from which the consequences were fewer kernal numbers/cob and lower grain yield as compared to the 1986 growing season. Kernal number/cob was about 70 percent that of the 1986 kernal number/cob. However, seed size did not differ significantly from the other cropping seasons. Mean yields of maize in the third season were significantly higher than those of the first two seasons, further indicating that poor growing conditions in the first two seasons were responsible for reduced grain yields of maize. A three-year average grain yield indicated that yields of maize were reduced by 15, 14, and 15 percent when maize was intercropped with Domino at 100,000, 150,000, and 200,000 plants/ha, respectively (Table 17.1).

The maize-Carioca combination at 100,000, 150,000, and 200,000 plants/ha of beans reduced grain yield of maize by 14, 13, and 15 percent, respectively, as compared with monocultural maize. Davis and Garcia (1983) observed 15-30 percent maize yield reduction when intercropped with climbing bean, while Mmbaga (1980) obtained 7-31 percent grain yield reduction compared with monocultural maize yield. Maize partial land equivalent ratio when associated with Domino was 0.85, 0.86, and 0.85 at 100,000, 150,000, and 200,000 bean plants/ha, respectively. The Carioca-maize combination provided maize partial LER of 0.86, 0.87, and 0.85 at the same bean density range, though not significantly different from maize-Domino LER. Furthermore, the efficiency of the two bean cultivars in combination with maize peaked at 150,000/40,000 plants/ha of bean/maize, respectively (Tables 17.1 and 17.2, and Figure 9). Any maize-bean combination which would not reduce maize yield (primary crop) and provide substantial bean yield (secondary crop) would be a wise investment, and maize (40,000

Table 17.1. Comparison of Maize Traits in Monoculture and in Associated Culture--Maize/Domino Combinations.

	Cropping Systems						
	Monocultural Maize	Intercropped Maize (40,000 pl/ha) with Domino Densities (10^3 pl/ha)					
Traits	40,000 pl/ha	100	% of Monoculture	150	% of Monoculture	200	% of Monoculture
Plant Height (cm)	195	190	(97)	183	(94)	179	(92)
Protein Yield (kg/ha)	701	591	(84)			590	(84)
Nitrogen Yield (kg/ha)	112	95	(85)			94	(84)
Phosphorus Yield (kg/ha)	38	32	(84)			31	(81)
Potassium Yield) (kg/ha)	33	28	(85)			27	(82)
Hundred Seed Weight (gm)	34	31	(91)	33	(97)	31	(91)
Maize Partial LER	1.00	0.85	(85)	0.86	(86)	0.85	(85)
Land Equivalent Ratio (LER)	1.00	1.20	(120)	1.26	(126)	1.29	(129)
Maize Grain Yield (kg/ha)	7006	5988	(85)	6023	(86)	5984	(85)

Table 17.2. Comparison of Maize Traits in Monoculture and in Associated Culture--Maize/Carioca Combinations.

	Cropping Systems						
	Monocultural Maize	Intercropped Maize (40,000 pl/ha) with Carioca Densities (10^3 pl/ha)					
Traits	40,000 pl/ha	100	% of Monoculture	150	% of Monoculture	200	% of Monoculture
Plant Height (cm)	195	186	(95)	184	(94)	181	(93)
Protein Yield (kg/ha)	701	604	(86)			597	(85)
Nitrogen Yield (kg/ha)	112	97	(87)			96	(86)
Phosphorus Yield (kg/ha)	38	31	(81)			31	(81)
Potassium Yield) (kg/ha)	33	26	(79)			26	(79)
Hundred Seed Weight (gm)	34	32	(94)	32	(94)	32	(94)
Maize Partial LER	1.00	0.86	(86)	0.87	(87)	0.85	(85)
Land Equivalent Ratio (LER)	1.00	1.21	(120)	1.24	(124)	1.25	(125)
Maize Grain Yield (kg/ha)	7006	6028	(86)	6104	(87)	5945	(85)

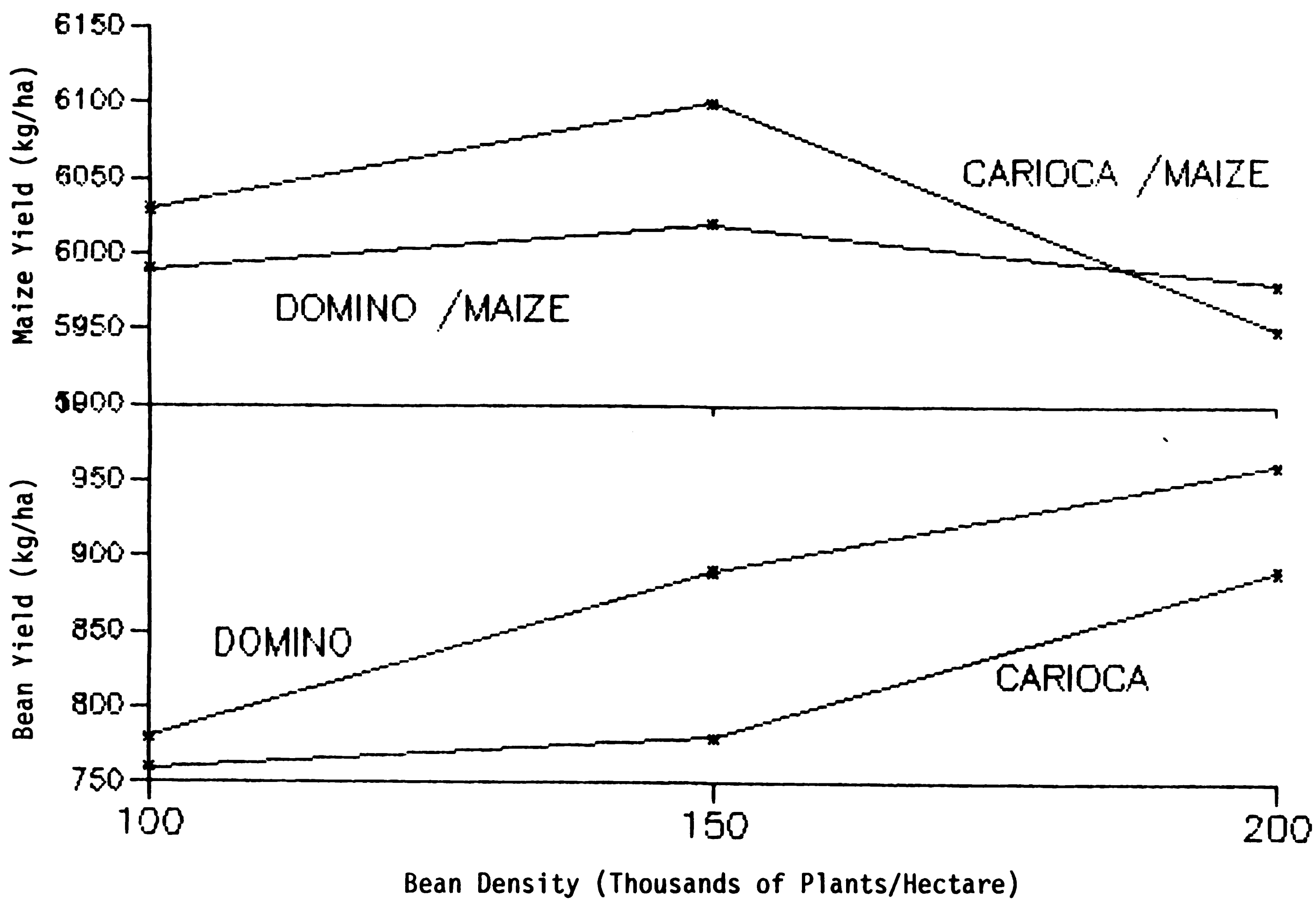


Figure 9. Yield of Bean and Maize at Different Densities

plants/ha) with beans (150,000 plants/ha) met the criteria and consistently offered greater yield than the other density combinations.

Nevertheless, bean yields at the three density levels in association with maize had always been non-significant; the finding agreed with Mmbaga et al. (1982). Since doubling bean density from 10 to 20 plants/m^2 (100,000 to 200,000 plants/ha) had no significant impact on bean seed yield, adopting the high bean density would be a waste of seed which is in limited supply for farmers. High bean density reduced maize plant height, maize grain size (Domino-maize combination), and maize grain yield more than any other bean density combination and would not benefit small holders (Tables 17.1 and 17.2). Planting of high density beans would require more labour and/or time which is also scarce and would not be productive for the farmers. Extra seed could be used for food which is limited or for marketing to earn cash for other household needs.

Recommending 100,000 bean plants/ha would be taken with some reservation since this combination had a slight reduction on land equivalent ratio, maize grain size (maize-Domino), and maize grain yield as compared with 150,000 plants/ha (Tables 17.1 and 17.2). Lower bean density appeared to have stronger root systems and thicker stems and effectively competed with maize roots for soil moisture for growth and development. On the other hand, higher bean densities had weaker root systems and thinner stems than the lower ones. However, due to high plant density, root mass was greatly increased resulting in increased inter- and intra-specific competition for moisture, leading to slightly reduced maize grain yield. At 150,000 bean plants/ha, root development and stem thickness appeared to be optimum and both inter- and intra-specific competition was optimum too. This led to less competition for moisture and consequently to higher maize grain yield than the extreme bean densities, though not significantly different.

Domino stem diameter at 100,000, 150,000, and 200,000 plants/ha was 88, 78, and 73 percent respectively, while Carioca was 94, 88, and 82 percent of their stem thickness in monoculture. In general, Domino stems were thicker than Carioca and the difference was reflected in the three-year maize grain yield being slightly higher in the maize-Carioca combination than maize-Domino intercrops at 15 bean plants/m^2, although the difference was not significant (Tables 17.1 and 17.2). Consequently, a combination of maize (40,000 plants/ha) with beans (150,000 plants/ha) provided a competitive balance between the two crop species and appeared to be superior to the other density combinations (Figure 9) and thus worth recommending to farmers in Tanzania. Nevertheless, combined yields produced from Tanzania might be relatively lower than yields produced in East Lansing due possibly to disease and pest infestation, unfavourable weather, poor soil fertility and crop husbandry, and low yield potential of the indigenous cultivars. Thus, recommendations based on experiments in East Lansing might not be truly appropriate for Tanzanian conditions.

Protein, N, and P yields of maize in monoculture during the first and third cropping seasons were not significantly different from their corresponding maize yields in associated culture (with few exceptions), showing that growing conditions in mixtures were probably not unfavourable for maize growth. Height of maize was significantly and positively correlated (0.598^{**}) with maize grain yield. However, kernel weight and land equivalent ratios were positively but not significantly correlated (0.048, 0.145), respectively, with maize grain yield. In contrast, bean biomass was significantly correlated while bean seed yield was not significantly correlated but both were negatively correlated ($-0.384,^{**}$ -0.199, respectively), with maize grain yield.

Bean densities affected land equivalent ratio (LER) for maize-Domino and maize-Carioca combinations. Land equivalent ratio and bean seed yield increased with the increasing bean densities for both bean-maize combinations, being highest at the highest bean density (200,000 plants/ha). It appeared that intercropping efficiency was determined by bean yield and not by the yield of maize. Mmbaga et al. (1982) observed a similar trend in bean-maize density studies at Lyamungu, Moshi, Tanzania. Highest three-year average intercropping efficiency (LER 1.29) was obtained when maize was intercropped with Domino at 200,000 plants/ha, probably due to efficient use of light and soil resources. High root mass at this density combination of 40,000 maize plants/ha plus 200,000 bean plants/ha was probably able to extract nutrients and moisture from different soil profiles for grain filling and ultimately seed yield.

Furthermore, at this density combination, plants were capable of covering the ground early in the season and possibly intercepted more light for photosynthesis and the stored assimilates were used for plant growth and development and for grain filling. High LAI, which is associated with high bean density, could have shaded the soil and helped control weeds and reduce loss of soil water by evapotranspiration. Soil water saved from evapotranspiration would be beneficial to crop components in association. At the lower plant density combinations, resource waste might have occurred due to less ground cover to capture more light and reduced root mass to exploit soil resources. Land equivalent ratio for the testing period ranged between 1.15 and 1.35, while Mmbaga (1980) obtained LERs ranging from 1.04 to 1.34 at the same location but with different bean and maize cultivars. Intercropping work at Lyamungu, Moshi, Tanzania produced LERs ranging from 0.96 to 1.58 (Mmbaga et al., 1982). Francis et al. (1982) obtained LER values of 1.52, 1.47, and 1.35 when maize was simultaneously intercropped with bean types I, II, and III, respectively.

Combined maize-bean yields were between 6,767 and 6,941 kg/ha while half hectare yields of each monocultural crop ranged only between 4,707 and 4,718 kg/ha. The highest monocultural yield was

7,006 kg/ha (Table 18.1; Figure 10), thus not in keeping with the hypothesis that combined intercrop yield would be higher than the best monocultural yield (Table 18.1). On the other hand, combined intercrop yields of the component crops were higher than their combined monocultural component crop yields (4,707 and 4,718 kg/ha), thus lending support to previous hypotheses (Table 18.1). Bean cultivars provided an appreciable combined maize-bean yield at 40,000/150,000 plants/ha maize-bean density combination, respectively, indicating that the density combination would be sufficiently productive to provide support for the homestead families in developing countries. Francis et al. (1982) obtained highest total grain and protein yields at a density combination of 3 to 4 and 10 to 15 plants/m^2 for maize and beans, respectively. Even though maize yield under monoculture was higher than any intercrop yield combination, an associated culture system is still more important than sole maize stand because mixtures of maize-bean provided high protein yield (Table 18.2). Protein plays an important role in human growth and development and legume seeds are nearly always a component of the human diets in most developing countries. Table 18.2 shows the three-year average of combined maize-bean protein yield ranging from 810 to 870 kg/ha in associated culture, whereas monocultural combined protein yield ranged from 671 to 681 kg/ha. The best monocultural protein yield (701 kg/ha) was always lower than combined protein yield in associated culture, thus supporting the hypothesis that combined yield in association

Table 18.1. Three-Year Average Yield of Bean and Maize as Affected by Bean Density.

