AGRONOMIC AND ECONOMIC CONTRASTS BETWEEN MONOCROP MAIZE AND ASSOCIATED MAIZE/BEAN SYSTEMS[1/]

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SUMMARY

A large proportion of the maize planted in the tropics and highlands of Latin America is associated with beans and other crops. Agronomic research generally has focused on the improvement of varieties and hybrids, and the development of systems and technology for monoculture. The high production potential of associated maize/bean cropping systems indicate that they should receive more attention in future research in the tropics. One of the important results in 1975 was the confirmed observation that maize does not suffer yield reduction when associated with beans. When the appropriate system is determined for each region, including density of planting, relative planting dates, and physical organization of the two crops in the field, there is sometimes an increase in maize production in these complex systems. It has been concluded that the land efficiency ratio (LER) is twenty to eighty percent greater in associated cropping compared to monoculture of either crop. Highest production and gross income are achieved with the monocrop climbing beans under high technology. Nevertheless, production costs are high. Net income in associated cropping systems almost always surpasses that of monocultures when the cost of labor and materials is high. These complex associated cropping systems have been developed

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by the farmer under certain climatic, resource, economic and cultural constraints. A better understanding of the system will allow the researcher to develop new technological alternatives to increase production potential, net income and nutrition for the small farmer in the tropics.

INTRODUCTION

Maize is one of the most important crops which contributes to the income and subsistence of the Latin American farmer. It is planted from sea level up to 4.000 meters elevation in the altiplano of Bolivia and Peru. Because of the importance of the crop and its wide adaptation, it is not surprising to find maize as the principal component in many agricultural systems. It is estimated that 60% of the total area planted to maize in Latin America is associated with other crops, principally beans. In addition, up to 80% of the beans in this region are planted with maize and other crops. These complicated systems are typical of subsistence agriculture and in addition contribute an important part of total food production.

Agricultural research has focused principally on commercial crops which are most profitable in this zone. In the case of maize and beans, research has concentrated on monoculture systems in the most favorable production zones. Many commercial farmers in these zones use good technology and harvest from three to six tons of maize, while the national averages in the tropics have not increased much. This average presently varies between .8 and 1.4 tons per hectare.

Recently there has been an increasing interest in the production systems used by the traditional farmer. This paper summarizes results on maize production in monoculture and associated cropping systems with beans. An evaluation of land efficiency is included. The interaction genotype by system is a critical factor in improvement programs, and an economic analysis is important to the farmer. It is concluded that these associated maize/bean systems represent a large production potential for the tropics. Using the appropriate technology for these systems, the small farmer with limited resources is able to incorporate a part of the green revolution into his present cropping systems.

MONOCULTURE MAIZE VS MAIZE ASSOCIATED WITH BEANS

According to data from FAO (1974), average production in the Latin American tropics for maize varies between 800 kg/ha in Guatemala and Haiti and 1400 kg/ha in Brazil and Peru. The highest yields are in temperate climates:Argentina, 2800 kg/ha and Chile 3400 kg/ha. In some regions with high investment in agricultural inputs, new hybrids have caused a "green revolution". Examples include the Cauca Valley of Colombia with an average of 3.5 ton/ha for commercial farmers in the level valley zone, and the coast of Peru with an average of 2.7 tons/ha with irrigation. In these same zones, experimental yields reach 5-8 ton/ha. This indicates a potential for increased production of maize in these tropical zones. The principal problems are transferring, adapting, and/or implementing this technology on the farm.

There are other alternatives to increase production and productivity in the tropics. What happens to maize yields in association with beans or other crops? How do these yields differ from monoculture maize? Data in the literature are variable, and often do not permit a direct comparison between the two systems, since other factors or levels of inputs are variable. Alvim and Alvim (1969) compared maize alone to maize associated with beans during the first month of the crop. In dry matter production, associated maize produced only half the amount of the maize in monocrop. In other reports, maize yields are reduced as a result of association, although these are confounded with planting density: Colombia, monocrop 7242 kg vs associated 5433 kg (ICA, 1972); México, monocrop 4219 kg vs associated 2639 (Turrent, 1973); Tanzania, monocrop 6500 kg vs associated 4140 kg (Enyi, 1973); and México, monocrop 2050 kg vs associated 1721 (Lépiz, 1974). In contrast, other researchers reported no yield loss: Uganda, monocrop 4000 kg vs associated 4400 in high densities (Willey and Osiru, 1972); Guatemala, monocrop 3799 vs associated 3750 kg (Garcia and Molina, 1973); Ecuador, monocrop 4090 kg vs associated 4691 kg in normal maize, and monocrop 4560 kg vs associated 4741 kg in brachytic maize (Buestan, 1973). In each of these reports the best association with beans is listed.

