THE DIFFUSION AND ECONOMIC IMPACT OF HIGH-YIELDING SEMI-DWARF RICE VARIETIES IN LATIN AMERICA

WORKING PAPER

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CONTENTS

1. INTRODUCTION

The History of Modern Rice Variety Development in Latin America

The discovery by IRRI in the early 1960's of the high yielding capacity of semi-dwarf varieties in tropical environments gained international awareness through the wide impact achieved by IR8. The confirmation of high yields with modern semi-dwarf varieties in Latin America began with introduced IR8. The variety produced record yields in Colombia, Ecuador, Peru, Costa Rica and other countries during the period of 1968 to the early 1970's.

IR 8 and subsequent modern introductions from Asia suffered inferior grain quality or susceptibility to local biological constraints. Breeding programs in Latin America oriented toward the development of locally adapted dwarf modern varieties for irrigated conditions began in Colombia in 1967 and soon thereafter in Surinam, Peru, Cuba, Mexico, the Dominican Republic and elsewhere.

The Colombian program centered in Palmira, united the resources of CIAT, ICA and the Colombian Rice Federation. It quickly established a comprehensive breeding effort with a strong international component achieved through a training program for Latin American breeders in Palmira. The trainees upon return to their national programs, evaluated advanced breeding lines under their local conditions. This early investment in research and training later evolved into the structured International Rice Testing Program network for Latin America (IRTP).

The Colombian program released its first variety, CICA 4, in 1971 and several other CICA varieties followed thereafter. In the late 1970's, the CICA acronym was dropped and all recent varieties have been released and named in Colombia by ICA.

The CICA varieties and several Colombian lines identified and named by national programs were rapidly and widely adopted throughout the Americas in the irrigated, rainfed, and more favored upland ecologies.

These were complemented by varieties bred by several national programs. Thus essentially all modern varieties grown extensively in the Americas originated from local breeding programs. Asian introductions have not achieved significant impact after the initial impetus provided by IR8 and IR22 in the late 1960's.

Objectives and Organization of the Study

The purpose of this study is to describe the current state of rice production in Latin America and to assess the effects of modern technology on the availability of rice in the region. An additional objective of this report is to present a cost-benefit analysis of the investment in rice genetic research which has been carried out in Latin America by a network of both International and National Rice Research Programs.

Section 2 presents the evolution of rice consumption, production and trade in Latin America, and how it relates to the introduction of modern rice technology. In the next section the main rice farming systems and production constraints encountered in the region are briefly described and their relative importance assessed. Section 4 includes estimates of the impact of modern high-yielding varieties in Latin America. In section 5, an attempt is made to measure the costs and returns to the research effort earlier described. Lastly, a series of final comments are presented.

2. EVOLUTION OF RICE CONSUMPTION, PRODUCTION AND TRADE IN LATIN AMERICA

Trends in Consumption

It is not easy to identify a typical Latin American diet, because food consumption patterns vary by region, income stratum, and between rural and urban populations.

According to available data (Table 1), rice provides, on average, around 9% of total calories to the Latin American population, ranging from 1.3% in- Argentina to 26.3% in Panama. Countries with the highest relative contribution of rice to total caloric intake are, besides Panama, Dominican Republic (19.5%), Cuba (18.3%), Brazil (15.5%), Costa Rica (15.5%), Colombia (13.1%) and Peru (11.4%).

Despite the differences noted above, it is possible to distinguish certain significant changes in the food consumption characteristics of the whole region, which have been observed to approach the consumption pattern of industrialized nations[1].

One such widespread change is the increase in per capita consumption of wheat, rice and livestock products while that of maize and other traditional cereals of the region (as well as roots, tubers and legumes) have quite clearly declined[2].

The increase in both wheat and rice per capita consumption, along with the other changes in food consumption which have been mentioned, can probably be attributed to a number of factors.

Firstly, there has been a drastic rural-urban migration process, which has promoted changes in the diets of consumers. For example, Brazilian data analyzed by Williamson (1982) show that within each income stratum, per capita daily caloric intake provided by rice was higher for urban than for rural consumers. Data available for several Central American nations and for Colombia, also reveal that the urban population consumes more rice per capita than their rural counterparts[3]. Thus, the strong urbanization process that characterizes the region, increases the crop's importance of rice in the diet.

1/ See Caballero y Maletta (1983)

2/ See Valdes and Muchnik de Rubinstein (1984)

3/ Bressani, R. (1971)

TABLE 1. Latin America: percent of total calories supplied by selected source. 1957-1977.

Country	Sugar	Wheat	Maize	Rice	Cassava	Potatoes	Beans	Beef	Milk	Oils
Mexico	16.5	11.4	36.7	2.0	0	0.6	4.8	2.1	5.4	7.8
Brazil	18.4	11.9	8.2	15.5	8.0	0.8	6.4	4.6	5.3	7.6
Bolivia	13.6	18.2	11.9	7.4	4.6	9.3	0.9	4.4	1.7	7.8
Colombia	23.8	5.6	11.7	13.1	5.1	3.8	1.3	5.9	5.2	7.7
Ecuador	19.2	11.7	9.5	9.9	2.6	5.6	0.8	3.0	7.6	7.9
Peru	15.9	17.8	9.5	11.4	2.4	6.6	1.9	1.5	4.1	9.3
Paraguay	7.3	6.3	19.4	4.8	14.9	0.07	7.6	7.5	2.8	7.0
Venezuela	18.2	13.4	15.3	5.4	1.9	0.8	2.0	5.7	7.9	8.9
Costa Rica	24.5	11.1	7.8	15.5	0.5	0.8	3.9	4.1	8.0	11.4
El Salvador	14.9	6.5	36.8	3.1	0.4	0.6	4.1	1.3	4.8	8.6
Guatemala	16.2	8.1	47.7	1.6	0.1	0.3	4.9	1.6	3.6	6.8
Honduras	14.6	5.6	44.6	2.8	0.3	0.09	3.3	1.3	4.1	7.1
Nicaragua	18.9	6.0	28.0	6.1	0.9	0.2	7.2	4.4	5.6	9.2
Panama	14.3	8.9	8.5	26.3	1.7	1.1	6.3	6.3	3.9	9.3
Cuba	20.0	20.0	0	18.3	1.9	0.9	0.8	3.5	7.7	8.9
Dominican Rep.	15.8	9.0	2.7	19.5	3.4	0.2	3.5	1.9	5.0	11.3
Haiti	13.6	7.0	15.2	9.0	2.8	0.1	4.1	1.2	1.5	3.3
Jamaica	19.1	22.0	3.2	7.7	0.9	0.3	0	2.5	4.2	11.0
Argentina	11.8	27.0	1.3	1.3	0.4	2.9	0.3	16.8	7.2	11.4
Chile	12.4	45.2	1.7	2.9	0	3.3	1.5	5.5	5.5	8.2
Uruguay	13.6	26.8	3.1	2.8	0.06	2.1	0.3	17.9	10.2	9.3

SOURCE: CIAT (1981).