Density (10^3 pl/ha)	Intercropped Maize/Bean Combinations kg/ha					
	Domino	Maize	Total	Carioca	Maize	Total
100	779	5988	6767	768	6028	6796
150	893	6023	6916	776	6104	6880
200	957	5984	6941	887	5945	6832
Monoculture	2430	7006	4718*	2408	7006	4707*

*Half monocultural bean and half monocultural maize yield.

Table 18.2. Three-Year Average Protein Yields of Bean and Maize as Affected by Bean Density.

Density (10^3 pl/ha)	Intercropped Maize/Bean Combinations kg/ha					
	Domino	Maize	Total	Carioca	Maize	Total
100	219	591	810	212	604	816
200	272	590	862	239	631	870
Monoculture	662	701	681*	642	701	671*

*Half monocultural bean and half monocultural maize yield.

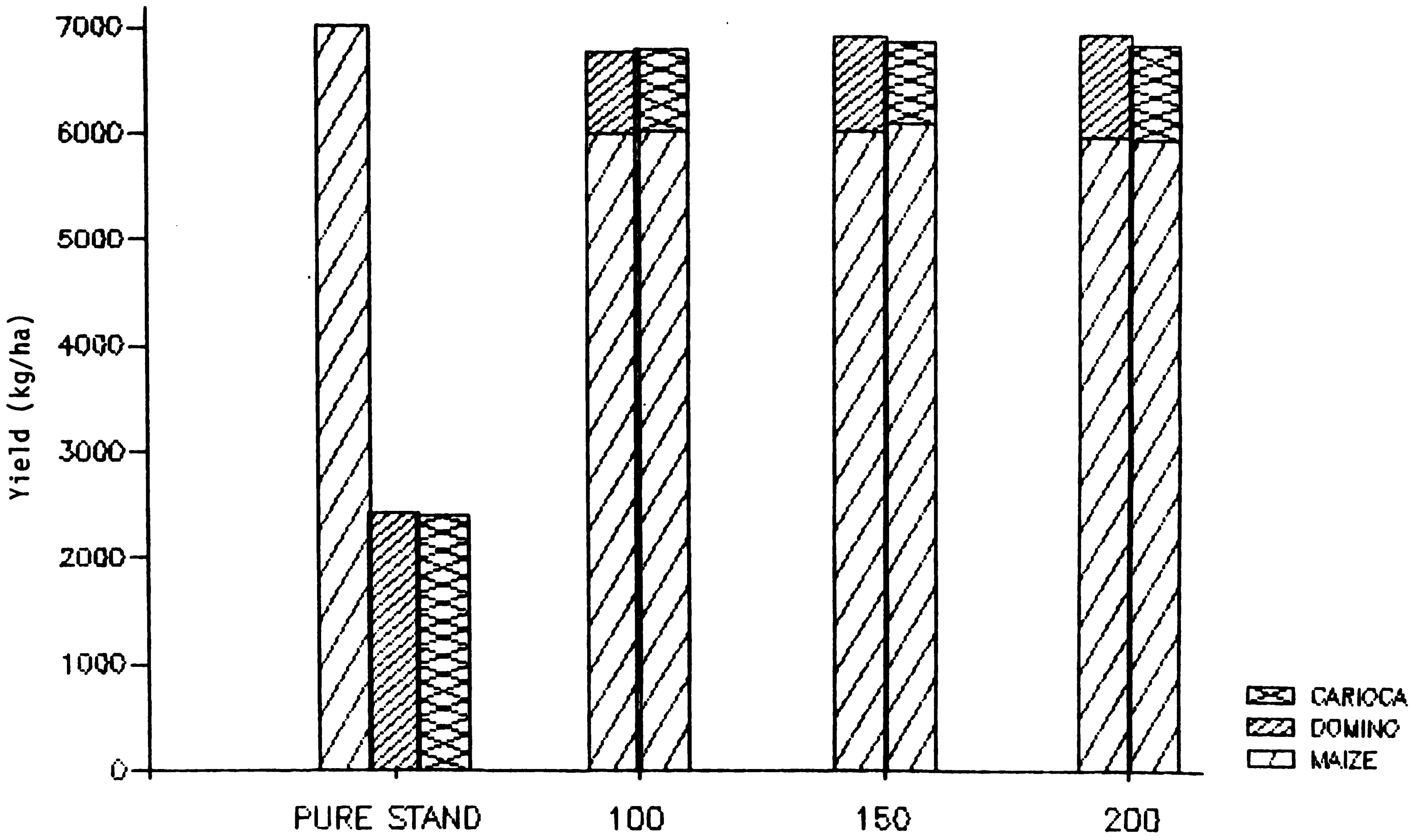


Figure 10. Performance of Bean and Maize in the Two Cropping Systems

would be higher than monocultural component crops or higher than the best monocultural yield due to more efficient use of natural resources.

Latham (1971) indicated that 65 g of protein were required daily for a 55-kg active man. Therefore, protein yield/ha in associated culture would be adequate to feed 34 to 37 adult men for one year while protein yield under monoculture would be enough to feed only 28 to 29 men annually.

$$\frac{810 \text{ kg/ha} \times 1000 \text{ g}}{65 \text{ g} \times 365 \text{ days/year}} = 34 \text{ men} \qquad \frac{870 \text{ kg/ha} \times 1000 \text{ g}}{65 \text{ g} \times 365 \text{ days/year}} = 37 \text{ men}$$

$$\frac{671 \text{ kg/ha} \times 1000 \text{ g}}{65 \text{ g} \times 365 \text{ days/year}} = 28 \text{ men} \qquad \frac{681 \text{ kg/ha} \times 1000 \text{ g}}{65 \text{ g} \times 365 \text{ days/year}} = 29 \text{ men}$$

Mmbaga (1980), in the same location but with different cultivars, obtained protein yields of combined maize-bean in association which were sufficient to feed 39 to 49 men yearly while monoculture produced enough protein to feed only 38 men for the same period. Edje et al. (1979) obtained similar results in their maize-dwarf beans intercrop trials in Malawi. When Domino was intercropped with maize, protein yield was between 810 and 862 compared to monocultural yield of 681 kg/ha, giving protein yield advantage of 19 and 26 percent while the protein advantage obtained from Carioca-maize association (816-870 kg/ha) was 22 to 30 percent higher than the monocultural protein yield (671 kg/ha).

Protein and/or nitrogen content of the maize grain and maize leaf were not significantly different from the monocrop maize, indicating that nitrogen excretion from bean roots and the uptake of the excreted bean nitrogen by maize roots did not occur. However, legume residual N could benefit succeeding non-legume crops. The greatest advantage of the maize-bean association was the increased combined protein yield which was due to a function of high maize yield in addition to bean yield in the intercrop rather than due to nitrogen transfer from legumes to non-legumes within the same growing season. The protein production is essential for daily human needs, especially in the developing world. Intercropping beans with a highly competitive cereal like maize, in addition to high total combined plant densities, might create unfavourable conditions for beans, consequently resulting in failure of beans to fix sufficient atmospheric nitrogen for their growth and development and the additional N for the companion crop. Furthermore, bean cultivars used in this experiment might not have the ability to fix nitrogen under the maize-dominated environment, resulting in reduced bean yield in associated culture.

Graham and Rosas (1978) observed that N_2 fixation by climbing bean (cv. P590) was essentially unaffected by intercropping with maize. Wahua and Miller (1978a, b) noted that shading by the cereal reduced both the seed yield and N_2 fixation. The transfer of N from cowpea to maize in association was not evident from either the field or the greenhouse pot studies by Ofori and Stern (1987). On the other hand, Eaglesham et al. (1981) presented evidence from the field of transfer of N from legume to an intercrop cereal, using the N^{15}-labeled fertilizer method. Nair et al. (1979) found a mean wheat yield increase of about 30 percent after a maize-soybean intercrop, and after maize-cowpea, the yield increase was 34 percent when compared to wheat after sole crop maize. De (1980) found that blackgram intercropped with either maize or sorghum improved succeeding wheat yield. Searle et al. (1981) found N uptake of wheat following maize-groundnut and maize-soybean intercrop systems to be higher than after maize alone.

5.4. Plant Nutrient Concentration

5.4.1. Bean Nutrient Concentration

Bean seed and leaf nitrogen concentrations in plants grown in association were not significantly different from that in plants grown in monoculture, indicating that nitrogen was not a differentiating factor during the trial period. Crop species in both cropping systems were capable of taking up adequate amounts of N for seed filling. It appeared that even the dry conditions of the 1985 season did not affect the N uptake of the two bean cultivars. Bean roots in monoculture and in association with maize were probably dense enough to capture an adequate amount of nitrogen for plant growth and development. Bean densities did not affect nitrogen uptake of the two bean cultivars, indicating that there was adequate nitrogen in the soil for the varied population densities.

Nutrient sufficiency ranges for dry edible beans at the upper fully developed leaf sampled prior to initial flowering were 42 to

55 gm/kg (1% = 10 gm/kg) for nitrogen (Vitosh et al., 1978). Nitrogen concentration for Domino and Carioca fell within the nutrient sufficiency range (Table 9). Nutrient sufficiency ranges for dry edible beans (2.5-6.0, 17-30, 3.5-20, and 2.5-10 gm/kg for P, K, Ca, and Mg, respectively) were similar to values obtained during the experimental period. However, phosphorus concentrations for the bean leaf and seed and magnesium concentration for bean seed were constant throughout the three growing seasons while bean leaf potassium, calcium, and magnesium concentrations changed with the variation in the environment (Table 9) though not significantly.

Bean leaf potassium concentration was higher during the moisture stress of the 1985 growing season and the disease attack of the 1986 season. Calcium uptake was greatly affected by the severe moisture shortage of the 1985 growing season but not by disease pressure of the 1986 cropping season. Calcium uptake of the 1984 and 1986 growing seasons was almost twice the amount absorbed during the 1985 cropping season (Table 9), indicating that bean plants might be deficient in calcium during dry conditions and in turn affect seed filling and eventually bean seed yield. Magnesium concentration was also affected by drought and to a lesser extent by disease infestation although not significantly different. Magnesium concentration of the 1984 growing season was almost two-fold the amount of magnesium in the 1985 cropping season.

Micronutrient concentration of bean seed indicated that there was no competition between maize and bean cultivars for boron, molybdenum, zinc, and copper nutrients. Since the concentration of these elements in the monocrop beans was not significantly different from the concentration in the associated beans, it appeared that competition for these elements was at a minimal level. Furthermore, moisture and disease stress did not seem to affect the boron, molybdenum, zinc (Table 7), and copper (Table 9) concentrations of bean seed since their concentrations remained constant during the three cropping seasons.

Nutrient sufficiency ranges for dry edible beans for the upper fully developed leaf sampled prior to initial flowering were 20-100, 50-450, 15-50, 10-30, 20-70, and 1-5 mg/kg (1 ppm = 1 mg/kg) for Mn, Fe, B, Cu, Zn, and Mo, respectively (Vitosh et al., 1978). The experimental bean leaf nutrient concentration data indicated that all the microelements were adequate in the soil and therefore competition for these elements was highly unlikely.

5.4.2. Maize Nutrient Concentration

Bean cultivars and densities did not affect maize grain protein, nitrogen, phosphorus, potassium, calcium, magnesium, or the micronutrient concentrations of the kernel. Since protein and nitrogen concentrations of the associated maize kernel were not significant as compared with monocultural maize, it seemed that neither competitive depression from bean plant nor nitrogen transfer from the bean cultivars occurred in the associated maize crop. Macro and micronutrient concentrations remained constant throughout the trial period, indicating that bean cultivars and densities had no significant effect on the maize grain nutrient concentration. It appeared that soil nutrients were available in sufficient amounts for the two crop species; otherwise, competition for these nutrients would have occurred and the concentration differences of maize grain in the two cropping systems would have shown clearly. Competitive pressure from bean cultivars at different densities for the soil elements was either at a minimum or did not exist; otherwise, maize grain nutrient concentration in the two cropping patterns would not be similar.

Dahl et al. (1982) conducted various experiments under various irrigation, mulch, tillage, and fertilizer levels at the Michigan State University Agronomy Farm. They obtained elemental composition of maize grain ranging from 9.9 to 16.6, 3.4 to 5, 4 to 5.4, 0.05 to 0.06, and 1.4 to 2.2 gm/kg for N, P, K, Ca, and Mg, respectively. Microelement composition ranged from 2 to 4, 2 to 3, 24 to 38, 5 to 11, and 23 to 40 mg/kg for B, Cu, Fe, Mn, and Zn, respectively. Their finding supported maize grain elemental composition results in Table 13, indicating that the macroelements were sufficiently high while the microelements were either moderately sufficient or sufficiently high. Macroelements were probably adequate for maize grain filling and therefore contributed to high grain yield. Similarly, micronutrients were within the optimum range and thus supported normal maize grain filling and yield.

Bean cultivar and density did not affect maize leaf nitrogen, potassium, calcium, magnesium, copper, and zinc concentration since monocultural results were not significantly different from the associated culture results. Furthermore, soil moisture stress during the 1985 cropping season lowered uptake of phosphorus, copper, iron, molybdenum, manganese, and zinc as compared to the first and third growing seasons.

Nutrient sufficiency range for maize ear leaf sampled at the initial silking stage was 27.6 to 35, 2.5 to 5, 17.1 to 25, 2.1 to 10, 1.6 to 6, and 1.6 to 5 gm/kg for N, P, K, Ca, Mg, and S, respectively (Vitosh et al., 1981). Similarly, micronutrient sufficiency range for maize ear leaf was 20-150; 21-250; 4-25; 6-20; 20-70, and 0.1-2 mg/kg for Mn, Fe, B, Cu, Zn, and Mo, respectively (Vitosh et al., 1981). Tyner (1946) observed the critical concentrations in maize leaves at silking to be 29, 2.9, and 13 gm/kg for N, P, and K, respectively. Results in Table 15 indicated that nitrogen concentration in the 1984 growing season was therefore below the critical N concentration (with few exceptions), further reducing maize grain yield. Besides nitrogen, nutrient concentrations of the maize plant were within the sufficiency range for normal maize growth and development. Judging from the concentration of maize leaf elements, it appeared that elemental nutrients were not a limiting factor for maize grain production. Nutrient uptake for both monocultural and intercrop maize were mostly not significant, indicating that the presence of bean cultivars with varying densities in intercrop system did not impose any competitive pressure on maize growth and development and ultimately maize grain yield.