Results from CIAT also are variable, although the several experiments show associations with beans superior in yield to monoculture maize. Tables 1 and 2 summarize results of several trials in 1975, listing in each case the comparison of monoculture maize with the best associated maize/bean system. A summary of experiments on associated maize/bush bean culture (Table 1) indicates no difference between the two systems. In the association of maize/climbing beans in twenty-five comparisons between the two systems, there were three cases when associated culture maize was significantly higher in production than monoculture maize, and one case when monoculture maize was higher. In the rest of the 21 comparisons there was no significant difference (Table 2). The conclusion from more than 30 such comparisons, in 13 trials during 1975, is that no difference in yields occurred in maize monocrop compared to maize in association with beans under the conditions of CIAT, and with the bean varieties used. If maize yield in monoculture is considered as one hundred percent, associated maize production was between 74 and 126%.

There were few observed agronomic differences in maize between the two systems, including such characteristics as plant height, harvest index, prolificacy index, biological yield, length and diameter of the ear and the cob, number of rows, percent moisture at harvest in both the grain and the stover. The only consistent difference between maize in the two systems was lodging. Maize in

Table 1. Yields of maize in monocrop and in association with bush beans in four trials; data from the association corresponds to the best treatment in each trial[1/].

Trial	Maize Hybrid	Maize Monoorop Dens. (1000/ha)	Maize Monoorop Yield (kg/ha)	Maize Associated Dens. (1000/ha)	Maize Associated Yield (kg/ha)	CV (%)	Yield Assoc.x100 / Yield Mono. (%)
7501	H-207	37	6535b	37	7631a	7.3	116
7501	H-210	55	8205a	57	8769a	7.3	107
7502	H-207	31	7221a	34	6926a	12.9	96
7511	H-207	38	5445a	35	6718a	13.2	123
7516	H-207	34	3729a	33	3414a	16.1	91

1/ Yield data from each trial (line) followed by the same letter do not differ significantly (5%).

Table 2. Maize yields in monoculture and in association with climbing beans in 9 trials; data from the association correspond to the best treatment in each trial 1/

Trial	Maize Variety or Hybrid	Maize monocrop Dens.	Maize monocrop Yield	Maize Associated Dens.	Maize Associated Yield	CV	Yield Assoc. / Yield Mono. x 100
		(1000/ha)	(kg/ha)	(1000/ha)	(kg/ha)	(%)	
7501	H-207	37	6535b	35	7318a	7.3	112
7501	H-210	55	8205a	58	8153a	7.3	99
7503	H-210	29	5016a	28	4371a	13.6	87
7503	H-207	29	5718a	28	5386a	13.6	94
7503	Br. Modif.	26	3102a	27	3901a	13.6	125
7503	Br. Normal	26	3632a	28	4211a	13.6	116
7503	H-210	49	7421a	45	6885a	13.6	92
7503	H-207	50	7415a	50	7189a	13.6	97
7503	Br. Modif.	39	4253a	42	4880a	13.6	115
7503	Br. Normal	45	6304a	45	5629a	13.6	89
7503	H-210	62	6383a	67	7174a	13.6	112
7503	H-207	72	7604a	72	8311a	13.6	109
7503	Br. Modif.	61	5277a	62	4786a	13.6	90
7503	Br. Normal	67	6597a	67	6053a	13.6	92
7503	H-210	87	7377a	84	7760a	13.6	105
7503	H-207	86	8496a	87	9222a	13.6	109
7503	Br. Modif.	88	6492a	83	6655a	13.6	102
7503	Br. Normal	86	7339a	79	6747a	13.6	92
7509	H-207	38	5674b	39	7175a	11.8	126
7510	H-207	40	5500b	38	6794a	15.7	124
7513	H-207	40	5096a	37	5923a	12.9	116
7515	H-207	39	5600a	36	4177b	14.3	74
7516	H-207	34	3729a	35	3193a	16.1	85
7517	H-207	32	4435a	36	4515a	15.1	103
7518	H-207	35	4739a	36	5126a	15.9	109

1/ Yield data from each trial (line) followed by the same letter do not differ significantly (5%).

monoculture had a greater percent lodged plants (33.8%) compared to the maize associated with beans (16.1%). This difference was due principally to differences in root lodging, and it is probable that the principal factor was an additional anchorage contributed by the bean roots in the same soil stratum.

