Multiple Cropping Potentials of Beans and Maize

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Multiple cropping systems are characterized by high plant species diversity, closed cycling of nutrients, reduced pest incidence, erosion control, low but stable yields, and an intensive exploitation of limited land resources. Used on small farms in Latin America for centuries, bean-maize systems provide a source of income and a balanced diet for the farm family. Limited technology has reached this sector of the agricultural population, and new research reveals an impressive potential for improving yields in the bean-maize cropping system.

Complex multiple cropping systems are relatively unknown in temperate, mechanized and commercial farming regions. Characterized by the simultaneous or relay planting of two or more crops in the same field, these systems predominate on small farms which produce cereals, grain legumes, starchy roots, plantains and other food crops in Latin America and in other tropical zones. Exceptions in the tropics include, in a few ecological zones, plantation crops and large mechanized farms with high inputs from modern technology.

Multiple cropping systems are characterized by high plant species diversity, closed cycling of soil nutrients, reduced pest incidence, erosion control, low but stable yields and an intensive exploitation of limited land resources (1, 8). Traditional systems provide the small farmer with a diversity in income and diet, as well as a degree of stability where large price fluctuations occur due to seasonal supply and limited storage of agricultural products. Small farmers have not benefited from improved technology because of the unavailability of appropriate recommendations and cultivars, and their lack of capital resources required to incorporate new practices. Traditional small farm systems are characterized by low use of technology, low but relatively stable yields and low investment and risk.

Bean-maize associations.

The center of origin for beans (Phaseolus vulgaris L.) and maize (Zea mays L.) includes the Central American and Andean zone centers described by Vavilov (21). Intercropping systems with the two species also evolved in these zones. Spanish conquerors and other explorers observed crop associations during their exploration of the Americas (19, 20). Indigenous peoples had developed useful crop cultivars, nutritious as a balanced diet, along with stable production systems. These associated cropping patterns have evolved with generations of farmers with small holdings, and still occupy an important role for food production in Latin America. Estimates of the proportion of beans produced in associated cropping systems are 40% in Mexico (17), 73% in Guatemala (14), 90% in Colombia (14), and 80% in Brazil (2). Surveys from various national programs indicate that about 60% of maize and 80% of beans are produced in associated cropping systems in Latin America (10).

In spite of the importance of these systems, only limited research has been done with associated cropping. Tropical research has designed cultivars and cultural practices for single crop systems that utilize infusions of capital, fertilizers, pesticides and other inputs necessary for larger farms and mechanization. In general, cultivars and cultural practices have been developed for a small number of favored ecological zones where production has increased markedly, conceptualized in the term "green revolution."

Results from controlled experiments and mechanized commercial farming areas have not reached the majority of farmers, and thus have caused only limited impact on national yields. In some cases, researchers have failed to identify the range of systems in which food crops are grown, and the complexity of factors which limit production in the tropics. Appropriate technology to improve these systems has not been available, or has been incorrectly applied. Pioneering works by Bradfield (7) and others have been summarized in several articles in a recent multiple cropping symposium (18). Significant efforts by national research programs, universities and international centers in the tropics are now under way to fill the technological gaps which exist in Latin America and elsewhere. Preliminary results indicate that new technology can be introduced into existing farming systems to increase production significantly.

Current yields and genetic potentials.

Present levels of dry bean and maize production are lower in the tropics than in temperate zones. For example, bean yields average 643 kg/ha in Latin America and 1,500 kg/ha in the U.S. Maize yields average 1,500 kg/ha in Latin America and 4,500 kg/ha in the U.S. Latin American averages are inflated by high yields of both crops in Argentina and Chile; subtracting yields from these 2 temperate countries, averages for the Latin American tropics and subtropics become 1,300 kg/ha for maize and 600 kg/ha for beans (5, 14, 16). Low yields reflect the complex and interrelated effects of planting traditional cultivars, limited use of new technology such as fertilizers and pesticides, and multiple cropping systems.

Potentials for production in a zone may be estimated in several ways. Commercial maize yields reach an
average of 2,700 kg/ha (Coast of Peru) and 3,500 kg/ha (Cauca Valley of Colombia) where improved technology is used. Some farmers harvest 5,000 to 6,000 kg/ha, and experimental yields on government stations reach 8,000 to 10,000 kg/ha in small plots. Bean yields in the Cauca Valley under commercial and high-input conditions average over 1,100 kg/ha while some farmers harvest 1,500 to 2,000 kg/ha (15). Experimental yields demonstrate that an increased production potential does exist in the tropics of Latin America. Most of the zone has a further potential for increased production through irrigation to produce two or more crops per year.