Secondly, as income increases, the consumption of food items with higher income (or expenditure) elasticities, increases more than proportionally, at constant prices. Estimates for Colombia and Brazil provide examples of elasticity estimates which help to explain the increment in rice consumption due to income increases. Sanint et. al. (1984) obtained a 0,83 estimate for the income elasticity of rice, which was the second highest among the eleven most important crop products in the diets of Colombian consumers. For Brazil, Williamson (1982) found a lower value for this parameter. But again, if compared to other cereals, roots and legumes, the estimated elasticity for rice is relatively higher within the low and middle income urban strata.

The Brazilian data show the expected pattern of high income elasticity of rice for the low-income group, falling to about zero for the high-income stratum. This decline, though, is much less noticeable in the case of Colombia (Sanint, 1984). The higher values of the income elasticity of rice for the lowest income groups, particularly in urban areas, indicates that demand for this commodity can be expected to grow relatively rapidly as industrial development proceeds.

The importance of rice in the budget of urban-consumers is also inversely related to income. For example, in Cali, the proportion of the food budget spent on rice has been observed to be 9,6% for the lowest, and 4,5% for the highest income strata. The corresponding figures for Guayaquil are 13,9% and 6,3%, while for northeast Brazil they are 6,7% and 4,3% respectively[4].

Both the patterns of income elasticities and budget shares accross income strata have implications in terms of the expected distribution of benefits from increased rice production and lower consumer rice prices.

4/ See Appendix 8 in CIAT (1981).
5/ Changes in rice prices due to adoption of improved technology may occur in countries which are close to self-sufficiency in rice or where economic policies such as tariffs, price controls, exchange controls, etc. effectively isolate internal prices from their international counterparts.

An additional force behind the changes observed in food consumption patterns, and rice intake in particular, is the changes that have taken place in relative prices. These may have occurred because of government market intervention and general economic policies, or due to technological change. Rapid increases in rice production because of the adoption of modern, high-yielding varieties, can under certain circumstances lead to substantial price reductions, thus encouraging increases in rice consumption[5]. Scobie and Posada (1977) showed that both producer and consumer real prices diminished in Colombia during the period 1965-1974 as a result of the adoption of modern rice varieties.

Regarding price policies, a large number of countries have over the past years established support prices at the producer level for paddy rice. According to FAO (1984), in 36 out of 50 countries in the world which provided information on this matter, the real support price for rice,remained constant or increased during the 1970's. This was also complemented with other policies which seek to restrict imports or stimulate exports.

As a result of all the above considerations, annual rice consumption in Latin America during the period 1965-1982 has increased from 6.5 to 10.9 million tons of milled rice.

In terms of per capita consumption, Table 2 is illustrative. It may be seen during this period that there was a significant increase in per capita rice consumption in Tropical South America, excluding Brazil (from 25 to 41 kgs) and in the Caribbean region (from 27 to 35 kgs), but not in Brazil, Mexico, Central America or the temperate countries of South America. The increase in per capita rice consumption in Tropical South America and the Caribbean was particularly strong between the end of the sixties and mid-1970's. As a result, average per capita consumption in Latin America has increased between 1965 and 1982 from 30 to 35 kgs of milled rice. This last figure is below the world average of 53 kg[6] , which is higher because of the weight of rice consumption in

6/ See FAO (1984)

TABLE 2. Average annual per capita consumption of milled rice in selected countries and regions of Latin America. 1965-1982. (Kgs/per capita).

Country or Region	Period					
	1965-67	1968-70	1971-73	1974-76	1977-79	1980-82
Brazil	58	55	52	57	52	57
Mexico	7	5	6	8	6	7
Tropical South America[1]	25	27	30	38	38	41
Central America	23	22	21	23	20	23
Caribbean	27	23	24	33	34	35
Tropical Latin America	31	31	30	34	32	36
Temperate South America	6	8	7	7	5	6
Latin America	30	30	29	33	31	35

1/ Excluding Brazil.

SOURCE: FAO Tapes.

Asia. Average per capita consumption of rice in East Asian countries is around 157 kg[7]. The relatively low consumption levels of rice in Latin America indicate that there is ample future scope to increase rice consumption, at least in the tropical areas of the region.

Latin American countries can be classified in three groups according to per capita rice consumption during 1980-82.

The Low Level Group (<20 kgs of milled rice) comprises ten of 24 Latin American countries (Table 3). These are either non-tropical (Argentina, Chile, Uruguay,) or have a tradition as maize consumers (Mexico, Bolivia, El Salvador, Guatemala, Honduras). The Intermediate Group (between 20 and 40 kg per person) comprises 5 countries (Ecuador, Peru, Venezuela, Jamaica, Barbados) and the High Level Group (<40 kgs) includes another 9 countries, all of them located in the tropical regions. They are wheat and maize importers, and rice is the only adapted grain crop.

Trends in Production, Area and Yields

According to data presented by FAO, paddy rice production in Latin America during 1980-82 was about 16 million tons, that is around 89 kg of paddy rice per capita[8]. Brazil is the largest rice producer in the region, providing in 1980-82 almost 57 percent of the total regional product, followed by Colombia (12%),Venezuela (4%) and Peru (3,9%). (See Table 4).

During the period 1965-1982, rice production in Latin America grew at a 3.3 percent annual rate, with area expanding at a rate of 2.3 percent per year and yields at a rate of 1.0 percent (Table 5). But the performance of individual countries and subregions was extremely heterogenous, as may be observed in Tables 4 and 5.