Bean seed N concentration was between 41 and 49, while bean leaf N ranged from 40 to 57 gm/kg, indicating that nitrogen requirement for human nutrition would probably be adequate, particularly in Tanzania where both bean seed and young fully expanded tender bean leaves are consumed. Furthermore, maize leaf N concentration was between 23 and 34 gm/kg, implying that animal nutrition might be improved by feeding sheep, goats, and cattle of the homestead with bean and maize leftovers after grain harvest. Crop researchers should put more emphasis on the development of crop species with high nutritive values. These improved nutritive values would combat malnutrition in the third world.

Nitrogen uptake for beans was about ten-fold the uptake of P and about three times the amount of K harvested from bean seed. On the other hand, maize N harvested from grain was two to three times higher than the uptake of P and K. Since associated culture is practised by low-resource farmers, it might be possible to increase yields simply by purchasing nitrogen fertilizer with their limited capital and applying it to their farms every year.

CHAPTER 6

SUMMARY AND CONCLUSION

Two cultivars of beans, Domino and Carioca, were evaluated at three densities in association with short season maize hybrid 422 at East Lansing, Michigan in the 1984 through 1986 growing seasons. Combination of experimental units included monocropping of the two bean cultivars and maize, and intercropping maize with three densities of each bean cultivar, making a total of nine treatment combinations.

Seed yield, biomass, relative light interception, pods, and leaf area index of bean in monoculture were significantly higher than the corresponding traits under maize-bean association. Pods/m^2, leaf area index, and biomass increased with increasing bean plant density. Seed yield also increased numerically with increasing bean plant density although the difference was not significant. Seeds/pod and hundred seed weight were stable even under the less favourable growing conditions. The results indicated that maize shading and bean density did not affect the performance level of these two yield components.

Seed yields of bean in associated culture ranged from 32 to 39 percent of the monocultural yield. Less favourable growing conditions in associated culture reduced leaf area index of Domino by 39 to 46 and Carioca by 23 to 37 percent. Highest bean LAI obtained from maize-Domino was 2.6 compared with the monocultural value of 4.2, while the Carioca-maize combination produced the highest bean leaf area index of 3.3 with the Carioca monocultural value at 4.3. Optimum biomass production during the vegetative phase appeared to be a prerequisite for increased yield components.

The relative light interception for the associated bean cultivars was between 43 and 53 percent of their monocultural light interception, resulting in reduced values of yield and yield-related components. Harvest index of bean in association did not reflect a predictable trend and ranged from 53 to 59 percent while HI of bean under monoculture ranged between 59 and 65 percent.

Protein, N, P, and K yields of bean under monoculture during the first and third growing seasons were three-fold their associated culture yields. Seed yield of bean was significantly and positively correlated with seeds/pod, leaf area index, pods/m^2, and biomass, positively, though not significantly, correlated with hundred seed weight. However, seed yield of bean was negatively though not significantly correlated with percent bean protein. Biomass was also negatively and significantly correlated with percent bean protein. Furthermore, biomass was positively and significantly correlated with leaf area index, seeds/pod, and pods/m^2. Biomass was positively though not significantly correlated with hundred seed weight.

High carbohydrate concentration in the second growing season was associated with a limited sink, resulting from pod abortion due to moisture stress. Correlation analysis for three seasons indicated that bean seed yield was positively but not significantly correlated with root carbohydrate. Furthermore, non-significant correlation tests showed that stem and leaf carbohydrates were negatively correlated with bean seed yield, possibly due to increased pod number/plant (1984) which remobilized and depleted stored root and stem carbohydrates for seed filling, resulting in increased seed yield. Alternatively, pod abortion in 1985 (due to dry conditions) reduced pod number/plant, resulting in high accumulation of CHO in root and stem tissues and reduced seed yield. A constant supply of high rates of carbohydrates accompanied by high pod number per plant might result in large yield increases.

Effects of years, bean cultivars, and bean density were not expressed for hundred maize kernel weight, indicating that maize was competitive and efficient in obtaining the essential resources for proper growth and development. Yields of maize under monoculture were not significantly different from the yields of maize in association in the first and third growing seasons. The observations indicated that each crop component reached a peak demand for resources at different times and from different soil profiles since the two crop species had different growth durations and morphology. Furthermore, the competitive ability of maize for under and above ground resources was higher than the bean cultivars. On the other hand, resources were adequate for the growth and development of the maize and bean cultivars in the first and third years.

Grain yields of maize were reduced by 15, 14, and 15 percent when maize was intercropped with Domino at 100,000, 150,000, and 200,000 bean plants/ha, respectively. The maize-Carioca combinations at 100,000, 150,000, and 200,000 plants/ha reduced grain yield of maize by 14, 13, and 15 percent, respectively, as compared with monoculture. The efficiency of the two bean cultivars in combination with maize (40,000 plants/ha) peaked at 150,000 bean plants/ha, indicating that the combination might be superior to the other bean density combinations. Highest combined maize-bean yields were between 6,767 and 6,941 kg/ha while a half-hectare of each monocultural crop only produced a maximum combined yield of 4,718 kg/ha. The highest monocultural yield was 7,006 kg/ha.

Even though grain yield of maize in monoculture was higher than any intercrop yield combination, the associated culture pattern would continue to be more important than monocrop maize because mixtures of maize-bean provided high protein yield needed for human diets in developing countries. Combined maize-bean protein yield ranged from 810 to 870 kg/ha, while monocultural combined protein yield ranged from 671 to 681 kg/ha. The best monocultural protein yield (701 kg/ha) was always less than the combined intercrop protein yield. Maize and bean in associated culture combined total protein yield/ha was adequate to feed 34 to 37 adult males for one year, while protein yield/ha in monoculture was enough to feed only 28 to 29 men annually. Land equivalent ratio increased with increasing bean density. A land equivalent ratio (three-year average) of 1.29 was obtained when maize was intercropped with Domino at 200,000 plants/ha. Protein, N, and P yields of maize in monoculture during the first and third cropping seasons were not significantly different from their corresponding yields in associated culture with few exceptions. Maize height was significantly and positively correlated with maize yield. However, kernel weight and land equivalent ratio were positively and not significantly correlated with maize grain yield. In contrast, bean biomass was significantly and negatively correlated, while bean seed yield was negatively but not significantly correlated with maize grain yield.

Seed protein, N, P, Mg, B, Mo, and Zn concentrations of bean in association were not significantly different from the corresponding monocultural values and their concentrations were within the nutrient sufficiency range for normal growth and development. Bean leaf protein, N, P, K, Ca, Mg, and Cu were not significantly different in the two cropping systems and their concentrations were sufficient for normal growth and development. Calcium and Mg uptake of the 1984 and 1986 growing seasons was almost twice the amount absorbed during the 1985 cropping season, indicating that bean plants might show calcium and Mg deficiency during dry conditions which in turn could affect seed yield.

Bean cultivars and densities did not affect grain protein, N, P, K, Ca, Mg, and the micronutrient concentrations of maize kernel. Since protein and nitrogen concentration of maize kernels in association was not significantly different from the monocultural values, it seemed that nitrogen transfer from bean roots to maize roots did not take place in the associated maize crop. Macro and micronutrient concentrations remained constant throughout the experimental period, indicating that the effect of bean cultivars and density on the grain nutrient concentration of maize was not significant. Grain macro and micro-element concentrations of maize were sufficiently high throughout the experimental period and generally contributed to kernel filling and final grain yield. Bean cultivar and density did not affect leaf nitrogen, P, K, Ca, Mg, Cu, and Zn concentrations of maize since monocultural values were not significantly different from the results in associated culture. Besides nitrogen (1984), nutrient concentrations of the maize plant were within the nutrient sufficiency range for normal maize growth and kernel yield. Density combination of 40,000/ 150,000 plants/ha maize/bean, respectively, produced greater yield and could be recommended to farmers in Tanzania, although the success will greatly depend on local weather, soil fertility, general crop husbandry, and local cultivars grown in the country.

Future Challenges

In the literature search conducted by Francis (1986), there were 187 published papers up to 1960, but 359 papers were published from 1961 to 1970, and between 1970 to 1980 there were 1,440 published papers, showing that there is an increasing recognition by scientists and agricultural administrators of the current and potential future importance of associated culture. The scientific community's role in attempting to increase yields from multiple cropping will be a continuous process since it is highly unlikely that farmers will adopt a monocropping system, due possibly to land, capital, and labour shortages. Family nutrition is very important for their livelihood and associated culture can improve the quality of the family's diet by providing high nutritive values of starch, protein, essential nutrients, and vitamins, in addition to those from fruits and vegetables. These high nutritive values can be obtained from a variety of crops grown in mixtures on a unit of land area.

Mixed cropping will continue to be important in the developing countries due mainly to population pressure and general poverty. Subsistence farmers lack capital for purchasing needed inputs like fertilizer. Thus intercropping cereals and legumes would possibly transfer (although evidence for transfer of N is not strong) some nitrogen to non-legume crops if legumes capable of fixing N in associated culture can be identified. Furthermore, these crop species differ in rooting patterns and can therefore exploit nutrients in different soil profiles. Mixed cropping, too, minimizes soil erosion due to early ground cover. In addition, some diseases and pests tend to avoid crops in mixtures and this is a bonus to a low-resource farmer in the third world. The intercropping system may use solar energy, nutrients, and water more efficiently than monocropping. Likewise, associated culture reduces risks due mainly to increased diversity in crops. Such advantages of intercropping are some of the reasons why farmers in the tropics adopted this system of production and why they will continue to practice it as long as their land, labour, and capital problems are unsolved.

Since the two bean cultivars planted at different densities did not show any significant yield differences, there is a need to continue with optimum bean density studies involving types I, II, III, and IV with preferred seed size, colour, and maturity in order to achieve high combined yields. Evaluating compatible crops with diverse maturity, optimum density, and diverse morphology will enable the compatible mixtures to explore a greater total soil volume and utilize light more efficiently than crop components with similar morphology. Each crop component will reach peak demand for resources at different times, thus minimizing competition and increasing yield potential of the cropping pattern.

It is speculated that greater biomass will be produced in a mixture than in monoculture, thus resulting in greater demand on soil resources, mainly water and nutrients. Studies on mixtures of crop components capable of utilizing low levels of resources more efficiently will benefit low-resource farmers. Furthermore, studies on critical fertility levels in associated culture will provide an insight for improvement of the cropping pattern. Leaf and row orientation studies will have relevance to reduced crop competition for light at critical stages of development and increase yield potential of the associated culture. Evaluating multilines of maize and bean cultivar mixtures with wide genetic diversity will probably minimize stress due to complexity of these associations. In addition, wide genetic diversity will reduce damage due to diseases, insects, and nematodes and maintain yield stability in bean-maize mixtures.

Future challenges should also include the breeding of bean cultivar(s) which will tolerate and perform better under a complex associated culture system. Such a cultivar should be able to utilize available light more efficiently. It should tolerate shading environment under the associated culture. The cultivar should be capable of fixing nitrogen even under less favourable environmental conditions in order to increase bean seed yield and consequently combined total seed yield. Carbohydrate results revealed some doubts as to whether the bean roots and stems stored and translocated adequate amounts of carbohydrates to the reproductive organs for seed filling. Therefore, the future challenge calls for screening of bean cultivars with high storage and translocatable root and stem TNC in order to increase seed yield in the two cropping patterns. However, these goals demand a greater degree of expertise in physiological, genetic, and breeding skills than encountered in national research centres in developing countries with the present outlook vis-a-vis personnel and financial support. Nevertheless, a close collaboration with international research centres would be a step in the right direction.

APPENDICES

APPENDIX A

ANALYSES OF VARIANCE

APPENDIX A

ANALYSES OF VARIANCE

Table A1. Analysis of Variance of Bean Yield and Yield-Related Traits in the Associated Culture.

		Mean Squares							
Source of Variation	Degree of Freedom	Biomass (gm/m^2)	Plant Height (cm)	Pods/m^2	Stem Diameter (cm)	Leaf Area Index (LAI)	Hundred Seed Weight (gm)	Seed Yield (kg/ha)	Relative Light Interception (%)
Year	2	131027.305**	7473.375**	26567.042**	0.074**	7.829**	64.517**	352148.722**	688.889**
Cultivar	1	5955.042	12090.125**	13475.347**	0.131**	0.161	369.920**	28401.389*	5.556
Year x Cultivar	2	4358.672	472.875*	1790.597	0.005	0.061	17.255**	29628.222**	22.222
Density	2	10350.761*	161.292	7603.125**	0.037**	0.577*	0.667	47918.014**	88.889
Year x Density	4	1790.768	106.604	670.792	0.003	0.180	0.202	3363.035	13.889
Cultivar x Density	2	286.011	163.292	1075.347	0.002	0.107	2.145	6132.097	22.222
Year x Cultivar x Density	4	7439.856*	92.354	735.597	0.005*	0.375*	0.131	5541.743	63.889
Error	51	2566.892	116.355	594.844	0.002	0.141	1.312	5201.343	83.987
CV (%)		30.4	16.5	21.0	8.8	18.8	5.5	14.2	34.7

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A2. Analysis of Variance of Bean Yield-Related Traits in the Associated Culture.

Source of Variation	Degree of Freedom	Mean Squares		
		Nodes/ Plant	Seeds/ Pod	Harvest Index
Year	1	22.688**	0.002	18.750
Cultivar	1	3.521*	4.625**	40.333
Year x Cultivar	1	6.021**	0.175	36.750*
Density	2	3.521*	0.053	2.333
Year x Density	2	1.188	0.053	9.250
Cultivar x Density	2	0.146	0.191	6.583
Year x Cultivar x Density	2	2.896*	0.341	3.000
Error	33	0.819	0.122	5.071
CV (%)		6.9	5.4	3.9

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A3. Analysis of Variance of Seed Nutrient Yield of Bean in the Associated Culture.