Effects of cropping systems.

Adverse climatic conditions, complex cropping systems and low levels of technology effectively reduce yield potentials of maize and beans. Research at CIAT has included proper land preparation, fertilizers (300 kg/ha of 15N–6.4P–12.4K), pesticides (4 to 8 applications/season), irrigation, and introduction of new cultivars to assess the potential for improving traditional cropping systems. Through agronomic studies of relative planting dates of the two crops, plant densities, planting systems and new cultivars, we have explored the hypothesis that planting either bush beans or climbing beans in association with maize can allow the farmer to realize a production and income stability which is greater than monoculture profits with good technology. An example of the close association of climbing beans with maize as support is shown in Fig. 1.

Planting date. Cropping systems exhibit a great range in relative dates of planting from monocultures of each crop planted in succession, or rotation, to a complete overlap of growth cycles with both crops planted on the same day. Our agronomic trials have focused on these extremes, under the assumption that the partial competition from relay or overlapping cropping patterns would give intermediate results. When both crops are planted on or near the same date, the absolute difference in planting date can be critical for yields. Fig. 2 illustrates the effect of planting 3 growth habits of beans as long as 15 days before maize, compared to simultaneous planting, and to a 15-day advance planting of maize. In all cases, the yield of maize planted before or simultaneously with beans was unaffected (9). When beans were planted before maize, the taller crop (maize) suffered from early competition, and yields were reduced 30 to 50% or more, depending on bean plant type and days to maturity.

Bean plant types react differently to maize competition. Yields of bush types II (indeterminate, erect) and III (indeterminate, branching) are reduced by simultaneous or earlier planting of maize. When planted 2 weeks before maize, yields may reach 70 to 80% of monocrop bush bean yields (13). The reduction in bean yield caused by early maize planting presumably is due to competition for light, since other growth factors were supplied and theoretically non-limiting. Highest yields of indeterminate beans in association with maize were attained with simultaneous planting. When maize was planted first, beans suffered from shading; when beans were planted first, the maize was shaded and did not provide the support system necessary to achieve maximum bean yield. Therefore, a near-simultaneous planting date is optimum for beans and maize grown in association at the CIAT location. Preliminary observations indicate that this optimum is temperature dependent, and varies with location and early crop vigor.

Plant density. Maize responds to increased plant densities up to $8 \times 10^4$ plants/ha in CIAT experiments (Fig. 3). These high populations present agronomic problems and are difficult to harvest commercially. Recommended plant densities for hybrids in the Cauca Valley range from 5 to $5.5 \times 10^4$ plants/ha, while most small farmers use 3 to $4 \times 10^4$ plants/ha under less favorable soil conditions with limited use of new technology. The importance of plant density in determining farm yields was confirmed in trials on the North Coast of Colombia (4). A correlation coefficient of $r = 0.85^{**}$ was obtained between density and yield in farm trials, and adequate plant densities increased maize yields from 3.5 MT/ha at $2 \times 10^4$ plants/ha to 5.5 MT/ha at a density of $4 \times 10^4$ plants/ha. An intermediate maize plant density of $4 \times 10^4$ plants/ha was chosen for these trials to provide adequate support for climbing beans, an intermediate level of shade for the associated bean crop, and maize yield high enough to make the system profitable. The 6 MT/ha yield of maize planted in association (Fig. 3) represents a 25% reduction from the monoculture potential. However, there was no reduction in maize yield caused by associated planting at the same density, when the bean densities varied (9). Maize yield is less critical to total system profits to the farmer due to higher relative prices for beans in most countries.

Climbing bean response to density is relatively unaffected by cropping system. Data obtained for monoculture (Fig. 3a) and associated cropping with maize (Fig. 3b) indicate that the optimum bean plant density is 1 to 1.2 $10^5$ plants/ha. Bean yields obtained from this plant density are consistently above 3,000 kg/ha for monoculture with trellis support, and above 1,500 kg/ha in association with maize when competitive and high yielding bean cultivars are used. The same response to increased plant density occurs in bush beans, with an optimum density between 2 and 2.5 $10^5$ plants/ha (3). These optimum plant densities are less specific to location than other agronomic variables, and general recommendations can be made for a wide range of temperature and soil conditions.