LAND EQUIVALENT RATIO

One method for comparing monocrop with associated crop systems is to calculate the efficiency of both systems in terms of total grain production per unit land area. This useful guide (LER) was published by Bantilan and Harwood (1973)[1/]. For example, maize in monocrop (5000 kg/ha) has an index of 1.0. A bean production of 1600 kg/ha has the same index of 1.0. If these two crops associated in the same trial produce 4000 kgs of maize and 1000 kgs of beans, the index (LER) would be $\frac{4000}{5000} + \frac{1000}{1600} = 1.42$. The index (LER) can be interpreted as as the number of hectares needed for the two independent monocultures under the same technology and conditions to produce the same total production as one hectare of the two crops in association. Results of a number of experiments with maize in monoculture, maize associated with beans, and beans in monoculture are summarized in Table 3. In each case, yield of the best associated crop system is reported for each trial. Increases in production from 21% up to 90% for associated crops are shown. This indicates a high production potential from these complex systems. Further, the effect of improving research technology during the year 1975 is illustraed in the table. As personnel in the program learned more about the association of crops and could adjust available technology to these systems, bean yields increased to a level in the final trial of 4000 kg/ha in

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1/ Index of "Land Equivalent Ratio" (LER) = $\frac{Y_1 \text{ Associated}}{Y_1 \text{ Monocrop}} + \frac{Y_2 \text{ Associated}}{Y_2 \text{ Monocrop}}$

[redacted]

Table 3. Land efficiency ratio of associated crops in 11 trials of maize and beans, compared to their respective monocrops 1/.

Trial	Monocrop Yields		Associated Crop Yields		Land Equivalent Ratio (LER)
	Maize	Bean	Maize	Bean	
	(kg/ha)	(kg/ha)	(kg/ha)	(kg/ha)	
7501	6535y	2148a	7318x	429b	1.32
7502	7221x	2033a	6926x	1033b	1.47
7503	6383x	2290a	7174x	334b	1.27
7509	5674y	2815a	7175x	1180b	1.68
7510	5500y	3486a	6794x	517b	1.39
7511	5445y	2165a	6718x	1443b	1.90
7513	5096x	2574a	5923x	1030b	1.56
7515	5600x	2688a	4177y	1275b	1.21
7516	3729x	1531a	3414x	1083b	1.62
7517	4435x	3696a	4089x	1732b	1.39
7518	4739x	4307a	4934x	2075b	1.52

1/ Maize and bean yields in each line followed by the same letter do not differ significantly (5%).

monoculture and 2000 kg/ha in association with maize. As discussed above, maize is not affected by the bean association, at least under the conditions of the Cauca Valley of Colombia using the present cultural practices in association in CIAT.

GENOTYPE BY SYSTEM INTERACTION

Crop improvement in national programs and international research centers has concentrated on varieties and hybrids for monoculture systems. It has been assumed that the optimum selections in this system are best for other systems as well. In reality, the magnitude of interaction of genotype by system in the tropics has yet to be established. It is critical to improvement programs to determine whether the results of genetic improvement for monocultures are applicable to associated cropping systems. Last year a methodology was presented for studying this interaction in maize, climbing beans and bush beans (Francis et al., 1975). Preliminary results of the application of this methodology to the three crops are variable, but indicate a minimum interaction between genotype and system. Maize was planted in three systems: monocrop, associated with beans, and associated with climbing beans. Among the fifteen varieties in the test were twelve full-sib families of short plant selections, plus three checks; H-207 and Tuxpeño Caribe-2 (normal), and H-210 (brachytic). A simple correlation between yield in monoculture and yield in association with bush beans was not significant (r = .23/ns). The correlation between yield in monoculture and yield in association with climbing beans also was not significant (r = .46/ns). However, the correlation between yields of the two associated cropping systems was highly significant (r = .66**). A preliminary conclusion from these trials with an apparent interaction of genotype by system, is that each system will require the selection of a different maize variety. Maize yields among the treatments was between 4200 and 4700 kg/ha, with no significant differences among varieties within each system. It is necessary to repeat the trial with a wider range of genotypes to test this hypothesis in the same location.

An interesting contrast in the interaction variety by system compares one trial in Ecuador (Buestan, 1973) and trial 7526 in CIAT. In each trial two maize varieties were included (normal and dwarf) with a series of bean varieties. In the trial in Ecuador, no differences were encountered in maize yields between the two varieties nor among association with 9 different beans. In evaluating bean yields there was no significant correlation between yields (r = 0.26/ns) nor rank order (r = 0.36/ns) between the two systems, ie. two maize varieties as support. It was concluded from this data that selection of a variety in one system does not necessarily provide the best variety for another system, even between two similar maize varieties used as support. In the CIAT trial with sixteen climbing bean varieties, the yield of normal maize (5702 kg/ha) was higher than that of the brachytic (4881 kg/ha). A highly significant correlation (r = 0.90**) was found between the yield of the two hybrids in CIAT across the sixteen bean varieties. In addition, yields of beans were highly correlated in the two systems (r = 0.76**), with the opposite conclusion of the previous trial in Ecuador. The best bean variety selected with one system of support was also the best for the other support system. From this work it is not possible to draw a final conclusion for either maize or for beans about the importance of the interaction of genotype by system (Francis *et al.*, 1975).