7/ See Cordeu, J.L. et. al. (1981)

8/ See Table 4 of the Appendix.

TABLE 3. Apparent per capita consumption of milled rice by country in Latin America, 1980-82. (Kgs/per capita).

Country	Kgs rice/per capita/ per year
Brazil	57
Mexico	7
Bolivia	13
Colombia	52
Cuba	56
Dominican Republic	58
Ecuador	38
Paraguay	16
Peru	35
Venezuela	31
Costa Rica	41
El Salvador	8
Guatemala	5
Honduras	9
Nicaragua	50
Panama	68
Barbados	29
Guyana	152
Haiti	17
Jamaica	25
Trinidad & Tobago	57
Argentina	5
Chile	9
Uruguay	11
Latin America	35

SOURCE: FAO Tapes. (See Table 3 of the Appendix).

TABLE 4. Paddy Rice: average production, area and yields: 1965/67, 1974/76, 1980/82.

Country	Production (1000 MT)			Area (1000 Ha)			Yields (MT/ha)		
	1965/67	1974/76	1980/82	1965/67	1974/76	1980/82	1965/67	1974/76	1980/82
Brazil	6.705	8.093	9.248	4.305	5.543	6.108	1.6	1.5	1.5
Mexico	391	558	565	153	196	162	2.6	2.8	3.5
Bolivia	53	108	94	32	66	61	1.6	1.6	1.5
Colombia	678	1.571	1.891	339	364	437	2.0	4.3	4.3
Cuba	72	447	486	38	171	146	1.9	2.6	3.3
Dominican Rep.	172	272	425	78	90	110	2.2	3.0	3.9
Ecuador	224	328	400	109	120	130	2.1	2.7	3.1
Paraguay	17	54	67	7	25	33	2.5	2.2	2.0
Peru	375	535	630	93	124	138	4.0	4.3	4.6
Venezuela	206	291	658	110	99	222	1.9	2.9	3.0
Tropical South America[1]	1.793	3.594	4.637	805	1.059	1.277	2.2	3.4	3.6
Costa Rica	147	247	248	55	82	72	1.5	1.9	2.5
El Salvador	54	42	48	20	14	14	2.7	3.0	3.4
Guatemala	17	33	44	9	19	14	1.9	1.8	3.1
Honduras	11	28	36	9	18	21	1.2	1.6	1.7
Nicaragua	63	76	145	26	27	43	2.4	2.8	3.4
Panama	147	170	181	131	117	96	1.1	1.5	1.9
Central America	375	504	631	250	276	261	1.5	1.8	2.4
Guyana	260	247	287	130	116	92	2.0	2.1	3.1
Haiti	81	121	95	47	43	50	1.7	2.8	1.9
Jamaica	1	2	2	1	1	1	1.3	1.9	2.3
Trinidad	11	19	28	5	7	10	2.2	2.7	2.8
Caribbean	348	388	412	182	166	153	1.9	2.3	2.7
Tropical Latin America	9.621	13.177	15.500	5.696	7.240	7.961	1.7	1.8	1.9
Argentina	216	327	326	59	88	93	3.7	3.7	3.5
Chile	81	68	109	32	22	36	2.5	3.1	3.0
Uruguay	97	188	345	31	47	66	3.1	4.0	5.2
Temperate South America	392	582	778	122	156	195	3.2	3.7	4.0
LATIN AMERICA	10.013	13.761	16.282	5.818	7.396	8.156	1.7	1.9	2.0

1/ Excluding Brazil.

SOURCE: FAO Tapes.

3LE 5. Paddy rice. Annual growth rates of production, area and yields (Percentage).

ıntry	Production			Area			Yields		
	1965/75	1976/82	1965/82	1965/75	1976/82	1965/82	1965/75	1976/82	1965/82
ızil	0.9	0.4	2.1	1.5	-0.6	2.4	-0.7	1.0	-0.3
‹ico	4.3	4.1	2.8	3.2	1.3	0.5	1.1	2.8	2.2
livia	6.3	-4.0	3.4	6.5	-3.6	3.8	-0.1	-0.4	-0.3
lombia	9.1	5.5	7.6	-0.2	4.7	2.6	9.2	0.7	5.0
ɔa	21.7	1.7	11.6	18.0	-1.5	6.9	3.7	3.2	4.7
minican Rep.	3.8	6.3	6.0	-0.9	-1.6	2.5	4.7	7.9	3.5
ıador	3.8	4.7	4.3	-1.1	2.8	1.4	4.9	1.9	2.9
raguay	14.0	1.7	9.0	16.1	1.1	10.4	-2.1	0.6	-1.3
ru	5.1	4.1	3.4	4.2	2.6	2.6	0.9	1.5	0.8
nezuela	3.9	15.6	8.2	-0.5	16.3	4.4	4.4	-0.7	3.8
opical South merica[1]	7.8	5.5	6.6	2.6	3.7	3.2	5.2	1.8	3.5
sta Rica	5.7	0.4	5.8	2.4	-0.4	3.0	3.3	0.8	2.8
Salvador	-2.2	3.5	-0.7	-5.2	-0.9	-1.8	3.0	4.3	1.1
ıtemala	8.9	7.9	6.1	8.1	-1.1	3.1	0.8	9.1	3.0
nduras	9.5	6.2	8.2	6.7	2.5	5.9	2.9	3.7	2.2
caragua	3.4	17.7	3.1	0.8	13.5	1.9	2.6	4.2	1.2
nama	1.3	2.6	1.4	-2.4	-3.7	-1.7	3.7	6.3	3.1
ntral America	3.1	5.4	3.4	0.0	0.1	0.6	3.2	5.3	2.7
yana	-0.8	3.9	1.8	-2.1	-4.2	-1.6	1.3	8.2	3.4
iti	4.9	-3.1	2.3	-0.9	3.9	1.1	5.9	-6.9	1.2
maica	-10.2	5.0	4.8	-14.2	-8.0	1.1	4.1	3.0	3.7
inidad	6.1	6.1	7.3	3.7	5.9	6.0	2.5	0.2	1.3
ribbean	1.0	1.6	2.2	-1.6	-1.4	-0.5	2.7	3.0	2.7
opical Latin merica	2.7	2.2	3.3	1.6	0.1	2.3	1.1	2.1	1.0
gentina	4.0	2.3	1.9	4.2	1.6	2.7	-0.2	0.6	-0.8
ile	-3.9	1.5	3.6	-5.9	2.6	1.9	2.0	-1.1	1.7
ıguay	6.5	10.6	8.3	3.5	4.1	5.7	3.0	6.5	2.6
mperate South merica	3.5	5.4	4.2	2.0	2.6	3.3	1.4	2.8	0.9
TIN AMERICA	2.7	2.3	3.3	1.6	0.1	2.3	1.1	2.2	1.0

Excluding Brazil.