![Fig. 1. Association of climbing bean variety 'PS89' (160,000 plants/ha) with hybrid maize 'H-207' (40,000 plants/ha).](image)

![Fig. 2. Effects of relative planting dates of beans (3 plant habits) grown in association.](image)
Planting system. The spatial organization of one crop relative to the other has little influence on the yield of either crop within reasonable limits of distribution, when both crops are planted at optimal densities. Fig. 4 compares 2 associated cropping alternatives with maize and bush beans, and their respective monocultures (10). Bean yields were reduced 30% in associated cropping and maize yields were variable but not significantly different. The 2 associated planting systems gave no differences for bean yields or other variables measured in the trial. Maize densities of $4 \times 10^4$ plants/ha were used both in monoculture and in association with beans to allow a critical comparison between the 2 systems. Yields of maize generally are reduced by about 25% at this low density, compared to the optimum density in this location of 6 to 8 $\times 10^4$ plants/ha. Lack of significant differences in maize yields among treatments was due to variation in the trial, and low number of replications (2 replications analyzed, CV=13.2%). A more comprehensive report on the effects of bean association in 10 trials substantiates the conclusion that maize yield is unaffected at the $4 \times 10^4$ plants/ha density (9). Maize yields from paired rows at this density are consistently lower than yields from equidistant rows (Fig. 4 and Fig. 5).

Monocultures and four different planting arrangements for maize and climbing beans at the same densities are compared in Fig. 5 (10). Bean yields were reduced 50% in associated cropping compared to monoculture climbers on trellis, while maize yields were not affected significantly by cropping system. Bean yields of 2.0 MT/ha were obtained when single or double rows of beans were planted in association with normally-spaced or paired row maize. Physical arrangement of beans relative to maize did not influence bean yields. Maize yields again were reduced (not significantly) in the paired row treatments in this 3-replication experiment (maize yield CV = 15.9%; bean yield CV = 21.2%). Data on both bush and climbing beans indicate that considerable flexibility exists when designing an efficient planting system for the 2 crops, especially if optimal densities are maintained for each crop in the association.

Other effects of associated cropping. Maize lodging complicates harvest operations and contributes to losses from ear rots due to soil contact. Total lodging of 34% and 16% occurred in monocrop maize and associated culture maize, respectively, in 13 trials in 1975. The principal difference between the 2 treatments was in root lodging or up-
rooting, and there were no differences in stalk lodging or breakage. This implies that better root anchorage developed in maize whose roots were interspersed between those of beans in the same soil strata.

Lower levels of cutworm or fall armyworm (Spodoptera frugiperda) damage occurred in maize in associated culture than in monoculture. Although field incidence of the insect is variable, 5 of 6 experiments in 1975 revealed significantly fewer damaged plants in the associated cropping system. Numbers of fall armyworm larvae in the whorls of maize plants were significantly higher in the monoculture system (1). There is less incidence of leafhopper (Empoasca kraemeri) in beans associated with maize (1). Reduced insect attacks in the associated culture could result in less stand loss and lower control costs for the farmer who preserves diversity in the cropping system.

Higher total plant density of crops grown in association produces more rapid ground cover and more shading, and prevents weed growth (6). Herbicide mixtures with low levels of active ingredient per ha are being tested for compatibility with the 2 species and for effectiveness of control across a wide spectrum of weed species. No substantial differences in disease incidence or damage have been observed between the 2 systems, monoculture and associated cropping, on either beans or maize. There may be enhanced N fixation in associated crop systems (P. H. Graham, 1977, personal communication).

Cultivar selection

Selection of crop cultivars for multiple cropping systems has been carried out by generations of farmers in the tropics. Natural selection has aided the typical indigenous farmer who chooses seed from his own fields for a specific microclimate and cropping system. New crop cultivars have not reached today’s small farmers in most countries of the tropics. Cultivars which perform well in monoculture tests may not be best for associated cropping. Research methodology for evaluating this genotype by system interaction was presented in the multiple cropping symposium in 1975 (11, 18). Cultivars of bush beans have been tested for 3 consecutive seasons in monoculture and in association with maize and among cultivars in the 3 seasons of testing, with significant differences in yield reduction among the cultivars tested. Yield reduction and cultivar ranking both were influenced by seasons.

These trials indicate that promising cultivars of bush beans can be selected in the monoculture system, and subsequently tested in the associated cropping system. The greater absolute differences which exist among cultivars planted in monoculture allow better separation of means and selection of superior cultivars, while the greater quantities of seed produced facilitate evaluation in succeeding cycles. It is critical to test promising selections in advanced generations under both cropping systems, to assure that results will be applicable to associated culture, and to detect outstanding types with specific adaptation to varied and complex systems.