AGRONOMIC FACTORS

In the CIAT environment, the agronomic aspects which showed the greatest differences in the two systems (monoculture and associated cropping) were planting density, lodging of maize and the incidence of fall armyworm (Spodoptera) in maize. Both crops responded to increases in plant density, both in monoculture and in association. Figure 1 illustrates the production increases due to increased plant density. In the associated cropping systems, maize is maintained at a constant density of planting of 40.000 plants/ha. Maize in monoculture increases in production up to 70-80.000 plants/ha, although there are difficulties of lodging at the high densities. Climbing beans also increased in yields to approximately 120.000 plants/ha, both in monoculture and in association. From these data, the importance of high plant density is obvious when these crops are planted in any of the three systems with high level of technology.

Lodging of maize is a problem to the farmer at harvest time, and also contributes to direct loss due to ear rots. In table 4, monoculture maize is compared to associated maize for root lodging and stalk lodging. Total lodging is always higher in monoculture. The principal difference between these systems is in root lodging, and it is probable that the improved root anchorage in the associated cropping system is the most important critical factor which prevents lodging. This advantage of less lodging may be very critical in regions where strong winds cause harvest problems of maize.

The incidence of fall armyworm (Spodoptera frugiperda) has been strikingly different between monoculture and associated crop maize in some seasons in CIAT. Figure 2 shows the percent infestation in maize in these two systems in one trial in 1975. There was little difference between the monoculture maize and the association of maize with climbing beans, where the beans were planted a week after