Source of Variation	Degree of Freedom	Mean Squares (kg/ha)			
		Bean Protein	Bean Nitrogen	Bean Phosphorus	Bean Potassium
Year	2	14560.583**	365.896**	5.689**	37.146**
Cultivar	1	1825.333	40.333	0.188	7.521**
Year x Cultivar	2	2382.333*	56.771	0.813*	3.771*
Density	1	6960.083**	176.333**	1.688**	17.521**
Year x Density	2	272.583	8.271	0.063	1.021
Cultivar x Density	1	736.333	18.750	0.021	0.021
Year x Cultivar x Density	2	170.333	3.563	0.021	1.396
Error	33	523.199	14.326	0.188	0.834
CV (%)		16.2	16.8	17.8	13.5

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A4. Effect of Year, Bean Cultivars, and Density on Carbohydrate Concentration during Mid-Pod Filling in Associated Culture.

Source of Variation	Degree of Freedom	Mean Squares (gm/kg)								
		Root Starch	Root Sugar	Root TNC	Stem Starch	Stem Sugar	Stem TNC	Leaf Starch	Leaf Sugar	Leaf TNC
Year	2	27.551**	30.275**	103.884**	23.783**	80.813**	185.254**	.035	5.844**	6.590**
Cultivar	1	20.935**	.827	30.083**	.935	.827	3.521	.130	.053	.350
Year x Cultivar	2	9.116**	.304	6.755*	2.563*	2.243	8.019	.019	.151	.104
Density	1	8.927**	4.260**	25.521**	8.927**	2.210	20.021*	.035	1.920*	2.475*
Year x Density	2	1.472	.375	2.876	1.833	1.985	3.881	.038	.357	.494
Cultivar x Density	1	.460	4.877**	8.333*	12.100**	10.735*	45.630**	.255	1.141	.317
Year x Cultivar x Density	2	2.003	3.739**	11.210**	4.013**	2.923	8.304	.029	.264	.319
Error	33	.765	.397	1.417	.708	1.890	3.076	.099	.363	.391
CV (%)		19.7	14.2	13.4	18.8	16.4	13.7	12.7	17.4	10.5

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A5. Analysis of Variance of Seed Nutrient Concentration of Bean in the Associated Culture.

Source of Variation	Degree of Freedom	Mean Squares (gm/kg)					
		Protein	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Year	2	14.464	0.371	0.043**	0.034*	0.008**	0.003**
Cultivar	1	16.603	0.426	0.001	0.053*	0.002	0.000
Year x Cultivar	2	6.537	0.167	0.008	0.014	0.000	0.000
Density	1	0.174	0.004	0.001	0.002	0.000	0.000
Year x Density	2	1.406	0.036	0.003	0.002	0.001	0.000
Cultivar x Density	1	0.443	0.011	0.006	0.012	0.002	0.000
Year x Cultivar x Density	2	11.024	0.282	0.002	0.005	0.001	0.000
Error	33	6.369	0.163	0.004	0.008	0.001	0.000
CV (%)		9.0	9.0	12.2	6.5	16.1	5.7

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A5 (cont'd.).

Source of Variation	Degree of Freedom	Mean Squares (mg/kg)					
		Boron	Copper	Iron	Molybdenum	Manganese	Zinc
Year	2	13.232**	58.446**	215.583**	19.877**	37.228**	12.521
Cultivar	1	4.066*	24.467**	379.688**	0.320	1.964	90.750
Year x Cultivar	2	2.497*	3.252	33.250	0.789	1.230	26.688
Density	1	0.355	0.062	1.021	1.394	0.050	10.083
Year x Density	2	0.656	2.622	1.333	0.513	0.757	1.646
Cultivar x Density	1	0.878	3.780	13.021	0.452	0.394	40.333
Year x Cultivar x Density	2	2.250	0.126	34.333	0.754	0.891	0.396
Error	33	0.581	2.497	32.122	0.755	1.176	22.854
CV (%)		7.3	13.8	8.0	19.1	9.1	13.8

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A6. Analysis of Variance of Leaf Nutrient Concentration of Bean in the Associated Culture.

Source of Variation	Degree of Freedom	Mean Squares (gm/kg)					
		Protein	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Year	2	52.691*	1.350*	0.116**	3.224**	17.771**	1.231**
Cultivar	1	30.163	0.773	0.019*	1.460*	0.816	0.006
Year x Cultivar	2	150.257**	3.845**	0.002	0.184	0.140	0.003
Density	1	10.726	0.275	0.003	0.494	0.244	0.029
Year x Density	2	9.203	0.236	0.012	0.370	0.001	0.016
Cultivar x Density	1	2.215	0.057	0.005	0.123	0.006	0.001
Year x Cultivar x Density	2	13.081	0.335	0.001	0.103	0.028	0.003
Error	33	13.062	0.334	0.004	0.222	0.687	0.009
CV (%)		12.3	12.3	12.5	21.4	26.4	9.9

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A6 (cont'd.).

Source of Variation	Degree of Freedom	Mean Squares (mg/kg)					
		Boron	Copper	Iron	Molybdenum	Manganese	Zinc
Year	2	3539.146**	224.33**	213874.646	87.852**	42894.083**	438.250**
Cultivar	1	315.188**	0.110	136533.333	16.457**	2422.52	652.688**
Year x Cultivar	2	103.938*	1.651	41466.021	4.844**	1164.083	34.750
Density	1	20.021	8.755	0.333	1.421	19112.688	15.188
Year x Density	2	2.271	15.703	3808.771	0.183	1252.750	75.250
Cultivar x Density	1	0.521	0.110	35970.750	1.203	42.188	63.021
Year x Cultivar x Density	2	7.896	1.563	12062.312	0.330	0.750	18.583
Error	33	31.465	10.300	8671.492	0.729	607.52	33.571
CV (%)		12.2	21.2	19.5	8.9	27.3	12.4

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A7. Analysis of Variance of Maize Yield and Yield-Related Traits in the Associated Culture.

Source of Variation	Degree of Freedom	Mean Squares			
		Maize Height (cm)	Hundred Seed Weight (gm)	Land Equivalent Ratio	Grain Yield (kg/ha)
Year	2	19340.014**	5.601	0.009	34777591.792**
Cultivar	1	2.347	0.027	0.006	14964.500
Year x Cultivar	2	16.681	2.847	0.021	508407.292
Density	2	311.931**	2.233	0.022	65437.125
Year x Density	4	67.076*	2.279	0.011	520320.042
Cultivar x Density	2	60.847	8.158	0.004	24761.792
Year x Cultivar x Density	4	79.743*	8.566	0.009	141135.833
Error	51	25.247	6.081	0.008	294897.462
CV (%)		2.7	7.7	7.0	8.6

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A8. Analysis of Variance of Grain Nutrient Yield of Maize in the Associated Culture.

Source of Variation	Degree of Freedom	Mean Squares (kg/ha)			
		Maize Protein	Maize Nitrogen	Maize Phosphorus	Maize Potassium
Year	2	325495.313**	8322.333**	367.938**	480.396**
Cultivar	1	1386.750	33.333	1.021	15.188
Year x Cultivar	2	6676.188	178.083	14.646	24.813*
Density	1	192.000	6.750	0.188	0.021
Year x Density	2	8109.188	203.250	37.938	11.646
Cultivar x Density	1	114.083	2.083	0.521	0.021
Year x Cultivar x Density	2	710.896	18.083	13.146	2.146
Error	33	6905.470	175.818	13.289	6.299
CV (%)		13.3	13.3	11.1	8.9

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A9. Analysis of Variance of Grain Nutrient Concentration of Maize in the Associated Culture.

Source of Variation	Degree of Freedom	Mean Squares (gm/kg)					
		Protein	Nitrogen	Phosphorus	Potassium	Calcium	Magnesium
Year	2	3.199**	0.082**	0.139**	0.011**	0.000*	0.021**
Cultivar	1	0.312	0.008	0.000	0.002	0.000	0.000
Year x Cultivar	2	0.179	0.005	0.003	0.005**	0.000	0.000
Density	1	0.012	0.000	0.000	0.000	0.000	0.000
Year x Density	2	0.177	0.005	0.002	0.000	0.000	0.000
Cultivar x Density	1	0.000	0.000	0.000	0.000	0.000	0.000
Year x Cultivar x Density	2	0.064	0.002	0.004	0.000	0.000	0.001
Error	33	0.543	0.014	0.002	0.001	0.000	0.000
CV (%)		7.4	7.4	7.6	6.6	16.0	8.8

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A9 (cont'd.).

Source of Variation	Degree of Freedom	Mean Squares (mg/kg)					
		Boron	Copper	Iron	Molybdenum	Manganese	Zinc
Year	2	0.247	0.238	80.646**	0.076	30.327**	174.813**
Cultivar	1	0.049	0.254	0.000	0.000	0.000	0.021
Year x Cultivar	2	0.024	1.670*	22.563	0.006	0.992	73.396**
Density	1	0.141	2.750*	1.333	0.024	0.090	0.021
Year x Density	2	0.050	0.097	13.771	0.005	0.662	1.021
Cultivar x Density	1	0.030	0.199	4.083	0.005	0.002	20.021
Year x Cultivar x Density	2	0.030	0.885	19.771	0.007	0.631	10.021
Error	33	0.138	0.435	9.977	0.028	0.616	11.511
CV (%)		14.9	16.2	11.1	43.7	13.2	11.0

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A10. Analysis of Variance of Leaf Nutrient Concentration of Maize in the Associated Culture.

Source of Variation	Degree of Freedom	Mean Squares (gm/kg)					Mean Squares (mg/kg)
		Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Boron
Year	2	1.557*	0.063**	0.741**	0.167**	0.027**	17.534**
Cultivar	1	0.005	5.005	0.209	0.001	0.003	0.001
Year x Cultivar	2	0.078	0.000	0.023	0.013	0.003	1.629
Density	1	0.949	0.006	0.088	0.055*	0.001	7.348*
Year x Density	2	0.512	0.002	0.039	0.005	0.000	0.077
Cultivar x Density	1	0.196	0.010*	0.065	0.000	0.005	10.286*
Year x Cultivar x Density	2	0.237	0.004	0.017	0.029	0.009	2.573
Error	33	0.372	0.002	0.102	0.009	0.004	1.634
CV (%)		21.5	10.5	13.8	12.5	14.3	11.5

*Significant at the .05 level.

**Highly significant at the .01 level.

Table A10 (cont'd.).

Source of Variation	Degree of Freedom	Mean Squares (mg/kg)				
		Copper	Iron	Molybdenum	Manganese	Zinc
Year	2	127.349**	7272.646**	17.258**	8978.313**	2827.938**
Cultivar	1	6.527	487.688	0.728	305.021**	52.083
Year x Cultivar	2	4.727	39.813	0.117	35.521	4.021
Density	1	4.142	391.021	0.506	105.021	44.083
Year x Density	2	3.218	50.771	0.198	53.896	61.896
Cultivar x Density	1	2.385	346.688	0.005	46.021	65.333
Year x Cultivar x Density	2	1.673	152.688	0.725	6.521	33.146
Error	33	3.306	132.925	0.354	7.920	79.217
CV (%)		11.6	8.9	11.3	14.5	14.9

*Significant at the .05 level.

**Highly significant at the .01 level.

APPENDIX B

CROP SCIENCE FIELD LAB RAINFALL DATA AT MICHIGAN STATE UNIVERSITY AGRONOMY FARM, EAST LANSING

APPENDIX B

CROP SCIENCE FIELD LAB RAINFALL DATA AT MICHIGAN STATE UNIVERSITY AGRONOMY FARM, EAST LANSING

Total Inches of Rain per Month

	Year						
	1984		1985		1986		
Month	Total	No. Days	Total	No. Days	Total	No. Days	23-Year Average Rainfall
April	3.59	14	4.28	10	2.89	12	3.21
May	5.42	16	2.44	8	3.56	12	2.96
June	0.19	4	2.29	7	8.91	12	4.04
July	1.93	8	2.19	9	2.49	10	2.87
August	3.72	6	4.29	13	3.84	6	3.07
September	3.54	14	3.22	8	9.56	15	3.27
October	3.80	11	5.02	10	2.84	11	2.15
TOTAL	22.19	73	23.73	65	34.09	78	21.57

Compiled by M.B. Tesar

APPENDIX C

BEAN AND MAIZE SEED YIELDS

APPENDIX C

BEAN AND MAIZE SEED YIELDS

1984 Growing Season

Treatment Combinations	Density (pl/ha)	Trait Readings in Each Replication I	II	III	IV	Mean (gm/plot)	Mean (kg/ha)
1. Domino	100,000	534	665	500	589	572	953
+							
Maize (H 422)	40,000	5,086	5,657	5,843	5,715	5,575	5,309
2. Domino	150,000	584	763	650	695	673	1,122
+							
Maize	40,000	5,982	5,822	5,942	5,903	5,912	5,630
3. Domino	200,000	728	666	690	610	673	1,122
+							
Maize	40,000	5,972	5,175	6,012	6,383	5,885	5,605
4. Domino (Monoculture)	200,000	2,081	1,711	1,982	2,076	1,962	3,271
5. Carioca	100,000	668	679	611	555	628	1,047
+							
Maize (H422)	40,000	5,390	5,490	5,930	5,991	5,700	5,428

1984 Growing Season (cont'd.).

Treatment Combinations	Density (pl/ha)	Trait Readings in Each Replication I	II	III	IV	Mean (gm/plot)	Mean (kg/ha)
6. Carioca	150,000	545	644	647	544	595	992
+							
Maize	40,000	5,296	6,084	6,276	5,717	5,843	5,565
7. Carioca	200,000	802	739	679	699	730	1,216
+							
Maize	40,000	6,802	5,927	5,471	5,634	5,958	5,674
8. Carioca (Monoculture)	200,000	2,132	2,040	2,084	2,104	2,090	3,483
9. Maize (Monoculture)	40,000	6,097	6,187	6,433	6,446	6,291	5,991

1985 Growing Season

Treatment Combinations	Density (pl/ha)	Trait Readings in Each Replication I	II	III	IV	Mean (gm/plot)	Mean (kg/ha)
1. Domino	100,000	531	521	344	434	457	762
+							
Maize (H 422)	40,000	5,019	6,905	4,873	5,049	5,461	5,201
2. Domino	150,000	576	534	345	609	516	860
+							
Maize	40,000	6,143	6,236	4,764	5,606	5,687	5,416
3. Domino	200,000	667	557	440	549	553	922
+							
Maize	40,000	5,409	5,724	5,432	5,821	5,596	5,329
4. Domino (Monoculture)	200,000	1,125	1,036	748	840	937	1,562
5. Carioca	100,000	487	467	316	298	392	653
+							
Maize (H 422)	40,000	5,490	5,839	4,847	4,706	5,220	4,971
6. Carioca	150,000	429	492	323	308	388	647
+							
Maize	40,000	6,411	6,494	5,282	4,868	5,763	5,488