Indeterminate climbing bean varieties were tested during three seasons in monoculture and in association with maize (12). Correlations between yields for the two systems were 0.41, 0.81** and 0.90** and between rank orders were 0.09, 0.80** and 0.88** in the 3 seasons, respectively. Yields and rank ordering of cultivars varied among seasons, similar to the bush bean results. One season is summarized in Fig. 7, where yield

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**Significant at the 5% (*) and 1% (**) levels.

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**Fig. 6. Bean seed yields in two cropping systems with bush types; correlations between two systems: rank order r = 0.58 (5%), yield r = 0.88 (1%), number in parenthesis is significance level; % reduction in association with maize given above each bar.**

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**Fig. 7. Bean seed yields in two cropping systems with climbing types; correlations between two systems: rank order r = 0.80 (1%), yield r = 0.81 (1%), number in parenthesis is significance level; % reduction in association with maize given above each bar.**
in monoculture, yield in associated culture and yield reduction are shown for 20 cultivars. In each trial, significant differences among yields and % yield reduction were observed among cultivars. The least expensive system to evaluate large numbers of climbing bean materials is associated cropping with maize, and this is most relevant because it is the predominant system into which promising materials will be introduced on the farm. The disadvantages of using an associated cropping system to test advanced generations of breeding materials include poor separation of cultivar means, limited seed production in each cycle and complexity of the system for observing individual lines. A decision concerning the system or combination of systems to use in a breeding and testing program depends on the factors discussed above. Undoubtedly cultivar differences exist for competing ability. Parallel evaluation of segregating materials in 2 contrasting systems may reveal a divergence for plant type and an increased potential for optimum performance in each specific system. However, such a division of materials in a breeding program would allow fewer resources to be dedicated to each group of materials, and would result in less rapid progress than if the same resources were used in a single research effort. Although there are not sufficient data available on divergence of types or system by genotype interaction, we believe that more rapid progress in selection for yield and yield stability will occur by concentrating efforts on a single group of materials representing each bean plant type, with the majority of evaluations made in the monoculture system. Parallel studies are in progress with a series of maize cultivars planted in 3 cropping systems.

Efficiency of associated cropping systems

Conclusions about the relative efficiencies of monoculture and associated cropping systems depend on levels of technology employed and indicators used to evaluate the systems. Comparisons may be based on total production, protein production, economic return or a combination of such criteria. Table 1 summarizes yield data from several trials with bush beans and climbing beans both in monoculture and in associated crops with maize. Maize production at the same density was not reduced by the presence of an associated crop grown in close proximity (9), while bean yields were reduced by 45% and 51% for bush and climbing beans, respectively.

Efficiency parameters calculated from these data include total yield, protein yield, land equivalent ratio and income. Total yield measures the effect of associated cropping, but is probably the least useful comparison since it does not reflect nutritional value, land use or economic return. Protein yield per hectare was highest in the associated cropping system. This crop mix also provides a diet with complementary sources of protein for better nutrition. Although protein content is important to human and animal nutrition, it rarely influences prices or rewards producers of tropical food crops. The land equivalent ratio (LER) represents the number of ha of monoculture required to produce an amount equal to 1 ha of associated crops. The comparisons listed demonstrate a 21 to 90% production advantage in the associated cropping systems under conditions in CIAT.

Economic return is the most important criterion for the farmer who participates in the market with all or a part of his crops. Gross incomes from monoculture and associated cropping systems were computed, assuming a maize price of US$120/ton and a bean price of US$480/ton in Colombia in 1975. Production costs estimated for each system on the CIAT farm ranged from US$600/ha for monoculture maize or bush beans to US$1,200/ha for monoculture climbers. Highest gross returns were realized from the monoculture climbing beans, although production costs at CIAT also were highest for this system. Maize-bean associations produced greatest net return in bush beans, and even higher profits in climbing beans. Associated cropping systems and monoculture climbing beans require much labor and therefore are more dependent on the availability of family labor for a small area. It is doubtful that either system would be practical for large farms in the near future.

Choice of cropping system, planting date, densities of the 2 crops and cultivars may be influenced by relative prices of each product. Assuming that all of the above factors can influence maize and bean yields, a bean:maize

Table 1. Efficiency measures of maize and bean yields in 3 systems.