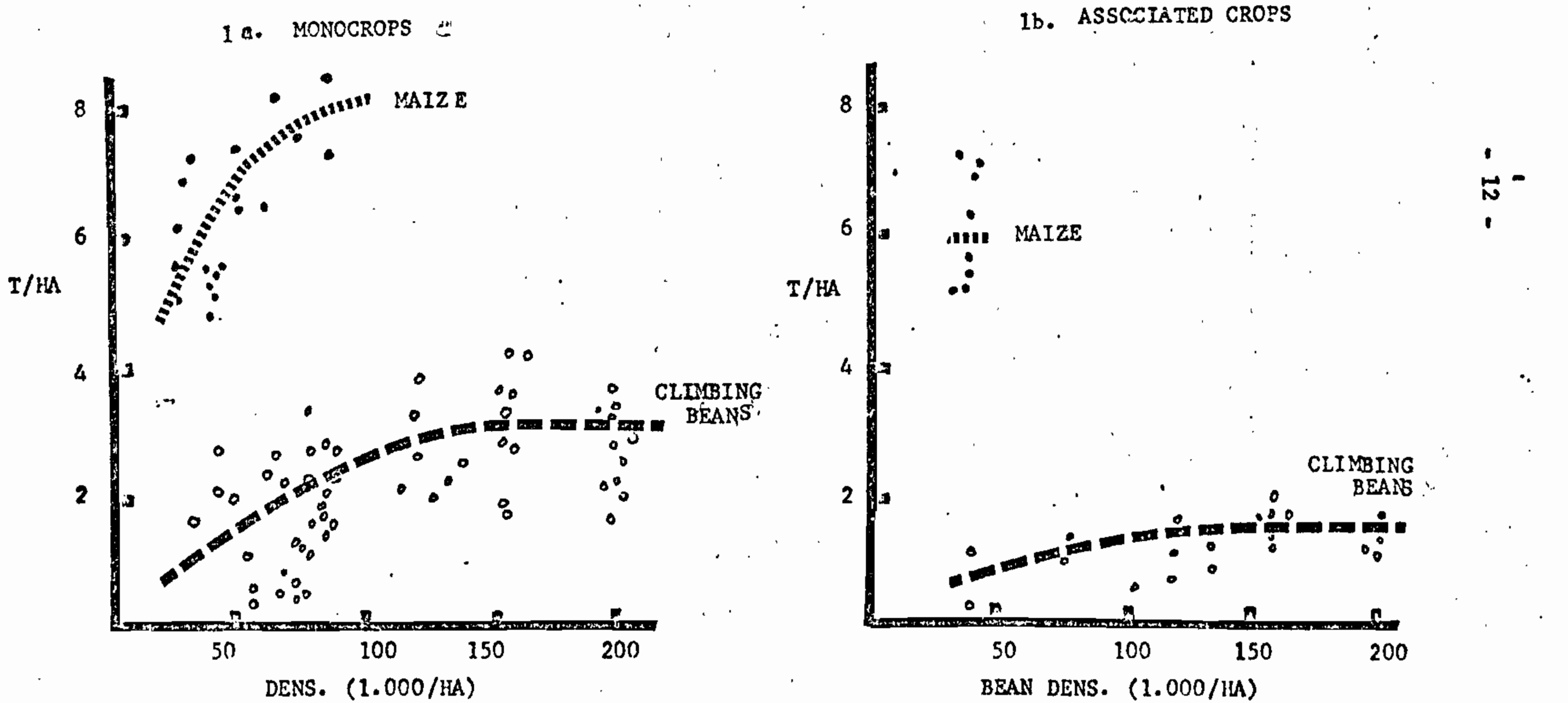


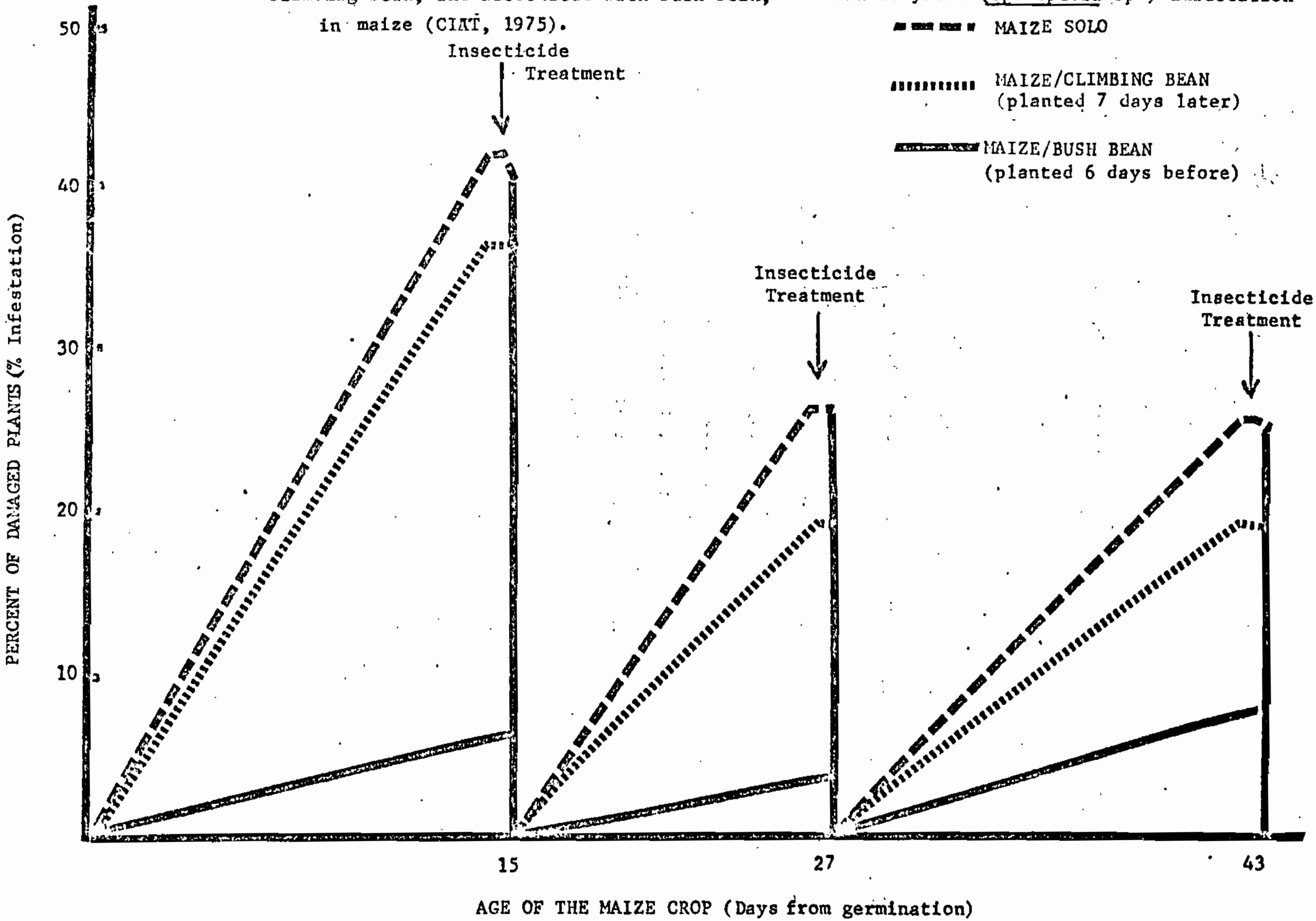
Figure 1. Yields of maize and beans in monocrop (1a) and in association (1b), as a function of planting density.