URCE: FAO Tapes.

Firstly, in Brazil, the main rice producer in Latin America, production has increased over the period 1965-82 at an annual rate of 2.1 percent, as a result of area expansion, while absolute yields did not change.

Tropical South America, excluding Brazil, showed an extremely different performance: the average annual rate of increase in production during 1965-82 was 6.6 percent, and 53 percent of the production increase was due to yield increases. Subdividing the observed period into two, it is possible to notice that the yield growth took place mainly before 1975 with a slow-down during the last seven years.

With respect to Central America, production growth stood at an average annual rate of 3.4 percent during 1965-82, and almost 80 percent of the increase in production was due to yield increases. The increase in yields was particularly high after the year 1975, that is, later than in Tropical South America. The cultivated area in Central America increased very little.

In the Caribbean, production grew at a slower rate (2.2 percent during 1965- 82), and this growth was due exclusively to yield increases as the area even decreased. Yield growth rates were not very different before and after 1975.

Finally, rice production in Temperate countries also increased at a high rate during the whole period. Production growth was particularly high in Uruguay and specially during the period 1976-82 (10.6%) when yields increased at an average annual rate of 6.5 percent.

Thus, yield increase was the main factor explaining production growth in Tropical South America (excluding Brazil) before 1975 and in Central America, the Caribbean and in Uruguay during the following 1976-82 period.

In general, the main driving force behind yield increases during the last 15 years was the diffusion of modern technology, basically improved varieties and cultural practices.

Modern rice technology involves the utilization of new semi-dwarf, high-yielding varieties along with fertilizers, herbicides, and adequate water control in the irrigated sector. Its adoption and following impact on yields is closely linked to the presence of a set of preconditions which are related, among others, to the physical environment, the availability of social infrastructure and the use of certain cultural practices. It is precisely because these ecological and institutional conditions vary so dramatically among countries in Latin America that both the rates of technology adoption and impact on production have differed markedly from one country to another. The following is an attempt to classify the countries according to their yield performance during the 1965-82 period and in relation to the adoption of modern varieties[9].

GROUP 1. Little change in yields. Brazil, Bolivia, Paraguay, Argentina, Chile and Haiti.

These countries, excepting Haiti, are totally or partially within the sub-tropical to temperate zone, an ecology largely ignored by the International Centers system. Existing technology is mostly adapted from the southern USA or is locally generated.

The main limiting factors behind yield stagnation in each of these countries are the following:

Brazil: mainly limitation of ecology (rainfall, soils). The bulk of rice is produced in unfavored upland systems where modern technology is unsuccessful[10]. It is for this reason that rice production is

9/ Dr. P.R. Jennings, in a personal communication has provided this classification of countries.
10/ Section 3 presents a description of the main characteristics of upland farming systems.

currently moving out of this unproductive area towards better upland conditions and varzeas[11].

Bolivia: although soils and rainfall are favorable, modern varieties can provide little advantage in this upland ecology, due to current production systems (migratory agriculture with slash and burn, manual, no modern inputs) and inadequate infrastructure (drying systems, transportation, roads, etc.).

Paraguay: inadequate cultural practices under irrigated conditions (land preparation, weed control) do not allow modern varieties to express yield advantages.

Argentina: all irrigated rice rice production, but low adoption of semi-dwarfs due to grain quality limitations of these varieties in an export-oriented country. Very recent adoption (1984) of high quality IRGA-409 and IRGA 410 varieties. In one large producing area, straighthead, a physiological soil-related, disease, is the major yield constraint. Resistant modern varieties are not currently available.

Chile: low temperature is the main varietal yield constraint. Yields of temperature-tolerant, japonica varieties currently used are constrained by inadequate weed control.

Haiti: inadequate water control and land preparation.

GROUP 2. Rapid yield increases with no new technology.
Uruguay.

11/ Adoption of modern varieties in Rio Grande do Sul (IRGA 409 and IRGA 410) initiated in 1980-81, has gained fast diffusion over the last two years covering 430,500 ha in the State during 1983-84. Average yields in the State have increased from 3.9 to 4.7 ton/ha as a result of this diffusion of modern-semi-dwarfs. This is not captured in the 1980-82 data. Source: Dr. M.A.Oliveira. Technical Director of IRGA. Personal communication.

Yield increases in Uruguay have been achieved through the use of early maturing, excellent quality, improved tall USA varieties (particularly Bluebelle) for export markets.

GROUP 3. Marked yield increases with early adoption of modern technology. Colombia, Peru and Venezuela.

Both Colombia and Venezuela were early adopters (late 60's to early 70's), with high adoption rates of semi-dwarfs. During last 10 years there has been no significant additional yield increases. Peru was also an early adopter in the irrigated sector, but with low adoption in the upland ecologies (25% of total area).

GROUP 4. Steady moderate yield increases under predominantly irrigated conditions. Cuba, Dominican Republic, Ecuador, Guyana and Nicaragua.

These countries have adopted modern varieties in different degrees, concurrent with gradual improvement in cultural practices. Therefore, average yields are below those of Group 3.

GROUP 5. Steady moderate yield increases under upland conditions

These are Costa Rica, El Salvador, Guatemala, Honduras and Panama.

Due to predominant upland conditions and in some cases poor cultural practices (Honduras, Panama), yield increases are moderate despite high adoption of modern technology. Guatemala is a late adopter of dwarf varieties. A large percent of its upland area is sown with improved tall USA varieties.