1985 Growing Season (cont'd.).

Treatment Combinations	Density (pl/ha)	Trait Readings in Each Replication				Mean (gm/plot)	Mean (kg/ha)
		I	II	III	IV		
7. Carioca	200,000	467	478	341	262	387	645
+							
Maize	40,000	5,421	5,441	4,513	4,440	4,954	4,718
8. Carioca (Monoculture)	200,000	1,081	1,006	692	477	814	1,357
9. Maize (Monoculture)	40,000	6,702	7,856	7,012	8,305	7,469	7,113

1986 Growing Season

Treatment Combinations	Density (pl/ha)	Trait Readings in Each Replication				Mean (gm/plot)	Mean (kg/ha)
		I	II	III	IV		
1. Domino	100,000	343	327	397	428	374	623
+							
Maize (H 422)	40,000	8,212	8,576	7,457	7,053	7,824	7,451
2. Domino	150,000	321	479	491	385	419	698
+							
Maize	40,000	7,315	7,059	8,015	7,106	7,374	7,023
3. Domino	200,000	420	450	615	499	496	827
+							
Maize	40,000	7,576	7,276	6,882	7,740	7,368	7,017
4. Domino (Monoculture)	200,000	1,700	1,428	1,458	1,309	1,474	2,456
5. Carioca	100,000	392	395	324	340	363	604
+							
Maize (H 422)	40,000	8,430	8,317	7,544	7,976	8,067	7,683
6. Carioca	150,000	385	421	409	458	418	697
+							
Maize	40,000	8,030	7,140	8,167	7,153	7,622	7,259

1986 Growing Season (cont'd.).

Treatment Combinations	Density (pl/ha)	Trait Readings in Each Replication I	II	III	IV	Mean (gm/plot)	Mean (kg/ha)
7. Carioca	200,000	447	475	560	439	480	800
+							
Maize	40,000	7,733	7,045	8,698	7,785	7,815	7,443
8. Carioca (Monoculture)	200,000	1,341	1,575	1,417	1,389	1,430	2,384
9. Maize (Monoculture)	40,000	8,642	8,122	8,817	7,663	8,311	7,915

APPENDIX D

BEAN AND MAIZE 100-SEED WEIGHT

APPENDIX D

BEAN AND MAIZE 100-SEED WEIGHT

1984 Cropping Season

Treatment Combinations	Density (pl/ha)	Trait Readings in Each Replication I	II	III	IV	Mean (gm)
1. Domino +	100,000	18.3	19.9	19.1	13.5	17.7
Maize (H 422)	40,000	29.0	28.3	30.4	32.2	30.0
2. Domino +	150,000	17.6	18.3	18.6	18.0	18.1
Maize	40,000	30.0	35.9	32.4	34.5	33.2
3. Domino +	200,000	18.7	17.1	18.8	17.9	18.1
Maize	40,000	32.3	31.3	38.4	31.5	33.4
4. Domino (Monoculture)	200,000	19.9	18.5	19.2	18.9	19.1
5. Carioca +	100,000	24.9	24.9	25.3	23.2	24.6
Maize (H 422)	40,000	32.9	31.1	33.8	34.2	33.0
6. Carioca +	150,000	24.1	23.5	25.4	23.7	24.2
Maize	40,000	30.1	34.0	28.7	32.0	31.2
7. Carioca +	200,000	23.1	24.9	24.0	23.5	23.9
Maize	40,000	33.2	28.2	32.4	31.7	31.4
8. Carioca (Monoculture)	200,000	23.7	24.0	25.1	24.0	24.2
9. Maize (Monoculture)	40,000	33.0	31.4	33.5	33.0	32.7

1985 Cropping Season

Treatment Combinations	Density (pl/ha)	Trait Readings in Each Replication I	II	III	IV	Mean (gm)
1. Domino +	100,000	17.5	18.3	18.2	16.9	17.7
Maize (H 422)	40,000	35.3	31.1	29.6	32.8	32.2
2. Domino +	150,000	17.2	17.9	19.2	16.9	17.8
Maize	40,000	40.2	30.9	29.1	37.1	34.3
3. Domino +	200,000	19.0	17.8	18.0	17.2	18.0
Maize	40,000	31.7	30.9	31.3	31.5	31.3
4. Domino (Monoculture)	200,000	18.9	18.7	17.0	16.6	17.8
5. Carioca +	100,000	22.2	23.0	22.1	18.6	21.5
Maize (H 422)	40,000	37.5	31.4	28.9	30.9	32.2
6. Carioca +	150,000	21.5	21.7	19.8	18.5	20.4
Maize	40,000	34.5	33.4	29.4	30.6	32.0
7. Carioca +	200,000	21.8	23.5	18.1	17.3	20.2
Maize	40,000	37.6	31.6	31.4	29.6	32.5
8. Carioca (Monoculture)	200,000	22.8	22.8	22.1	20.0	21.9
9. Maize (Monoculture)	40,000	37.6	33.8	31.6	34.4	34.3

1986 Cropping Season

Treatment Combinations	Density (pl/ha)	Trait Readings in Each Replication I	II	III	IV	Mean (gm)
1. Domino +	100,000	20.2	20.4	20.5	19.7	20.2
Maize (H 422)	40,000	32.8	32.6	32.4	29.6	31.8
2. Domino +	150,000	20.1	20.1	21.2	19.8	20.3
Maize	40,000	30.3	30.7	33.3	31.0	31.3
3. Domino +	200,000	20.4	19.6	20.4	20.7	20.3
Maize	40,000	31.2	31.0	28.6	29.1	30.0
4. Domino (Monoculture)	200,000	22.1	18.5	19.0	19.6	19.8
5. Carioca +	100,000	25.7	25.0	25.8	23.9	25.1
Maize (H 422)	40,000	31.6	33.1	31.2	31.5	31.8
6. Carioca +	150,000	24.8	25.7	24.4	25.0	25.0
Maize	40,000	34.7	30.4	32.6	29.9	31.9
7. Carioca +	200,000	24.5	23.2	24.8	24.8	24.3
Maize	40,000	30.3	29.9	33.6	33.8	31.9
8. Carioca (Monoculture)	200,000	23.2	24.3	24.9	24.7	24.3
9. Maize (Monoculture)	40,000	37.6	33.2	32.3	33.3	34.1

APPENDIX E

BIOLOGICAL (BIOMASS) YIELD (gm/m^2)

APPENDIX E

BIOLOGICAL (BIOMASS) YIELD (gm/m^2)

Treatment Combinations	Year	Trait Readings in Each Replication I	II	III	IV	Mean (gm/m^2)
1. Domino	1984	184.6	269.9	243.6	231.6	232
+	1985	169.4	181.8	92.6	121.6	141
Maize (H 422)	1986	99.8	60.4	144.2	77.0	95
2. Domino	1984	222.1	291.3	166.1	443.2	281
+	1985	201.4	151.9	124.8	223.1	175
Maize	1986	43.9	95.8	104.1	113.4	89
3. Domino	1984	151.2	202.4	227.2	302.4	221
+	1985	266.8	195.6	166.4	227.6	214
Maize	1986	62.4	75.2	226.4	173.2	134
4. Domino	1984	382.0	690.4	665.2	810.4	551
(Monoculture)	1985	369.6	332.4	278.0	369.2	337
	1986	331.6	348.4	247.1	380.4	327
5. Carioca	1984	220.0	192.0	211.0	215.4	210
+	1985	141.2	71.8	63.0	113.2	97
Maize (H 422)	1986	82.0	93.6	135.4	74.0	96
6. Carioca	1984	254.9	209.2	219.1	230.8	228
+	1985	204.2	151.1	130.2	113.2	150
Maize	1986	93.4	111.6	146.3	101.5	113
7. Carioca	1984	280.0	391.2	252.0	310.8	308
+	1985	157.6	217.6	126.8	94.4	149
Maize	1986	87.6	66.0	83.2	72.8	77
8. Carioca	1984	615.8	617.6	508.4	673.2	604
(Monoculture)	1985	357.2	263.2	268.4	157.6	262
	1986	282.0	432.0	308.0	332.8	339

Note: Treatments 1 and 5 (100,000 bean pl/ha); 2 and 6 (150,000 pl/ha); 3, 4, 7, and 8 (200,000 bean pl/ha).

APPENDIX F

MAIZE-BEAN LAND EQUIVALENT RATIOS (LER)

APPENDIX F

MAIZE-BEAN LAND EQUIVALENT RATIOS (LER)

Treatment Combinations	Year	Trait Readings in Each Replication I	II	III	IV	Mean
1. Domino	1984	1.14	1.29	1.17	1.16	1.19
+	1985	1.22	1.38	1.15	1.12	1.22
Maize (H 422)	1986	1.15	1.28	1.12	1.25	1.20
2. Domino	1984	1.30	1.38	1.24	1.23	1.29
+	1985	1.43	1.31	1.14	1.40	1.32
Maize	1986	1.03	1.20	1.24	1.22	1.17
3. Domino	1984	1.37	1.23	1.27	1.27	1.28
+	1985	1.40	1.27	1.36	1.35	1.35
Maize	1986	1.12	1.21	1.20	1.39	1.23
4. Carioca	1984	1.22	1.21	1.21	1.20	1.21
+	1985	1.27	1.21	1.15	1.19	1.20
Maize (H 422)	1986	1.27	1.27	1.08	1.28	1.22
5. Carioca	1984	1.14	1.32	1.29	1.15	1.22
+	1985	1.35	1.31	1.22	1.23	1.28
Maize	1986	1.20	1.15	1.21	1.26	1.20
6. Carioca	1984	1.52	1.32	1.18	1.21	1.31
+	1985	1.24	1.17	1.13	1.08	1.15
Maize	1986	1.23	1.17	1.38	1.28	1.28
7. Maize/Bean Monoculture	1984-1986	1.00	1.00	1.00	1.00	1.00

Note: 1 and 4 (100,000 bean pl/ha)
2 and 5 (150,000 bean pl/ha)
3 and 6 (200,000 bean pl/ha)

APPENDIX G

BEAN LEAF NUTRIENT CONCENTRATION

APPENDIX G

BEAN LEAF NUTRIENT CONCENTRATION

1984 Cropping Season

			gm/kg						mg/kg					
Replication	Variety	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	265.0	42.4	3.9	15.1	35.6	12.4	34	9.6	494	11.10	138	35
1		200	289.4	46.3	3.9	15.1	36.4	14.0	34	11.1	659	11.40	78	42
1	Carioca	100	263.1	42.1	4.9	18.6	44.8	11.8	41	13.0	644	12.30	187	57
1		200	288.1	46.1	4.1	16.6	40.7	12.7	36	13.1	638	11.40	91	51
1	Mono. Domino	200	304.4	48.7	4.1	16.0	34.4	12.4	38	10.7	508	10.90	164	40
1	Mono. Carioca	200	275.6	44.1	4.8	17.0	43.9	14.6	37	15.4	846	12.00	136	56
2	Domino	100	208.7	33.4	3.9	16.4	36.3	12.9	36	11.1	499	11.00	148	40
2		200	231.2	37.0	3.9	14.6	33.9	12.4	35	11.0	590	10.90	71	40
2	Carioca	100	300.6	48.1	3.7	12.7	32.0	13.3	33	9.4	789	11.70	110	47
2		200	308.1	49.3	4.2	16.4	37.3	12.4	37	11.5	564	11.80	97	46
2	Mono. Domino	200	309.4	49.5	4.0	14.9	36.7	12.8	33	11.5	573	11.20	140	46
2	Mono. Carioca	200	294.4	47.1	4.4	16.8	38.4	12.5	38	10.2	781	11.80	125	65

1984 Cropping Season (cont'd.)

			gm/kg						mg/kg					
Replication	Variety	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	287.5	46.0	3.6	15.7	29.3	11.3	31	9.0	437	11.20	103	35
3		200	298.1	47.7	3.4	15.3	27.9	10.3	32	8.0	396	10.80	105	34
3	Carioca	100	293.1	46.9	4.0	14.6	31.7	11.9	34	9.0	696	11.70	129	49
3		200	271.9	43.5	3.5	15.5	29.3	10.9	35	10.3	506	11.10	156	38
3	Mono. Domino	200	306.9	49.1	3.7	16.0	28.8	9.8	33	9.0	356	11.20	99	38
3	Mono. Carioca	200	281.2	45.0	4.4	16.5	30.9	10.3	33	13.5	675	11.70	110	55
4	Domino	100	315.0	50.4	4.5	19.9	39.5	14.1	45	12.1	578	9.82	114	45
4		200	285.0	45.6	4.1	18.1	35.9	13.8	39	11.6	678	9.77	124	44
4	Carioca	100	315.6	50.5	5.1	23.5	47.9	13.8	45	13.0	668	10.30	218	60
4		200	310.0	49.6	4.4	20.5	44.5	13.7	40	10.9	613	9.74	162	46
4	Mono. Domino	200	323.1	51.7	4.4	20.0	43.7	12.8	36	25.7	509	9.97	105	46
4	Mono. Carioca	200	273.7	43.8	4.9	19.9	45.4	13.8	48	13.2	611	10.40	118	62

1985 Cropping Season

			gm/kg						mg/kg					
Replication	Variety	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	235.0	37.6	4.4	16.7	11.1	6.5	33	13.4	311	5.60	24	36
1		200	229.4	36.7	4.3	17.5	13.4	7.4	35	13.4	346	5.98	28	36
1	Carioca	100	375.0	60.0	7.1	35.9	18.9	7.5	45	24.6	313	7.35	34	54
1		200	358.1	57.3	4.4	16.0	12.2	7.3	33	11.8	337	6.28	25	38
1	Mono. Domino	200	299.4	47.9	4.3	14.4	12.3	7.3	32	12.9	291	6.05	25	36
1	Mono. Carioca	200	296.9	47.5	4.5	16.1	11.7	7.1	29	12.8	403	5.95	26	40
2	Domino	100	247.5	39.6	4.8	24.7	17.0	6.6	35	15.3	246	6.65	28	37
2		200	393.7	47.0	4.4	19.8	14.9	7.6	35	12.8	281	6.22	31	38
2	Carioca	100	297.5	47.6	5.4	26.9	20.5	7.5	40	18.6	355	7.28	32	45
2		200	319.4	51.1	4.8	19.2	17.3	8.1	38	15.2	324	6.48	29	39
2	Mono. Domino	200	283.1	45.3	4.4	19.8	15.7	7.1	33	13.8	444	6.12	28	39
2	Mono. Carioca	200	285.6	45.7	5.0	22.7	18.6	7.2	34	19.4	383	7.10	30	43