Table 4. Maize lodging in monoculture and in association with bush and climbing beans[1/]

Trial	Maize Hybrid	Associated Bean Variety	Root Lodging Assoc.	Root Lodging Mono.	Stalk Lodging Assoc.	Stalk Lodging Mono.	Total Lodging Assoc.	Total Lodging Mono.
7501	H-207	P-259	29.4	22.8	6.4	6.6	35.8	29.4
7501	H-210	P-259	1.6	.3	9.6	3.8	11.2	4.2
7501	H-207	Pijao	29.4	9.6	6.4	5.2	35.8	14.8
7501	H-210	Pijao	1.6	.6	9.6	2.4	11.2	3.0
7502	H-207	Pijao	23.3	6.3	7.3	5.0	30.6	11.3
7507	H-207	P-259	53.2	17.0	6.2	6.5	59.4	23.5
7508	H-207	Jamapa	64.3	14.0	1.0	3.3	65.3	17.3
7509	H-207	P-259	46.5	2.2	15.8	3.0	62.3	5.2
7510	H-207	P-259	2.0	3.2	22.5	6.2	24.5	9.4
7511	H-207	Pijao	14.0	26.0	9.0	0	23.0	26.0
7513	H-207	P-259	9.0	10.0	6.0	3.0	15.0	13.0
7515	H-207	P-259	10.2	16.2	18.7	12.2	29.0	28.5
7516	H-207	P-259	14.0	10.0	22.0	14.0	36.0	24.0

1/ Underscored data in adjoining columns are not significantly different (5%).

Figure 2. Relationship between three planting systems of maize: monocrop, associated with climbing bean, and associated with bush bean, and fall armyworm (Spodoptera sp.) infestation in maize (CIAT, 1975).



the maize. However, there was much less attack by the insect in the maize-bush bean association when the beans were planted a week before the maize. The attack occurred three times: following planting and several days following each insecticide treatment. These results indicate important advantages for the associated cropping systems in terms of reduced insect attack, and consequently, reduced cost to farmers for controlling one of the most damaging insects in many maize growing regions of the Andean Zone.

ECONOMIC RESULTS

Among the most important criteria used by the small farmer to decide which crop and systems to plant in a given year are production, net profit, and security of harvesting the crop. As mentioned above, planting density of maize and beans are critical to yield, and influence both production and profitability. Figure 3 illustrates the differences in total income for three systems as a function of plant density. Plant density at harvest is indicated in the figure for both monoculture crops, and for beans in association. Maize in association is maintained at 40.000 plants/ha. Income was based on a maize price of US$ 120/ton and a bean price of US$480/ton. There is an obvious advantage of monocrop climbing beans at all density levels. Optimum densities are 70-80.000 plants of maize/ha in monoculture, and 100-120.000 plants of beans/ha in either of the two systems.

Although climbing beans in monoculture produced a higher total income the system has additional costs for the support system, whether trellis or stakes. Most production costs such as land preparation, planting, fertilization, and plant protection are essentially equal; with increase in plant density, costs are increased for seed and labor at harvest time. Based on costs in CIAT, the net income from these three systems has been calculated (Figure 4). With these costs

Figure 3. Total income of three systems: bean, maize, and maize/bean association as a function of planting density; maize is maintained with 40.000 plants/ha in association (Francis et al., 1976).