Trends in Trade

Latin America is currently a net importer of rice, but net imports represent a very small fraction of apparent rice consumption (Table 6)[12]. They also correspond to a very small proportion of the world rice market. During 1980-82 net imports in Latin America were in the order of 220 thousand tons of milled rice, or 2% of apparent consumption (production plus net imports).

The fact that such a small fraction of production and consumption is traded internationally is characteristic of the rice market, where producing zones are also typically rice consuming zones. According to FAO (1984), out of the ten largest rice producers in the world, which together represent over 85 percent of world production, only one (Thailand) exports more than 10 percent of its production. World trade in rice represents around 4 percent of production as compared to 20 percent in the case of wheat.

Nevertheless,there are important differences within Latin America, particularly between Tropical and Temperate South America.

The latter, being a wheat consuming area, exported, during 1980-82, over 50 percent of its rice production. Instead, Tropical South America obtained almost 10 percent of the rice it consumed from other regions. Mexico and the Caribbean region are also net rice importers, while Central America is fairly self-sufficient. (Table 6).

Only six Latin American countries were net rice exporters during 1980-82. They were, in order of importance, Uruguay, Argentina, Guyana, Costa Rica, Colombia and Venezuela (Table 7). In the case of Costa Rica, the position as rice exporter after the mid-70's has-been maintained at the expense of a reduction in internal per capita consumption.

12/ Net imports as measured here do not cancel out flows within the region.

TABLE 6. Milled rice: Production, net trade and consumption by region in Latin America. 1965-67, 1974-76, 1980-82. (1000 MT).

Region	1965-1967			1974-1976			1980-1982		
	Production	Net Imports 1/	Apparent Consumption	Production	Net Imports 1/	Apparent Consumption	Production	Net Imports 1/	Apparent Consumption
Mexico and Caribbean	479	- 25	454	615	39	654	635	124	759
Central America	245	15	260	329	1	330	410	- 1	409
Tropical South America 2/	5606	7	5613	7712	183	7895	9193	362	9555
(Brazil)	(4371)	(-186)	(4185)	(5266)	(- 18)	(5247)	(6013)	(151)	(6165)
Temperate South America	256	- 58	198	380	-121	259	509	-264	244
Latin America 2/	6585	- 61	6524	9036	101	9137	10748	221	10969

1/ Negative signs indicate net exports

2/ These figures unlike the ones presented elsewhere, include both Brazil and Surinam.

SOURCE: FAO Tapes.

TABLE 7. Average exports, imports and net trade of milled rice in Latin America. 1965/67, 1974/76, 1980/82. (1000 MT).

Country or Region	Exports (X)			Imports (M)			Net Trade (X-M)		
	1965/67	1974/76	1980/82	1965/67	1974/76	1980/82	1965/67	1974/76	1980/82
Brazil	186	46	22	1	27	173	185	19	-151
Mexico	0	3	0	10	24	65	- 10	- 21	- 65
Bolivia	0	1	0	2	2	2	- 2	- 1	- 2
Colombia	1	51	25	1	0	2	0	51	23
Cuba	0	0	0	195	219	208	-195	-219	-208
Dominican Rep.	0	0	1	12	59	33	- 12	- 59	- 32
Ecuador	12	13	10	6	0	13	6	13	- 3
Paraguay	0	1	1	0	0	0	0	1	1
Peru	0	7	0[a]	55	80	127[a]	- 55	- 73	-127[a]
Surinam	22	55	117[a]	0	0	0[a]	22	55	117[a]
Venezuela	45	34	20	3	1	1	42	33	19
Tropical South America	266	208	196	275	388	559	- 9	-180	363
Costa Rica	1	7	34	7	1	1	- 6	6	33
El Salvador	9	1	1	4	3	4	5	- 2	- 3
Guatemala	2	1	1	2	3	4	0	- 2	- 3
Honduras	1	0	0	6	5	4	- 5	- 5	- 4
Nicaragua	1	4	1	12	1	22	- 11	3	- 21
Panama	2	1	0	1	1	1	1	0	- 1
Central America	16	14	37	32	14	36	- 16	0	1
Guyana	106	77	66	1	1	0	105	76	66
Haiti	0	0	0	1	7	24	- 1	- 7	- 24
Jamaica	1	1	1	32	45	51	- 31	- 44	- 50
Trinidad	1	1	1	31	36	44	- 30	- 35	- 43
Caribbean	109	80	68	73	96	127	36	- 16	- 59
Tropical Latin America	391	305	301	390	522	787	1	-217	-486
Argentina	50	68	100	1	1	5	49	67	95
Chile	0	0	4	21	35	29	- 21	- 35	- 25
Uruguay	29	89	194	1	1	0	28	88	194
Temperate South America	79	157	298	23	37	34	56	120	264
LATIN AMERICA	470	462	599	413	559	821	57	- 97	-222

a/ Average 1980/81

SOURCE: FAO Tapes.

The largest importing countries in 1980-82 were Cuba, Brazil, Peru, and Mexico, all of which increased their rice purchases from abroad to sustain their levels of per capita consumption. (Table 7).

During the last two decades, the international rice market has been characterized by large price fluctuations and this has been transmitted to some extent to both Latin American export and import prices. (See Table 8). According to FAO (1984), short-run price instability in rice ranks high in comparison with other agricultural commodities and this is undoubtedly related to the "thinness" of the rice market in relation to world production. Other factors explaining short-run price instability of rice are generalized low price elasticities of rice imports and exports.

3. RICE RESEARCH IN THE LIGHT OF RICE FARMING SYSTEMS AND PRODUCTION CONSTRAINTS

Rice research development in Latin America is best understood when rice production conditions are typified along with their main production constraints.

Rice Farming Systems in the Region

The CIAT Rice Research Program has tentatively defined six main cropping systems, on the basis of rainfall patterns, availability of irrigation water, topography, soil fertility, availability of infrastructure and agronomic practices. These are:

- Highly favored upland,
- Moderate favored upland,
- Unfavored upland,
- Subsistence upland,
- Irrigated rice,
- Rainfed lowland rice.

TABLE 8. Annual international prices of rice in the Thai and Latin American markets. 1970-1981 (1981 US$/ton).