1985 Cropping Season (cont'd.)

			gm/kg						mg/kg					
Replication	Variety	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	256.2	41.0	5.4	28.7	22.4	6.6	42	25.1	382	6.71	33	48
3		200	277.5	44.4	4.8	19.6	22.9	7.7	38	18.9	379	7.48	32	44
3	Carioca	100	272.5	43.6	5.0	27.2	18.0	7.2	37	14.9	352	7.13	31	42
3		200	318.7	51.0	4.9	21.6	18.4	7.2	37	15.4	281	7.18	33	44
3	Mono. Domino	200	142.5	22.8	4.9	23.7	20.5	7.2	37	18.0	384	7.55	32	47
3	Mono. Carioca	200	254.4	40.7	5.4	25.3	19.2	7.5	38	17.0	361	7.49	29	46
4	Domino	100	227.5	36.4	5.1	26.2	27.0	6.3	39	23.0	525	7.76	31	47
4		200	193.1	30.9	4.9	28.2	23.6	6.6	40	22.4	368	6.73	34	42
4	Carioca	100	355.0	56.8	6.0	35.1	24.8	6.7	44	20.9	454	7.61	35	51
4		200	257.5	41.2	5.4	35.3	26.5	7.2	43	20.8	496	8.36	35	48
4	Mono. Domino	200	248.1	39.7	4.8	32.7	27.7	6.8	37	20.9	470	7.85	28	48
4	Mono. Carioca	200	275.0	44.0	6.3	29.4	22.2	6.2	38	20.4	377	6.92	33	51

1986 Cropping Season

Replication	Variety	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
			gm/kg						mg/kg					
1	Domino	100	341.2	54.6	5.8	25.0	33.8	8.2	64	19.1	346	9.77	107	52
1		200	392.5	62.8	6.7	24.0	28.8	8.4	63	16.9	488	9.23	141	56
1	Carioca	100	250.6	40.1	6.0	25.5	35.7	9.2	67	15.1	499	11.10	124	60
		200	278.7	44.6	5.2	19.4	37.6	11.2	67	15.8	520	11.20	113	58
1	Mono. Domino	200	391.9	62.7	5.7	21.2	35.4	9.4	51	15.7	191	9.42	99	54
1	Mono. Carioca	200	298.1	47.7	6.0	22.1	29.1	8.9	51	12.6	225	10.70	64	48
2	Domino	100	310.0	49.6	5.6	28.0	54.1	8.8	69	20.0	346	10.20	135	47
2		200	338.1	54.1	6.3	23.8	28.8	8.6	60	18.1	597	9.65	125	55
2	Carioca	100	240.0	38.4	6.0	31.4	50.0	7.9	71	15.7	652	12.50	122	51
2		200	311.2	49.8	7.1	30.8	31.0	9.7	69	16.5	595	10.20	119	68
2	Mono. Domino	200	344.4	55.1	7.7	30.0	42.9	8.9	55	17.6	345	9.20	122	72
2	Mono. Carioca	200	306.2	49.0	5.7	25.4	56.2	9.8	52	17.9	301	10.60	83	51

1986 Cropping Season (cont'd.)

			gm/kg						mg/kg					
Replication	Variety	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	327.5	52.4	5.2	17.4	38.1	8.8	57	16.0	310	9.68	115	50
3		200	340.0	54.4	6.2	22.5	49.6	9.5	54	18.7	338	10.30	86	51
3	Carioca	100	323.1	51.7	6.3	30.1	50.5	9.6	77	18.2	473	12.90	131	59
3		200	331.2	53.0	5.8	26.5	57.5	10.1	73	17.5	688	11.90	126	56
3	Mono. Domino	200	350.6	56.1	5.1	16.6	32.6	10.7	46	11.7	178	9.05	78	40
3	Mono. Carioca	200	314.4	50.3	5.9	23.7	53.7	10.3	51	14.5	343	11.50	67	47
4	Domino	100	370.0	59.2	4.8	14.8	27.0	8.3	44	11.6	274	9.22	85	37
4		200	285.0	45.6	4.6	17.9	35.4	11.2	51	13.3	283	9.92	77	41
4	Carioca	100	243.7	39.0	4.7	21.1	25.1	7.8	59	15.2	790	14.70	101	50
4		200	341.9	54.7	5.9	28.3	33.1	8.8	67	17.4	464	13.00	94	52
4	Mono. Domino	200	340.0	54.4	5.7	16.7	34.1	10.9	47	12.9	212	9.59	100	44
4	Mono. Carioca	200	316.9	50.7	5.3	20.7	38.7	9.9	52	12.6	227	11.80	61	45

APPENDIX H

MAIZE LEAF NUTRIENT CONCENTRATION

APPENDIX H

MAIZE LEAF NUTRIENT CONCENTRATION

1984 Cropping Season

Replication	Maize Intercropped with	Density (10^3 pl/ha)	gm/kg					mg/kg					
			N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	20.6	4.4	19.9	7.7	5.0	14.7	15.3	130	4.95	35	67
1		200	35.0	4.4	22.5	6.4	4.5	13.8	14.1	140	4.49	43	59
1	Carioca	100	18.8	4.5	23.5	7.8	4.9	14.2	15.9	131	4.74	39	62
1		200	23.3	3.9	20.1	6.9	4.7	11.1	13.5	116	4.65	35	52
1	Mono. Maize	40	23.6	4.9	26.5	8.6	4.7	12.3	18.3	153	4.90	58	75
2	Domino	100	16.1	4.5	22.2	8.1	5.0	11.2	15.4	138	5.67	43	63
2		200	21.6	4.2	20.7	6.5	5.0	13.0	13.7	128	4.42	41	58
2	Carioca	100	20.3	4.6	24.0	7.4	4.4	11.4	15.6	140	5.35	50	64
2		200	23.3	4.5	21.8	6.7	4.7	10.8	14.8	128	5.09	46	61
2	Mono. Maize	40	23.1	4.4	19.8	7.1	5.3	10.2	14.1	134	5.99	37	64

1984 Cropping Season (cont'd.)

Replication	Maize Intercropped with	Density (10^3 pl/ha)	gm/kg					mg/kg					
			N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	33.6	4.5	26.7	7.4	4.5	10.5	16.1	134	4.98	43	54
3		200	23.6	4.3	20.8	7.4	5.7	11.1	15.3	126	5.21	41	63
3	Carioca	100	32.2	5.8	25.3	8.1	5.6	12.7	16.0	150	5.85	56	64
3		200	20.5	4.6	23.8	7.6	5.3	11.3	15.4	132	5.19	45	60
3	Mono. Maize	40	34.5	5.1	24.8	8.3	6.1	11.8	17.2	143	6.20	50	66
4	Domino	100	23.3	4.2	23.6	7.9	4.4	10.3	18.3	119	5.30	43	55
4		200	31.6	4.3	24.5	6.5	4.5	10.8	14.7	117	5.09	32	49
4	Carioca	100	32.2	5.0	25.6	8.1	4.9	12.3	15.8	141	5.75	47	60
4		200	23.6	3.8	21.3	6.1	3.8	9.4	14.7	122	5.31	36	54
4	Mono. Maize	40	35.6	4.6	27.2	9.1	5.0	11.0	16.6	147	6.54	42	67

1985 Cropping Season

Replication	Maize Intercropped with	Density (10^3 pl/ha)	gm/kg					mg/kg					
			N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	23.8	3.4	17.0	8.1	5.0	13.2	11.3	96	4.98	16	43
1		200	31.4	3.6	21.1	6.2	3.8	12.1	11.2	93	3.97	18	44
1	Carioca	100	32.8	3.5	17.9	6.9	4.4	10.6	17.4	101	4.54	16	42
1		200	21.1	3.7	18.2	7.2	5.0	10.2	15.0	101	4.67	17	44
1	Mono. Maize	40	23.8	3.9	19.8	8.8	5.4	9.6	14.0	110	5.24	14	48
2	Domino	100	35.2	3.4	19.4	8.9	4.9	10.8	14.0	112	5.06	14	42
2		200	22.2	3.2	17.8	6.9	4.5	11.5	11.7	94	4.22	14	42
2	Carioca	100	34.7	3.3	18.9	4.7	3.5	10.6	11.9	93	3.62	16	39
2		200	35.1	4.1	24.0	6.2	3.0	10.8	13.6	108	4.38	20	51
2	Mono. Maize	40	35.4	3.7	19.4	9.6	5.5	11.8	15.3	122	5.84	17	51

1985 Cropping Season (cont'd.)

Replication	Maize Intercropped with	Density (10^3 pl/ha)	gm/kg					mg/kg					
			N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	34.0	4.2	22.3	5.0	3.8	10.3	10.8	107	3.38	19	46
3		200	35.1	3.6	15.8	6.6	5.1	10.7	11.6	104	4.40	19	54
3	Carioca	100	33.2	4.1	22.0	5.8	4.1	11.8	10.7	114	3.72	22	47
3		200	23.8	3.9	18.7	5.8	4.4	9.9	9.6	101	3.85	20	44
3	Mono. Maize	40	23.6	4.1	18.3	6.0	5.0	9.5	10.0	107	4.07	15	44
4	Domino	100	25.4	4.1	23.3	7.8	4.9	14.2	13.5	104	4.33	18	45
4		200	22.8	4.5	27.5	5.6	3.3	11.6	19.3	114	3.80	23	46
4	Carioca	100	26.0	4.8	28.5	7.2	3.6	13.8	14.4	129	4.69	25	60
4		200	32.5	4.3	26.5	7.3	3.7	13.1	14.1	124	5.35	25	60
4	Mono. Maize	40	23.2	3.4	19.4	6.1	3.7	9.8	11.5	112	4.51	15	50

1986 Cropping Season

Replication	Maize Intercropped with	Density (10^3 pl/ha)	gm/kg					mg/kg					
			N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	36.5	5.4	26.3	7.5	4.1	8.78	17.5	153	5.57	58	84
1		200	17.9	5.6	27.4	8.3	4.7	8.83	18.8	163	6.38	74	89
1	Carioca	100	36.8	6.1	33.1	10.3	4.1	13.2	22.1	174	6.83	73	96
1		200	31.8	5.0	28.8	8.9	4.2	8.86	18.4	155	6.87	72	73
1	Mono. Maize	40	35.4	5.5	31.1	8.5	3.7	9.85	20.6	174	5.89	90	92
2	Domino	100	28.3	5.3	25.1	7.9	4.6	9.93	17.3	146	5.72	69	87
2		200	22.9	4.5	24.0	6.8	4.1	8.37	16.4	133	4.96	57	73
2	Carioca	100	28.7	5.6	26.9	10.2	5.0	9.71	20.9	169	6.64	84	87
2		200	12.2	4.9	22.3	6.7	4.6	8.67	16.4	140	5.46	66	72
2	Mono. Maize	40	13.7	5.5	27.6	7.6	4.8	9.11	18.1	155	6.07	69	82

1986 Cropping Season (cont'd.)

Replication	Maize Intercropped with	Density (10^3 pl/ha)	gm/kg					mg/kg					
			N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	36.5	4.7	24.0	8.6	4.7	8.6	18.5	144	6.58	67	60
3		200	32.5	5.5	23.2	8.1	5.5	10.2	17.8	133	5.60	56	65
3	Carioca	100	35.4	5.4	25.2	9.6	6.3	11.0	19.4	155	7.34	77	71
3		200	36.1	5.2	27.9	9.5	5.5	9.5	20.2	154	6.49	77	79
3	Mono. Maize	40	35.5	5.6	27.5	9.9	6.3	11.1	23.9	160	7.89	80	80
4	Domino	100	36.0	4.0	21.1	8.8	5.3	9.6	17.0	121	6.36	60	56
4		200	34.3	5.3	24.2	10.6	6.6	11.8	18.7	155	8.11	55	65
4	Carioca	100	35.9	5.3	24.7	8.8	5.9	12.0	19.1	148	6.99	64	63
4		200	34.6	4.0	23.1	7.6	4.1	9.0	21.1	131	6.06	51	54
4	Mono. Maize	40	43.9	4.8	25.8	8.8	5.5	10.5	16.4	148	7.68	55	58

APPENDIX I

BEAN SEED NUTRIENT CONCENTRATION

APPENDIX I

BEAN SEED NUTRIENT CONCENTRATION

1984 Growing Season

			gm/kg						mg/kg					
Replication	Variety	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	260.0	41.6	4.9	13.5	1.6	2.3	8.72	12.20	79	5.44	11.80	31
1		200	285.6	45.7	4.8	13.5	1.7	2.2	9.59	13.50	87	6.26	11.60	32
1	Carioca	100	277.5	49.4	4.4	11.9	1.8	2.3	9.96	12.50	76	4.54	11.90	36
1		200	248.1	39.7	4.7	12.7	1.5	2.3	10.70	11.70	63	5.13	12.30	33
1	Mono. Domino	200	275.6	44.1	4.8	13.3	1.4	2.1	9.11	12.50	69	4.06	11.80	35
1	Mono. Carioca	200	257.5	41.2	4.7	13.1	1.3	2.0	9.90	11.40	69	4.26	11.60	29
2	Domino	100	269.4	43.1	5.1	14.5	1.7	2.2	9.59	13.10	75	6.07	13.10	34
2		200	285.6	45.7	4.7	13.1	1.7	2.3	9.43	13.60	71	6.14	12.60	32
2	Carioca	100	317.5	50.8	4.2	12.5	1.9	2.4	11.30	10.10	71	5.48	11.80	32
2		200	255.0	40.8	4.3	12.6	1.7	2.3	12.20	13.40	82	6.47	11.70	49
2	Mono. Domino	200	265.6	42.5	4.5	12.4	1.6	2.1	11.20	13.20	71	5.38	11.40	33
2	Mono. Carioca	200	307.5	49.2	4.8	13.3	1.4	2.2	10.90	10.50	60	4.82	12.40	30