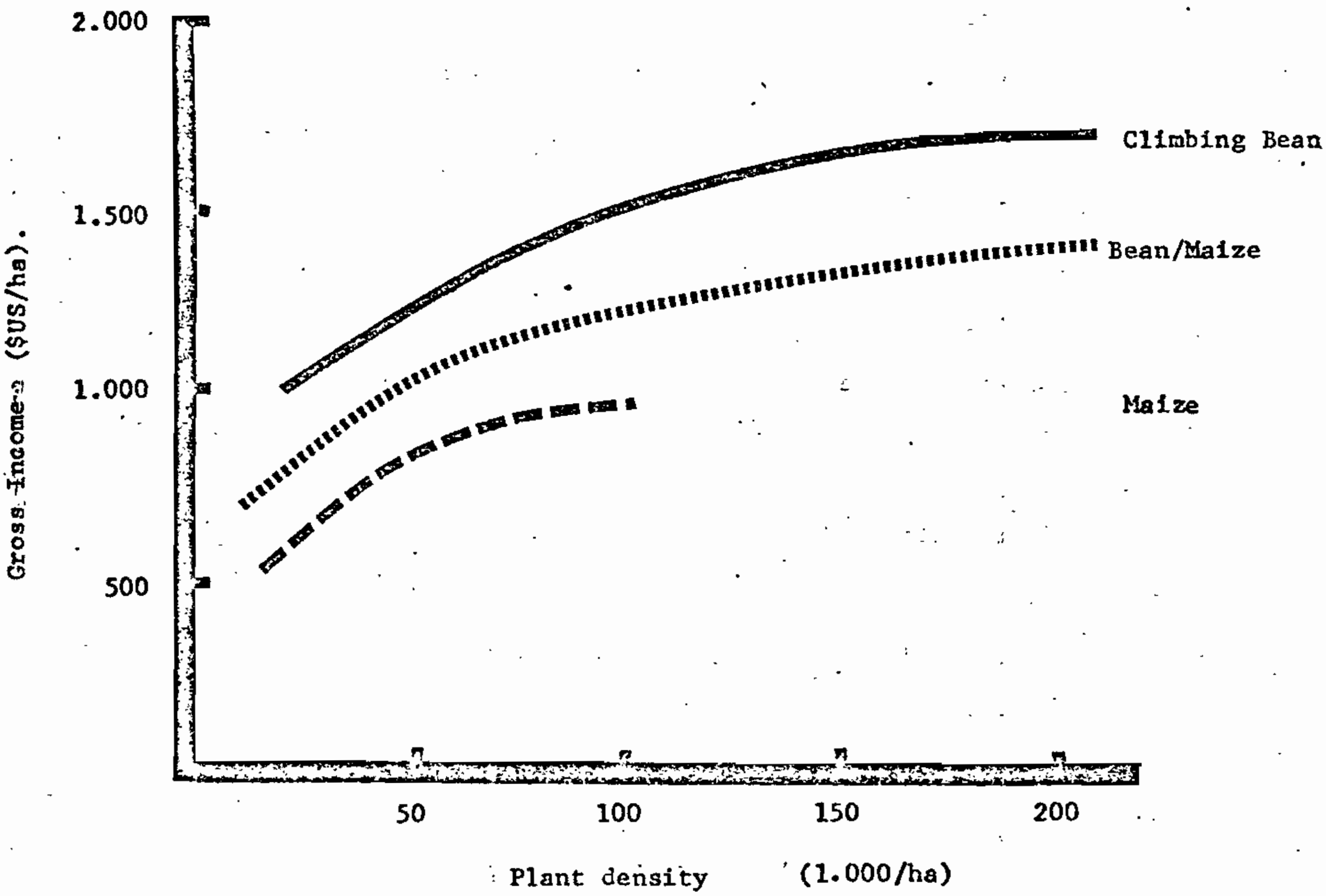
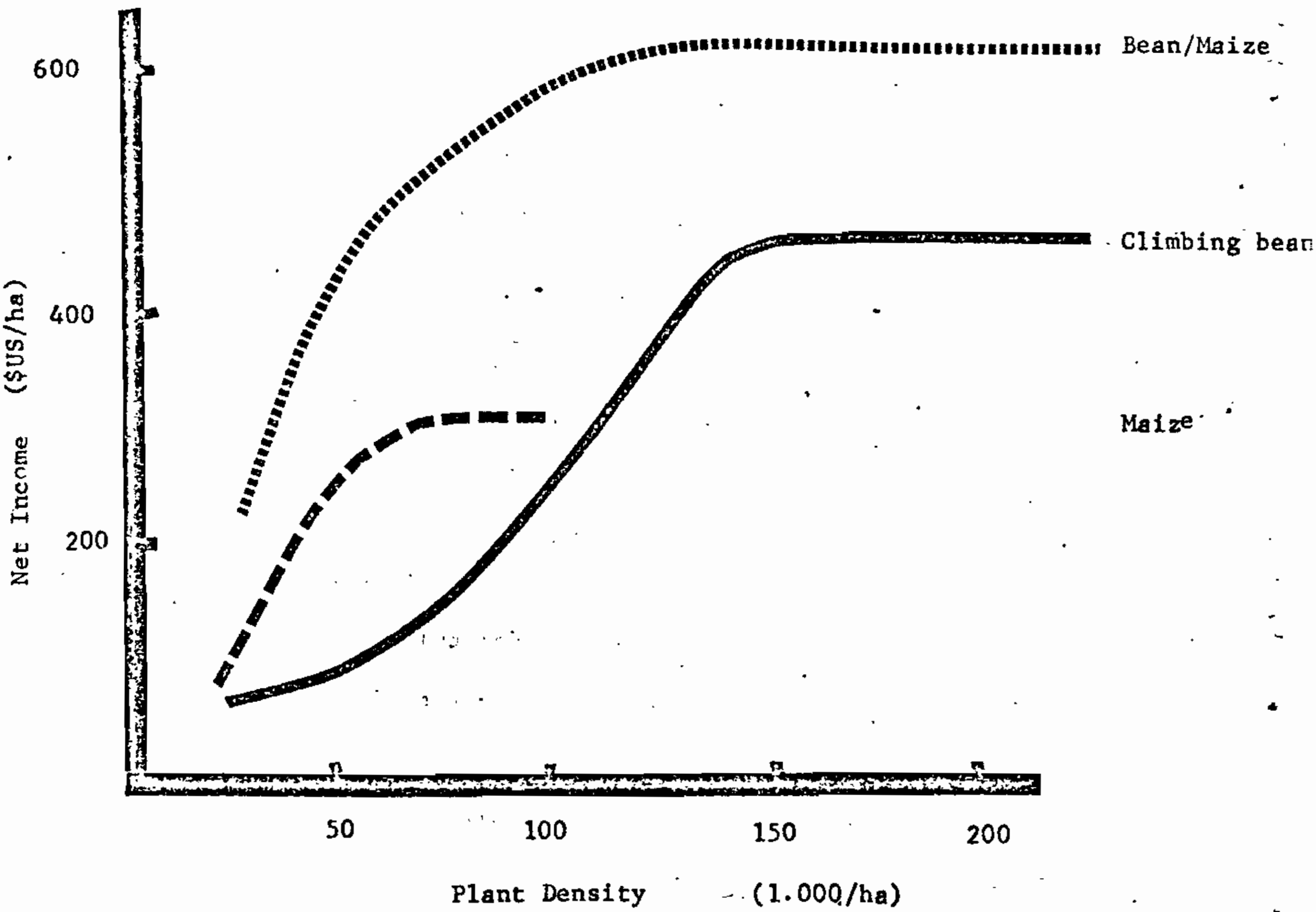