Year	Thai[1] (FOB Bangkok)	Latin American export price[2]	Latin American import price[2]
1969	610.0		
1970	442.6	329.6	543.4
1971	298.5	319.3	450.0
1972	324.1	394.0	436.0
1973	738.7	539.9	607.6
1974	922.9	681.6	881.5
1975	532.1	565.9	700.6
1976	373.0	399.0	582.8
1977	347.2	339.5	474.2
1978	413.3	359.9	511.0
1979	338.3	373.8	395.0
1980	393.0	408.4	436.8
1981	440.0	465.2	485.2
Average	463.6	431.3	542.1

1/ 15% broken, milled. This quality of rice is closer to Latin American standards than the 5% broken which is usually cited in other studies. Source: Brazil. (1982).

2/ Weighted average price of Latin American rice exports and imports. Source: FAO Trade Yearbooks.

Note: Prices have been deflated by the C.I.F. Manufacturing Unit Value Index of the World Bank.

Table 9 presents a summary of the estimated areas and average yields involved in each of the systems during 1981 which have been identified in Latin America. It may be observed in this table that in terms of area, the unfavored upland system predominates (38 percent of total area devoted to rice) with yields well below the irrigated and rainfed systems.

According to CIAT's Rice Program the main characteristics and constraints of each of the production systems are the following:

1. Irrigated Rice

The area cultivated under irrigation is estimated to be slightly over 2 million hectares, that is, in about 24 percent of the total area sown to rice in Latin America (Table 9). Yet over half of the region's rice production comes from irrigated rice. This system is found in nearly all countries and predominates in Southern Brazil, Colombia, Cuba, Guyana, Nicaragua, Peru, Surinam, Venezuela, and the Southern Cone countries[13]. It is characterized by water management, improved, high-yielding varieties, use of purchased inputs, and mechanical land preparation and harvesting. Average national yields with this system range from 3 to over 5 tons per hectare.

Important production constraints include rice blast (Pyricularia), hoja blanca, iron toxicity, lodging, and in some countries, low temperature and lack of suitable grain quality in the varieties available. Also, infrastructure problems in some countries limit the application of existing technology.

This system has received major attention for technology development. Dwarf lines and varieties as well as cultural practices have been produced and adapted for this system, except for Uruguay, Chile and part of Argentina.

13/ See CIAT-IRTP (1984), Table 66, p. 158.

TABLE 9. Paddy Rice: summary of estimated area and yield in major production systems, Latin America. 1981-1982.

System	Area (Million has)	%	Average Yield (ton/ha)	Production (Million ton)	%
Irrigated	2.1	0.24	4.0	8.4	0.52
Rainfed	0.4	0.05	2.5	1.0	0.06
Upland:					
Favored[a]	2.0	0.23	2.0	4.0	0.25
Unfavored	3.3	0.38	0.7	2.3	0.14
Subsistence	0.9	0.10	0.5[b]	0.4	0.02
TOTAL	8.8	1.00	1.8	16.1	1.00

a/ It includes favored and moderately favored upland systems.

b/ Estimated as residual.

SOURCE: CIAT-IRTP (1984)

2. Highly Favored Upland Rice

This system is generally confined to flat fertile areas receiving over 2,000 mm of rainfall in seven or eight months of the year. Normally there are no marked dry periods during the rainy season. This system uses modern dwarf varieties (which, as they had been developed for the irrigated system, w unexpectedly suitable), improved agronomic practices, and mechanized farming methods. Yields average 2.5 ton/ha, with better farms consistently prod 4-5 tons/ha.

This system is important in parts of Brazil, Venezuela, Central America, and Colombia and could be used in large areas of unexploited land in th region. Major constraints are grassy weeds after two or th blast (Pyricularia), and lodging. More recently, leaf scald and grain spotting have become important in some areas. The hoja blanca virus disease reçently has also caused widespread damage in Colombia, Venezuela and Ecuador.

3. Moderately Favored Upland Rice

Much of the rice in Central America and sub-Amazonian Brazil is produced with this system. It is also found in some areas of Bolivia, Ecuador and Mexico. It differs from the preceding system in that it has a shorter wet season with less overall rainfall, and a two- to three-week dry period during the growing season. In many areas the soils are also less fertile. Dwarf varieties are used in Central America and in some areas in Bol Mexico, and Venezuela. The system yields about 2 ton/h and around 1.5 ton elsewhere, with large yield variance rainfall. Constraints to rice production include mild to moderate droughts, mineral deficiencies, diseases (particularly blast, brown spo scald), and weeds.

Together, favored and moderately favored upland rice sy around 25% of Latin American production and correspond to about 23 percent of the rice area (Table 9).

4. Unfavored Upland Rice

This system is characterized by irregular and low rainfall, high mechanization, poor soils, and low planting densities. Tall varieties are used and produce an average yield of around 0.7 to 1 ton/ha. Yield variance is extremely high. Much of Brazil's rice is produced with this system in acid soils with often relatively high levels of aluminum and poor water holding capacity. The main system constraint is low total rainfall and dry periods during the growing season, plus infertile soils which result in mineral nutrition problems. Only 14% of rice production in 1981-82 was obtained with this system.

5. Subsistence Upland Rice

This is a slash-and-burn, shifting system in a forest ecology characterized by high rainfall. Tall, unimproved varieties are planted at low density. The crop is totally manually managed with no purchased inputs. Farm size is less than one hectare. Average yields are close to half a ton per hectare, supplying about 2% of total rice production in Latin America.(Table 9).

6. Rainfed Lowland Rice

This system is presently relatively small, and is a transition system between irrigated and upland, using rainwater trapped and held by field levees. Nevertheless, water deficits and/or flooding are common. Tall varieties dominate although dwarf varieties can be grown with adequate water control procedures. Use of purchased inputs is limited, and the crop is often handled manually. Average yields are 2.5 ton/ha. It is important in Coastal Ecuador (in the Pozas System), Colombia's Northern Coast, the Dominican Republic, Peru and Varzeas in Central Brazil. The main problem in this system is inadequate water control requiring tall varieties, and low levels of purchased inputs. It is estimated that about 6 percent of total rice production in Latin America is supplied by 400,000 hectares of rainfed lowland rice. It is considered that this production system can expand significantly in the future particularly because it can be mechanized and yields are more stable than in upland rice.