1984 Growing Season (cont'd.)

Replication	Variety	Density (10^3 pl/ha)	gm/kg						mg/kg					
			Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	261.2	41.8	5.0	13.6	1.5	2.2	9.75	10.60	84	5.64	13.60	35
3		200	278.1	44.5	4.9	13.6	1.6	2.1	9.98	11.00	78	5.99	13.10	36
3	Carioca	100	269.4	43.1	4.3	12.0	1.7	2.2	11.00	10.10	67	4.58	11.70	34
3		200	256.9	41.1	5.0	13.6	1.6	2.2	10.60	9.88	63	5.87	13.20	32
3	Mono. Domino	200	264.4	42.3	4.8	13.6	1.5	2.1	8.83	10.90	76	4.97	11.90	33
3	Mono. Carioca	200	250.6	40.1	4.8	13.4	1.3	2.1	10.50	8.93	58	4.28	12.20	30
4	Domino	100	260.6	41.7	4.9	13.5	1.5	2.3	10.40	12.90	81	7.02	13.60	38
4		200	267.6	42.8	5.1	13.9	1.5	2.2	9.80	9.84	82	6.48	13.40	35
4	Carioca	100	265.6	42.5	5.0	13.1	1.7	2.4	11.30	11.20	70	5.49	13.00	38
4		200	271.9	43.5	5.9	14.8	1.1	2.1	11.90	12.70	74	6.33	15.00	35
4	Mono. Domino	200	258.7	41.4	5.2	14.0	1.4	2.1	10.90	9.21	75	5.27	12.40	29
4	Mono. Carioca	200	265.0	42.4	5.0	13.4	1.2	2.0	13.00	10.20	65	4.59	12.30	41

1985 Growing Season

Replication	Variety	Density (10^3 pl/ha)	gm/kg						mg/kg					
			Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	268.7	43.0	4.8	14.0	1.6	2.3	10.50	14.90	78	4.62	9.47	32
1		200	256.9	41.1	5.0	14.2	1.8	2.2	9.45	14.40	69	3.13	9.53	33
1	Carioca	100	251.9	40.3	4.1	12.5	2.5	2.5	9.45	12.50	72	4.18	8.51	33
1		200	267.5	42.8	4.9	13.3	2.0	2.4	9.98	11.70	68	4.10	8.01	32
1	Mono. Domino	200	266.2	42.6	4.7	12.4	1.6	1.9	10.60	13.50	61	4.24	8.79	30
1	Mono. Carioca	200	263.7	42.2	4.9	13.0	2.6	2.3	10.10	12.10	63	3.72	8.47	31
2	Domino	100	269.4	43.1	5.2	14.6	1.2	2.2	9.45	12.50	64	3.72	10.50	32
2		200	303.7	48.6	5.2	13.9	1.5	2.2	9.58	13.00	60	3.66	11.10	30
2	Carioca	100	249.4	39.9	4.2	13.0	2.1	2.3	9.03	11.50	52	3.36	9.39	29
2		200	297.5	47.6	4.3	12.5	2.0	2.3	8.58	10.90	59	3.32	8.24	33
2	Mono. Domino	200	275.6	44.1	4.9	13.4	2.0	2.3	9.70	12.30	73	3.31	9.17	35
2	Mono. Carioca	200	235.0	37.6	5.0	12.8	1.9	2.3	9.94	11.00	53	3.18	9.48	31

1985 Growing Season (cont'd.)

Replication	Variety	Density (10^3 pl/ha)	gm/kg Protein	N	P	K	Ca	Mg	mg/kg B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	300.0	48.0	5.5	13.7	1.6	2.5	9.37	14.40	75	3.26	9.76	33
3		200	262.5	42.0	5.5	14.1	2.2	2.5	8.88	13.30	67	3.68	10.60	32
3	Carioca	100	343.1	54.9	5.9	14.2	1.3	2.3	9.53	11.10	60	2.56	10.30	39
3		200	331.9	53.1	7.9	16.4	1.3	2.6	9.69	15.30	77	3.68	13.40	54
3	Mono. Domino	200	276.9	44.3	6.1	15.1	1.8	2.6	9.98	12.80	67	5.01	10.90	35
3	Mono. Carioca	200	260.0	41.6	5.2	12.1	2.0	2.4	9.11	11.30	55	4.29	8.72	35
4	Domino	100	300.0	48.0	6.0	14.1	1.6	2.3	9.85	13.40	69	5.79	9.40	33
4		200	291.2	46.6	5.4	14.3	1.7	2.5	8.86	14.70	75	4.60	10.40	33
4	Carioca	100	212.5	34.0	7.4	16.8	1.9	2.9	10.70	13.70	71	6.19	12.40	43
4		200	228.7	36.6	7.3	13.9	1.8	2.6	8.60	14.10	71	6.93	11.10	40
4	Mono. Domino	200	308.1	49.3	6.3	14.3	1.5	2.4	10.90	14.10	73	4.80	9.53	36
4	Mono. Carioca	200	329.4	52.7	7.4	14.1	1.3	2.5	7.85	12.10	57	4.63	10.20	38

1986 Growing Season

Replication	Variety	Density (10^3 pl/ha)	gm/kg						mg/kg					
			Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	293.7	47.0	4.8	15.4	1.2	2.2	12.20	10.40	72	2.36	14.90	34
1		200	275.0	44.0	4.3	13.6	1.7	2.1	10.30	9.93	74	2.62	12.90	29
1	Carioca	100	285.6	45.7	4.1	12.5	1.2	2.0	10.50	9.40	64	1.99	12.00	32
1		200	280.0	44.8	4.1	12.7	1.5	2.2	10.20	8.97	67	3.58	11.40	44
1	Mono. Domino	200	266.2	42.6	4.3	12.8	1.6	2.0	9.33	9.10	64	2.07	12.10	30
1	Mono. Carioca	200	278.7	44.6	3.6	11.4	2.4	2.1	9.24	7.95	52	3.29	10.50	25
2	Domino	100	296.9	47.5	4.8	14.3	1.0	2.1	12.90	11.30	67	2.67	14.20	35
2		200	303.7	48.6	4.3	13.8	1.3	2.1	11.40	9.81	65	2.86	13.50	33
2	Carioca	100	250.0	40.0	4.0	12.6	1.4	2.1	11.00	7.29	64	2.33	12.90	32
2		200	260.0	41.6	3.9	12.9	1.3	2.0	11.50	7.43	67	2.50	12.70	31
2	Mono. Domino	200	255.6	40.9	4.3	12.4	1.5	2.0	9.63	10.50	68	2.50	12.20	28
2	Mono. Carioca	200	261.2	41.8	4.0	11.8	2.1	2.2	10.60	7.64	56	3.11	10.80	29

1986 Growing Season (cont'd.)

Replication	Variety	Density (10^3 pl/ha)	gm/kg Protein	N	P	K	Ca	Mg	mg/kg B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	299.4	47.9	4.8	13.3	1.3	2.2	10.60	10.80	75	4.66	12.60	33
3		200	303.7	48.6	4.8	13.6	1.3	2.3	10.50	10.00	74	4.18	13.00	35
3	Carioca	100	283.1	45.3	4.9	12.9	1.3	2.2	12.40	8.77	77	4.88	13.20	35
3		200	278.1	44.5	4.5	12.9	1.3	2.0	13.00	8.50	67	4.13	12.90	33
3	Mono. Domino	200	298.7	47.8	4.6	12.8	1.8	2.4	11.00	18.30	85	4.13	11.50	41
3	Mono. Carioca	200	265.6	42.5	4.1	12.1	1.9	2.2	9.86	7.98	58	4.01	11.30	28
4	Domino	100	335.6	53.7	5.0	13.4	1.0	2.2	10.40	8.30	74	3.49	12.90	34
4		200	310.0	49.6	5.2	13.9	1.2	2.3	10.70	9.32	82	6.90	12.70	33
4	Carioca	100	291.2	46.6	4.7	12.1	1.2	2.2	11.30	7.97	69	4.87	11.70	32
4		200	283.7	45.4	4.3	13.0	2.0	2.4	11.70	7.42	71	4.83	11.80	32
4	Mono. Domino	200	290.6	46.5	4.7	12.4	1.6	2.3	9.89	9.09	77	4.16	11.90	45
4	Mono. Carioca	200	252.5	40.4	4.0	12.2	2.0	2.3	9.87	7.19	56	5.18	10.90	30

APPENDIX J

MAIZE SEED NUTRIENT CONCENTRATION

APPENDIX J

MAIZE SEED NUTRIENT CONCENTRATION

1984 Cropping Season

			gm/kg						mg/kg					
Replication	Maize Intercropped With	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	93.1	14.9	5.7	4.8	0.2	2.1	2.37	4.12	24	.23	5.20	31
1		200	100.0	16.0	6.3	5.2	0.2	2.4	2.38	4.24	28	.23	6.47	31
1	Carioca	100	86.9	13.9	6.5	5.1	0.1	2.4	2.38	5.77	31	.32	6.78	44
1		200	98.1	15.7	6.6	5.3	0.2	2.5	2.65	3.48	30	.16	7.64	35
1	Mono. Maize	40	98.7	15.8	6.3	5.2	0.2	2.3	2.58	4.04	30	.25	6.75	31
2	Domino	100	91.9	14.7	6.2	4.9	0.2	2.4	2.29	4.36	28	.24	7.23	34
2		200	93.7	15.0	6.8	5.1	0.2	2.7	2.59	4.01	31	.44	7.85	34
2	Carioca	100	93.7	15.0	6.8	5.1	0.2	2.7	2.51	5.97	32	.29	8.31	39
2		200	94.4	15.1	6.3	5.0	0.2	2.5	2.49	4.13	30	.31	7.52	35
2	Mono. Maize	40	90.0	14.4	6.7	5.0	0.2	2.5	2.19	5.09	32	.12	7.27	33

1984 Cropping Season (cont'd.)

			gm/kg						mg/kg					
Replication	Maize Intercropped With	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	96.2	15.4	6.3	4.8	0.2	2.5	2.32	3.92	30	.38	7.55	33
3		200	91.9	14.7	6.9	4.6	0.1	2.7	2.52	3.19	31	.50	9.05	36
3	Carioca	100	101.2	16.2	6.8	5.2	0.2	2.6	2.49	4.03	31	.23	8.23	36
3		200	81.2	13.0	6.7	4.9	0.2	2.6	2.51	5.33	32	.34	8.22	38
3	Mono. Maize	40	86.2	13.8	7.0	5.2	0.2	2.6	2.88	4.99	35	.27	8.31	37
4	Domino	100	79.4	14.3	5.6	4.2	0.2	2.2	2.41	4.37	26	.46	6.58	29
4		200	79.4	15.9	6.0	4.1	0.1	2.4	2.46	2.61	27	.51	6.99	30
4	Carioca	100	90.0	14.4	5.9	4.4	0.2	2.3	2.14	3.73	26	.40	6.77	29
4		200	103.7	16.6	6.0	4.3	0.1	2.4	2.37	4.18	29	.58	7.36	40
4	Mono. Maize	40	87.5	14.0	6.1	4.6	0.2	2.3	2.69	3.69	30	.33	7.48	31

1985 Cropping Season

Replication	Maize Intercropped With	Density (10^3 pl/ha)	gm/kg						mg/kg					
			Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	106.9	17.1	5.8	5.0	0.2	2.2	3.24	4.77	28	.65	5.61	36
1		200	96.2	15.4	4.6	4.4	0.2	1.7	2.89	3.95	24	.59	4.53	24
1	Carioca	100	116.2	18.6	5.5	4.1	0.2	2.2	2.77	5.02	31	.63	6.39	28
1		200	107.5	17.2	6.0	4.4	0.2	2.3	3.12	3.53	28	.67	5.50	32
1	Mono. Maize	40	111.9	17.9	5.9	4.9	0.2	2.3	3.00	3.63	29	.47	6.04	31
2	Domino	100	100.6	16.1	4.9	4.2	0.2	1.9	2.23	3.05	23	.33	4.44	26
2		200	103.1	16.5	5.3	4.5	0.2	2.0	3.37	3.92	26	.58	4.88	30
2	Carioca	100	95.6	15.3	4.8	4.2	0.2	1.8	1.94	4.29	27	.23	4.32	26
2		200	108.1	17.3	5.6	4.8	0.2	2.0	2.95	3.54	24	.35	4.53	29
2	Mono. Maize	40	100.6	16.1	5.2	5.0	0.2	1.8	2.89	3.96	24	.38	4.41	31

1985 Cropping Season (cont'd.)

			gm/kg						mg/kg					
Replication	Maize Intercropped With	Density (10^3 pl/ha)	Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	103.1	16.5	5.1	4.4	0.2	1.9	2.20	4.66	31	.26	4.09	31
3		200	103.1	16.5	5.6	4.7	0.2	2.1	2.48	3.91	28	.24	4.90	31
3	Carioca	100	104.4	16.7	5.1	4.2	0.2	1.9	1.98	4.72	24	.27	3.87	27
3		200	101.9	16.3	4.9	4.1	0.2	1.8	1.98	4.76	24	.33	4.10	29
3	Mono. Maize	40	110.0	17.6	5.8	4.6	0.2	2.2	2.17	3.91	26	.34	4.40	31
4	Domino	100	93.7	15.0	5.3	4.0	0.2	2.0	2.65	3.49	25	.69	4.43	30
4		200	96.9	15.5	4.7	4.0	0.2	1.7	2.37	3.47	21	.40	3.87	26
4	Carioca	100	95.0	15.2	5.1	4.5	0.2	1.8	3.14	4.16	29	.65	4.27	28
4		200	100.0	16.0	4.9	4.1	0.2	1.8	2.64	3.30	24	.57	3.99	27
4	Mono. Maize	40	102.5	16.4	5.6	4.4	0.2	2.1	2.95	3.73	25	.64	5.09	35