Figure 4. Net income of three systems, bean, maize and maize/bean association as a function of planting density; maize is maintained with 40.000 plants/ha in association (Francis *et al.*, 1976).



and consistent yields of 3 ton/ha of beans in monoculture, this system is apparently less profitable than the maize/bean association with a production of 1.5 ton/ha of beans and 6 tons/ha of maize, at the optimum densities. A valid comparison among these systems must include plantings under other conditions. For example, a farmer with rustic materials to use as support for beans and his family's labor available at low cost, would have a much lower total production cost and a higher net income per hectare with the climbing bean monoculture. Data from Figures 3 and 4 emphasize again the importance of density on production and profit of several planting systems.

CONCLUSIONS

The results of one year of intensive field research in systems of associated planting of maize and beans indicate that a great potential exists for increasing the productivity of these traditional systems. This technology will have applications in a number of tropical regions, especially those zones with many small farmers in "minifundio" with limited resources.

One significant result of this research indicates that maize yields are not reduced as a result of the association with beans. Yields of beans associated with maize may reach 1500 kg/ha with bush beans and 2000 kg/ha with climbing beans. This significantly affects farm income, since maize is not reduced in production and beans can be considered an additional income of much importance, due to the high price of this product in the majority of Latin American countries.

The land efficiency ratio is increased with the association of these two crops, with results from 21% up to 90% greater efficiency in association compared to the appropriate monocrops.

Among the agronomic factors most critical for increasing production both in monoculture and in association, plant density appears to be of singular importance. Maize yields increased with plant density up to 70-80.000 plants/ha. Bean yields also increased up to 120.000 plants/ha for climbing varieties. These levels of plant density are much higher than those used by the farmer, and can be achieved with relatively simple changes in present cultural systems. One interesting consequence of the association of maize with beans is the reduction of attack of fall armyworm in the maize. This protection of the maize crop due to the planting system can significantly reduce production costs for plant protection. Another important consequence of the association of maize with beans is reduced lodging in maize. This reduction is principally in root lodging, related to better root anchorage when the two crops are planted in close proximity.

A simple economic evaluation of the income obtained from three planting systems (monoculture maize, climbing beans in monoculture, and associated maize-beans) indicates the advantage of the associated cropping systems when costs are high in the monoculture climbing beans. This relative advantage of the associated system would change drastically in a situation where lower costs of labor and materials for support systems are available for the monoculture climbing beans. The associated cropping system not only is more profitable in CIAT and has a higher land equivalent ratio, but it also has a much lower production cost. This implies less investment and lower risk for the farmer, factors which are of critical importance in his decision-making process on which system to use.

These results indicate a significant advance in our understanding of the potential of associated cropping systems for the small farmer in Latin America. The next important step is the validation or testing of these results in other climates. Only then will it be possible to draw more broadly based conclusions about the wider potential of these adaptations of green revolution technology to small farm conditions. This is one step in the process of adapting technology for the small farmer,in order to improve production, income and nutrition, and the general well-being of the rural population in the tropics.

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