Table 10 shows the area distribution among the different ecosystems by country during the 1981-82 rice harvest.

Rice Research and Farming Systems

As mentioned earlier, in the introduction of this paper, research in Latin America began in Colombia with the establishment of CIAT's Rice Program in close association with ICA, the national agricultural research organization. Since its begining, and because of the example set with the introduction of dwarf materials from IRRI (which showed dramatic yield increases) the basic research strategy was to seek improved yields through breeding programs aimed at irrigated rice systems. It was considered that given limited resources, the strategy of raising productivity in a single production system, which offered the greatest opportunity for rapid results, would provide the critical mass required for impact.

The first modern varieties released by the joint CIAT-ICA program (CICAs) were thus only tested under irrigation, and they first diffused into irrigated areas of Colombia and throughout the tropics.

Diffusion accelerated via the early training program at CIAT of rice researchers from the different national programs. Between 1969 and 1976 a total of 87 Latin American professional coming from 16 countries were trained in CIAT's Rice Program[14]. These rice workers carried germplasm back to their countries and continued to test the germplasm made available by the CIAT-ICA research program. This collaboration between the Colombian team and researchers in other national programs was formalized in the mid-1970's, with the creation of the International Rice Testing Program (IRTP), a collaborative CIAT-IRRI project funded by

14/ The number of trainees in the Rice Program of CIAT reached 274 by 1983.

TABLE 10. Area distribution for different rice production ecosystems in Latin America (000 ha), 1981/82 harvest.

Countries	Irrigated	Lowland Rainfed	Highly Favored Upland	Moderately Favored Upland	Unfavored Upland	Subsistence Upland	Area Total
Argentina	110.0	0	0	0	0	0	110.0
Belize	1.2	0	0	0	0	2.2	3.4
Bolivia	0.5	0	0	34.7	0	23.5	58.7
Brazil[1]	740.6	327.9	650.6	849.8	3319.3	750.2	6638.4
Chile	37.0	0	0	0	0	0	37.0
Colombia	345.9	0	64.4	0	0	43.0	453.0
Costa Rica	2.0	1.0	26.3	35.0	7.0	1.0	72.3
Cuba	130.0	0	0	0	0	0	130.0
Dominican Rep.	100.0	0	0	3.1	0	0	103.1
Ecuador	60.1	37.6	0	30.1	0	7.5	135.2
El Salvador	1.4	0	0	12.5	0	0	13.9
Guatemala	0	0.8	5.3	6.2	2.3	0.8	15.4
Guyana[1]	86.4	0	0	35.2	0	0	121.6
Haiti	31.7	3.3	2.1	1.7	1.3	2.1	42.2
Honduras	6.0	3.0	15.0	5.0	2.1	3.1	34.1
Jamaica	1.5	0	0	0	0	0	1.5
Mexico	96.4	2.7	20.2	60.7	20.2	6.7	206.9
Nicaragua	22.2	0	3.3	5.9	5.9	4.6	41.8
Panama	5.2	8.3	12.5	10.4	8.3	59.4	104.2
Paraguay	21.3	0	0	11.0	0	0	32.3
Peru	120.4	9.6	8.0	6.4	16.1	0	160.5
Surinam	35.7	0	0	0	0	0	35.7
Uruguay	68.0	0	0	0	0	0	68.0
Venezuela	60.0	0	140.0	0	0	0	200.0
TOTAL	2087.4	394.2	948.0	1107.5	3382.3	904.1	8819.6
%	23.7	4.5	10.7	12.5	38.3	10.2	100.0

1/ Harvest data 1980/1981 for Brazil, and 1977/1978 for Guyana.

SOURCE: CIAT-IRTP (1984).

UNDP. The objective of the IRTP has been to evaluate and distribute the best available germplasm in distinct nurseries and for different ecologies. Since 1977, rice researchers from throughout the region, meet every two years to share ideas and experiences. Information is provided at these meetings on the utilization and performance of the germplasm available in each country.

National breeding programs for irrigated conditions also developed during the 60's and 70's in the following countries: Cuba, Chile, Dominican Republic, Guyana, Mexico, Peru, Surinam, and Rio Grande Do Sul in Brasil. These programs made an important contribution, producing dwarf varieties which were often widely grown within the specific country. Their varieties came from local crossing programs often using CIAT-ICA lines as parents, or from direct selection of lines obtained from CIAT and locally released. Yet, due to their limited adaptability, there was very little spillover into other countries.

Until recently, there were no specific breeding programs for rice production under rainfed lowland systems (or varzeas). Nevertheless, there was an unplanned spillover of CIAT-ICA material, and of germplasm from the Dominican Republic and Mexican Research Programs into the various rainfed ecologies of the region. Recently, EMBRAPA in Goiania began a specific breeding program for their varzeas.

There was also an unexpected spillover of CIAT-ICA's new rice technology into the more favored and moderately favored upland rice production systems, begining in the early 1970's, of Central America, Colombia, Venezuela, Ecuador and Bolivia. Other national programs which have had an impact on more favored upland systems are those of Surinam (into Central America) and Mexico (within the same country).

In 1981, CIAT began a specific breeding program for the more favored upland ecologies, since germplasm developed for irrigated conditions does not exhibit adequate yield stability, and obviously lacks tolerance to stresses which are characteristic of upland soils.

Currently, the CIAT Rice Research Program for upland conditions is large, and is located at Villavicencio (Colombia) and in Panama.

Rice research for unfavored upland conditions has a long tradition only in Campinas, Brazil, where breeding for this type of farming system was undertaken by the Instituto Agronomico do Campinas (IAC). This program has released many IAC varieties, that presently cover a large percentage of the huge unfavored upland area in Brazil. More recently, EMBRAPA has undertaken a large research program for this system in Goiania.

With respect to the remaining subsistence upland farming system, no research has yet ever been initiated nor have any spillover taken place in this agroecosystem.