1986 Cropping Season

Replication	Maize Intercropped With	Density (10^3 pl/ha)	gm/kg						mg/kg					
			Protein	N	P	K	Ca	Mg	B	Cu	Fe	Mo	Mn	Zn
1	Domino	100	100.0	16.0	5.0	4.9	0.2	1.8	2.32	5.33	30	.14	6.68	35
1		200	92.5	14.8	4.8	4.9	0.2	1.8	2.18	4.43	30	.14	6.30	31
1	Carioca	100	88.7	14.2	4.7	4.2	0.2	1.8	2.61	3.29	29	.50	5.90	31
1		200	99.4	15.9	4.8	4.1	0.2	1.9	3.09	3.84	28	.86	5.74	31
1	Mono. Maize	40	101.2	16.2	5.0	4.9	0.2	1.8	2.21	4.38	31	.25	6.07	32
2	Domino	100	108.7	17.4	4.5	4.4	0.2	1.7	2.17	3.87	30	.14	6.11	27
2		200	95.0	15.2	4.5	4.8	0.2	1.7	2.11	4.21	32	.22	6.15	32
2	Carioca	100	105.6	16.9	5.0	4.7	0.2	1.9	2.50	4.13	31	.10	6.57	30
2		200	90.6	14.5	4.3	4.7	0.2	1.6	2.08	4.08	29	.10	5.81	31
2	Mono. Maize	40	102.5	16.4	4.7	4.8	0.2	1.7	2.23	4.10	31	.20	6.11	29

1986 Cropping Season (cont'd.)

Replication	Maize Intercropped With	Density (10^3 pl/ha)	gm/kg Protein	N	P	K	Ca	Mg	mg/kg B	Cu	Fe	Mo	Mn	Zn
3	Domino	100	98.1	15.7	4.4	4.4	0.2	1.8	2.88	4.12	39	.30	5.60	29
3		200	106.2	17.0	4.1	4.4	0.2	1.8	2.37	3.22	29	.43	5.53	29
3	Carioca	100	103.7	16.6	3.7	3.8	0.2	1.5	2.20	3.30	26	.26	4.63	22
3		200	105.6	16.9	4.2	3.8	0.2	1.7	2.52	3.51	27	.31	5.42	26
3	Mono. Maize	40	93.7	15.0	4.0	3.9	0.2	1.6	1.93	3.51	29	.40	5.10	24
4	Domino	100	97.5	15.6	5.5	5.0	0.3	2.3	2.72	5.64	34	.70	7.34	36
4		200	104.4	16.7	4.4	4.3	0.2	1.8	2.78	3.25	30	.53	5.53	28
4	Carioca	100	116.9	18.7	3.8	3.7	0.2	1.6	1.77	3.49	24	.32	5.01	22
4		200	111.9	17.9	4.1	3.9	0.2	1.7	1.93	4.02	39	.40	6.11	25
4	Mono. Maize	40	109.4	17.5	4.6	4.5	0.2	1.9	2.77	3.20	33	.48	5.67	28

APPENDIX K

BEAN CARBOHYDRATE CONCENTRATION

APPENDIX K

BEAN CARBOHYDRATE CONCENTRATION

1984 Cropping Season

			gm/kg								
Replication	Bean Cultivar	Density (10^3 pl/ha)	Root Starch	Root Sugar	Root TNC	Stem Starch	Stem Sugar	Stem TNC	Leaf Starch	Leaf Sugar	Leaf TNC
1	Domino	100	33	49	82	35	83	118	21	27	48
1		200	26	50	76	44	61	105	19	34	53
1	Carioca	100	34	59	93	37	79	116	25	26	51
1		200	29	42	71	32	75	107	24	35	59
1	Mono. Domino	200	50	53	103	45	64	109	26	34	60
1	Mono. Carioca	200	40	69	109	41	110	151	27	33	60
2	Domino	100	36	50	86	38	87	125	26	29	55
2		200	41	41	82	35	67	102	28	34	62
2	Carioca	100	43	38	81	33	80	113	27	26	53
2		200	38	52	90	53	101	154	28	29	57
2	Mono. Domino	200	44	59	103	50	90	140	29	32	61
2	Mono. Carioca	200	55	40	95	31	81	112	28	31	59

1984 Cropping Season (cont'd.)

Replication	Bean Cultivar	Density (10^3 pl/ha)	gm/kg Root Starch	Root Sugar	Root TNC	Stem Starch	Stem Sugar	Stem TNC	Leaf Starch	Leaf Sugar	Leaf TNC
3	Domino	100	31	41	72	37	55	92	18	24	42
3		200	47	53	100	31	36	67	29	26	55
3	Carioca	100	19	29	48	38	39	77	21	27	48
3		200	33	44	77	48	71	119	24	34	58
3	Mono. Domino	200	49	49	98	34	54	88	29	34	63
3	Mono. Carioca	200	29	52	81	49	87	136	29	37	66
4	Domino	100	33	42	75	54	62	116	24	21	45
4		200	54	43	97	32	38	70	28	23	51
4	Carioca	100	29	40	69	31	50	81	26	23	49
4		200	45	46	91	59	68	127	21	25	46
4	Mono. Domino	200	60	46	106	54	61	115	25	28	53
4	Mono. Carioca	200	45	46	91	39	82	121	26	25	51

1985 Cropping Season

			gm/kg								
Replication	Bean Cultivar	Density (10^3 pl/ha)	Root Starch	Root Sugar	Root TNC	Stem Starch	Stem Sugar	Stem TNC	Leaf Starch	Leaf Sugar	Leaf TNC
1	Domino	100	70	68	138	72	121	193	22	45	67
1		200	60	53	113	58	88	146	22	28	50
1	Carioca	100	25	46	71	40	117	157	25	36	61
1		200	56	81	137	91	136	227	26	36	62
1	Mono. Domino	200	108	67	175	81	131	212	25	49	74
1	Mono. Carioca	200	52	57	109	57	124	181	24	36	60
2	Domino	100	95	71	166	46	119	165	26	36	62
2		200	84	58	142	42	116	158	25	32	57
2	Carioca	100	33	52	85	41	105	146	25	30	55
2		200	72	81	153	75	126	201	26	38	64
2	Mono. Domino	200	59	66	125	55	117	172	25	31	56
2	Mono. Carioca	200	44	63	107	46	121	167	23	32	55

1985 Cropping Season (cont'd.)

			gm/kg								
Replication	Bean Cultivar	Density (10^3 pl/ha)	Root Starch	Root Sugar	Root TNC	Stem Starch	Stem Sugar	Stem TNC	Leaf Starch	Leaf Sugar	Leaf TNC
3	Domino	100	71	56	127	43	93	136	22	39	61
3		200	79	49	128	51	106	157	26	39	65
3	Carioca	100	33	36	69	56	89	145	29	43	72
3		200	47	66	113	96	109	205	25	47	72
3	Mono. Domino	200	88	60	148	60	90	150	25	34	59
3	Mono. Carioca	200	55	58	113	74	113	187	25	35	60
4	Domino	100	53	54	107	60	101	161	24	40	64
4		200	87	55	142	54	110	164	27	41	68
4	Carioca	100	35	45	80	45	112	157	26	38	64
4		200	53	57	110	67	93	160	20	52	72
4	Mono. Domino	200	78	59	137	91	115	206	25	44	69
4	Mono. Carioca	200	51	58	109	38	95	133	24	38	62

1986 Cropping Season

Replication	Bean Cultivar	Density (10^3 pl/ha)	gm/kg Root Starch	Root Sugar	Root TNC	Stem Starch	Stem Sugar	Stem TNC	Leaf Starch	Leaf Sugar	Leaf TNC
1	Domino	100	41	27	68	30	61	91	25	42	67
1		200	50	37	87	40	92	132	21	46	67
1	Carioca	100	42	26	68	31	73	104	23	40	63
1		200	45	31	76	45	96	141	25	53	78
1	Mono. Domino	200	48	37	85	43	68	101	28	38	66
1	Mono. Carioca	200	44	34	78	42	79	121	30	41	71
2	Domino	100	45	41	86	41	101	142	21	43	64
2		200	48	44	92	40	96	136	26	47	73
2	Carioca	100	43	27	70	35	60	95	22	29	51
2		200	48	27	75	36	66	102	25	45	70
2	Mono. Domino	200	45	35	80	39	57	96	20	30	50
2	Mono. Carioca	200	41	26	67	35	62	97	21	33	54

1986 Cropping Season (cont'd.)

			gm/kg								
Replication	Bean Cultivar	Density (10^3 pl/ha)	Root Starch	Root Sugar	Root TNC	Stem Starch	Stem Sugar	Stem TNC	Leaf Starch	Leaf Sugar	Leaf TNC
3	Domino	100	29	20	49	35	52	87	26	29	55
3		200	35	27	62	41	54	95	31	30	61
3	Carioca	100	28	18	46	24	37	61	27	27	54
3		200	22	31	53	31	68	99	27	37	64
3	Mono. Domino	200	41	39	80	38	78	116	29	26	55
3	Mono. Carioca	200	30	30	60	28	72	100	25	30	55
4	Domino	100	36	33	69	37	83	120	24	31	55
4		200	42	37	79	43	92	135	21	37	58
4	Carioca	100	27	28	55	30	95	125	33	32	65
4		200	30	34	64	32	92	124	27	31	58
4	Mono. Domino	200	43	34	77	39	83	122	25	29	54
4	Mono. Carioca	200	33	25	58	34	103	137	24	28	52

APPENDIX L

GLUCOSE STANDARD SOLUTIONS

APPENDIX L

GLUCOSE STANDARD SOLUTIONS

Stock Standard	Distilled Water	Final Sugar Concentration
0 ml	10.0 ml	0 mg/L
.1 ml	9.9 ml	10 mg/L
.2 ml	9.8 ml	20 mg/L
.3 ml	9.7 ml	30 mg/L
.4 ml	9.6 ml	40 mg/L
.5 ml	9.5 ml	50 mg/L
.6 ml	9.4 ml	60 mg/L
.7 ml	9.3 ml	70 mg/L
.8 ml	9.2 ml	80 mg/L
.9 ml	9.1 ml	90 mg/L
1.0 ml	9.0 ml	100 mg/L

APPENDIX M

STARCH STANDARD SOLUTIONS

APPENDIX M

STARCH STANDARD SOLUTIONS

Stock Standard	Distilled Water	Final Starch Concentration
0 ml	4.0 ml	0 mg/L
.1 ml	3.9 ml	10 mg/L
.2 ml	3.8 ml	20 mg/L
.3 ml	3.7 ml	30 mg/L
.4 ml	3.6 ml	40 mg/L
.5 ml	3.5 ml	50 mg/L
.6 ml	3.4 ml	60 mg/L
.7 ml	3.3 ml	70 mg/L
.8 ml	3.2 ml	80 mg/L
.9 ml	3.1 ml	90 mg/L
1.0 ml	3.0 ml	100 mg/L

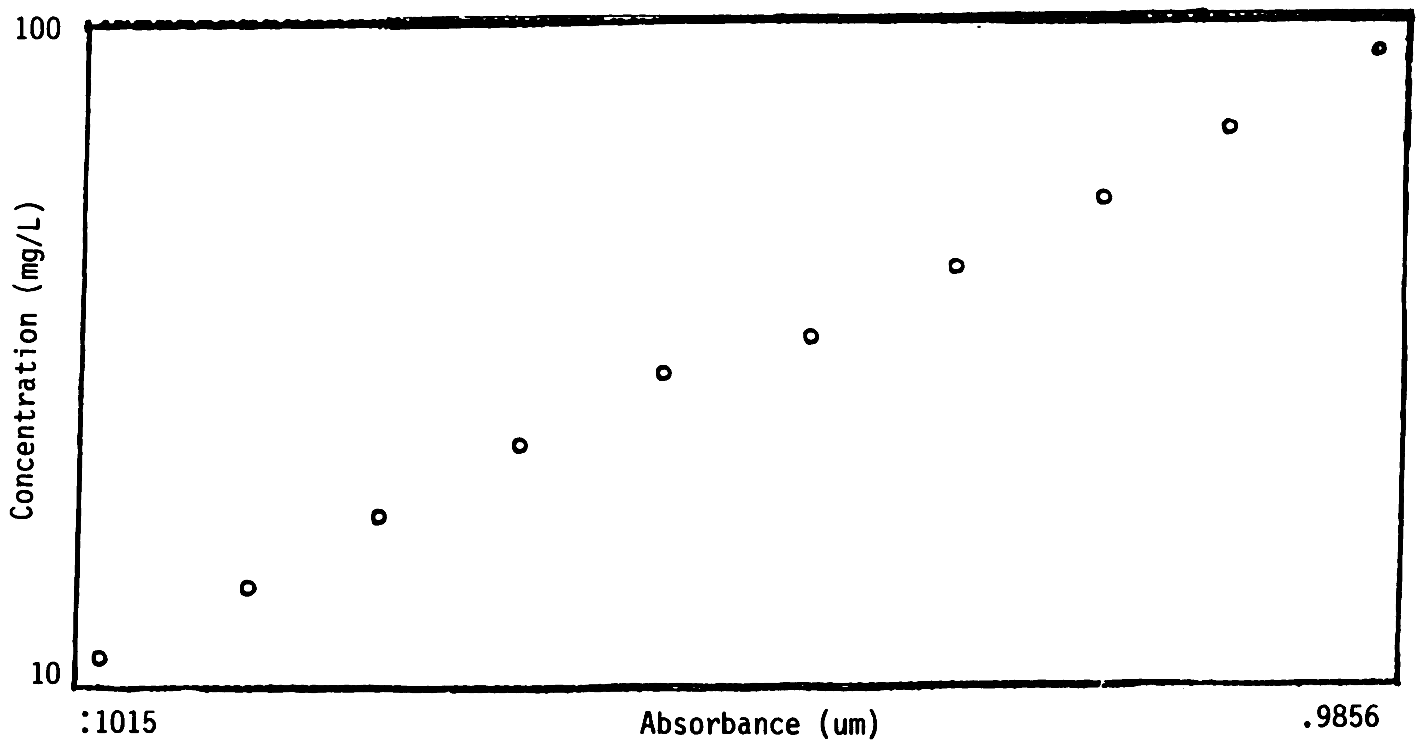
APPENDIX N

STANDARD CURVE FOR CARBOHYDRATE ANALYSIS

APPENDIX N

STANDARD CURVE FOR CARBOHYDRATE ANALYSIS

Quick Plot



Equation: Y = .1485132 + 100.9877* X: Correlation: r^2 = .999825

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