<table>
<thead>
<tr>
<th>Crop trial</th>
<th>Monoculture</th>
<th>Associated</th>
<th>Protein</th>
<th>LER</th>
<th>Gross income</th>
<th>Net income</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Total</td>
<td></td>
<td></td>
<td></td>
<td>Mono</td>
<td>Bean</td>
</tr>
<tr>
<td>Bush beans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Maize</td>
<td>Bean</td>
</tr>
<tr>
<td>Trial 7501</td>
<td>6535 1738</td>
<td>7631 845</td>
<td>4876 654</td>
<td>382</td>
<td>949 1.65</td>
<td>784 834</td>
</tr>
<tr>
<td>Trial 7502</td>
<td>7221 2033</td>
<td>6926 1033</td>
<td>7959 722</td>
<td>447</td>
<td>920 1.47</td>
<td>867 976</td>
</tr>
<tr>
<td>Trial 7511</td>
<td>5445 2165</td>
<td>6718 1443</td>
<td>8161 544</td>
<td>476</td>
<td>989 1.90</td>
<td>653 1039</td>
</tr>
<tr>
<td>Trial 7512</td>
<td>3729 1531</td>
<td>3414 1083</td>
<td>4497 373</td>
<td>337</td>
<td>579 1.62</td>
<td>447 735</td>
</tr>
<tr>
<td>Avg</td>
<td>6227 1841</td>
<td>6692 1010</td>
<td>7702 623</td>
<td>405</td>
<td>891 1.62</td>
<td>747 884</td>
</tr>
</tbody>
</table>

*Total yield (kg/ha) = sum of bean and maize yields in association.

Protein yield based on maize with 10% protein + bean with 22% protein.

xLER = Land Equivalent Ratio = ∑Ai/Mi where the yield of crop A in association is Ai, and the yield of the same crop in monoculture is Mi; LER of each monoculture is 1.00.

wGross income based on maize price of US$120/ton and bean price of US$480/ton.

vNet income based on production costs: maize = US$ 600/ha, bush beans = US$ 600/ha, climbing beans = US$1,200/ha, maize/beans = US$ 750/ha.
price ratio of 2:1 (Mexico), 4:1 (Colombia), 7:1 (Brazil) could influence the choice of crops and systems. In general, a valuable product such as beans must be favored in the system, while it is desirable to preserve the maize component to give an adequate return from the total system, increase production stability and thus reduce risk, and provide a low-cost support system for beans.

Future research directions.

National research programs, commercial companies and more recently international research centers have taken the initial steps to improve the technology available for multiple cropping systems. Emphasis on cultivar improvement includes a concern for increased productivity of the total system into which a cultivar will be introduced on the farm. Research results presented above indicate that improved cultivars can be introduced into associated cropping systems, and that these systems have potential for greatly increasing production and land use efficiency in the tropics.

An interdisciplinary research thrust unique to beans and to the tropics has brought together scientists of many nationalities at the International Center for Tropical Agriculture (CIAT) located near Cali, Colombia. Breeders, agronomists, pathologists, entomologists, soil specialists, microbiologists, physiologists, and economists are working together in an integrated effort to solve the most urgent problems which limit bean production in the tropics. Through training courses, travel, international trials and publications, this team is rapidly disseminating germplasm and information to national programs whose personnel will then evaluate these varieties and practices for application to their specific needs.

However, demonstration of improved cultivars or technology on the farm represents only the initial step toward increased national production. If additional resources are scarce or nonexistent for small farmers, these carefully designed production alternatives may only prove to be academic exercise by the researcher. The appropriate improved multiple cropping schemes should require less input of pesticides and fertilizer than an intensive monoculture designed for maximum production. However, there is still a critical need for credit programs which are designed, funded, and managed effectively to reach even the smallest farmer with production potential. If any step in the production-marketing scheme is deficient (i.e., storage on the farm or in a centralized facility), farmers will quickly become discouraged when they are unable to realize the full economic potential of their production gains. Access to many remote areas is difficult; new inputs cannot easily reach the farm, and products cannot be moved easily to market. Governmental agencies must accelerate development of appropriate infrastructure for these zones.

Multiple cropping has a potential for increased production and an obvious historical appeal to the small farmer. Low but stable production, diversification of crops and diets, nutrient re-cycling, reduced insect prevalence, increased predator populations, and reduced risk all influence the farmer's decision to maintain this traditional system. These systems will continue to play a major role in food production for the tropics in the future. Decisions by researchers, politicians and policy makers should take this into account when plans are designed to solve food production and nutritional problems of developing countries in Latin America and other areas of the world.

Literature Cited