The following section of this paper refers to the impact that the adoption of modern semi-dwarf varieties has had, under irrigated, the more favored upland, and rainfed systems. Because research cost figures are only available in relation to the IRTP network including national program contributions and the CIAT breeding programs, only production increases which can be linked to these two activities are included in the analysis. No attempt has been made to identify or quantify the impact of the national rice breeding programs which have been identified.

4. THE IMPACT OF HIGH-YIELDING RICE VARIETIES IN LATIN AMERICA

In 1977, CIAT published a study by Scobie and Posada which quantified the impact of high yielding varieties (HYV's) in Colombia, including the size and distribution of the economic benefits resulting from their introduction in this country[15].

15/ HYV's are defined in this report as semi-dwarf varieties.

In 1974, the last year included in their analysis, already 91% of the rice area in Colombia was planted with semi-dwarf varieties; and 27% of the total rice area corresponded to CICA 4, the first variety which had been released by the joint CIAT-ICA rice program in 1971. The authors estimated that in 1974 the total area sown to HYV's in Latin America was approximately 800,000 hectares, and that, excluding Brazil, this meant that rice production was 40% higher than it would have been in the absence of HYV's. If Brazil was included, the corresponding figure was 14.5%.

Adoption of HYV's in Latin America has continued in the last nine years; the area sown to HYV's in 1981 is estimated at 2,286,000 hectares, which represents around 26% of the total rice area. Adoption is 70% if one excludes Brazil, where improved technology is not suited for adoption in the major upland area.

The new material introduced into the region by the joint CIAT-ICA program has dominated the area sown to HYV's with a few exceptions. Table 11 shows the relative importance of this material in the case of Colombia. It may be observed that varieties are continually replaced because of disease problems after a few years, and also because of improvement in yielding capacity in newer materials.

The subsequent analysis will cover the following aspects:

- the diffusion of HYV's in Latin America, and
- the impact of HYV's in the rice production of Latin America and
- the role of CIAT and collaborators in National Programs

The Diffusion of HYV's in Latin America

The historical diffusion of semi-dwarfs in Latin America can be visualized with the aid of Table 12 which summarizes the new materials that were released as commercial varieties in each country through 1982. The dates presented in the top row of this Table indicate the year when each variety was released by the national programs. This

Table 11. Percentage distribution of rice area among varieties grown in Colombia, 1965-1983. Selected years

Year	Blue bonnet 50	Tapuripa	Other tall	Semi-dwarf varieties							
				IR-8	IR-22	CICA-4	CICA-6	CICA-7	CICA-9	CICA-8	METICA 1
1965	86.6	-	11.7	-	-	-	-	-	-	-	-
1969	50.1	36.2	7.0	5.5	-	-	-	-	-	-	-
1973	2.2	-	-	41.2	38.8	17.8	-	-	-	-	-
1976	0.8	-	-	10.0	27.7	37.1	24.8	-	-	-	-
1979		4.0			24.0	22.0	4.0	4.0	6.0	40.0	-
1981	-	-	1.2	-	15.3	9.9	-	7.6	1.5	54.8	9.7
1983					21.1	18.2	-	3.9	7.8	21.7	13.6

SOURCE: CIAT, Annual Reports.
Scobie and Posada (1977).
CIAT-IRTP (1984).
Fedearroz.

Table 12. High yielding varieties derived from CIAT germplasm, released by Latin American National Programs.

Country	1968	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982
Argentina												IR-841			
Belice					CICA-4					CR-1113 CICA-7 CICA-9 CICA-6	CICA-8				
Bolivia							SaavedraV5	CICA-6			CICA-8	IR-1529			
Brazil					CICA-4 IR-22				IRGA-407 IRGA-408		IR-841	IRGA-409		IRGA-410 EMPASC-101 EMPASC-102 EMPASC-103	TAC-1278 INCA-4440
Chile															
Colombia	IR-8			IR-22 CICA-4			CICA-6		CICA-9 CICA-7		CICA-8			METICA-1 METICA-2	ORYZICA-1
Costa Rica				IR-22	CICA-4		CR-1113			CICA-7 CR-5272 CICA-9				CR-201	
Cuba								NAYLAMP			IR-1529[1]				
Ecuador	IR-8			INIAP-6 INIAP-2				NAYLAMP	INIAP-7			INIAP-415			
El Salvador					CICA-4				X-10	CICA-9	CR-1113				CENTA-A2 CENTA-A3
Guatemala					CICA-4			ICTA-6		TIKAL-2		ICTA-CRISTINA ICTA-VIRGINIA		TEMPISQUE	
Guyana															
Haiti												CICA-8	MCI-65 MCI-3		
Honduras					CICA-4		CICA-6	IR-100[1]		CICA-9	TIKAL-2 CICA-8	CR-1113			
Jamaica								CICA-4		CICA-9			CICA-8		
Mexico	IR-8				CICA-4		CICA-6			CICA-7			CICA-8	CARDENAS-A80	
Nicaragua				IR-22	CICA-4				IR-100d	CR-1113 LINEA-9 IR-665		CICA-8			
Panama	IR-8								CR-1113	CICA-7	CR-5272	CICA-8			TOCUMEN-5430
Paraguay					CICA-4 IR-22				CICA-6	CICA-7 CICA-9		CICA-8			
Peru	IR-8			NAYLAMP	CHANCAY			INTI							
Dominican Republic	IR-6[1] IR-8[1] IR-5[1]				AVANCE-72					ISA-21 ISA-22	ISA-44 ISA-40				
Surinam									DIWANI		ELONI				
Uruguay															
Venezuela	IR-8				IR-22 CICA-4		CICA-6			ARAURE-1 CICA-7 CIARLLACEN-1					ARAURE-2

1/ Varieties obtained directly from IRRI or local crosses based on IRRI material.

information does not indicate the relative importance of each of the varieties; moreover, a few may have never reached the farm gates. It is quite evident that there was an impressive diffusion throughout Latin America of HYV's from CIAT and other sources, a process which is still actively developing.

Information on the area sown to each variety has been provided by the heads of national rice research programs during the biannual meetings which are organized by IRTP. For most countries, at least three observation point estimates are available, indicating what percentage of the total rice area was sown to HYV's.

In order to obtain a continuous plot of the diffusion process of HYV's over time by country, a logistic or S-shaped curve has been adjusted in each case based on available observations[16].

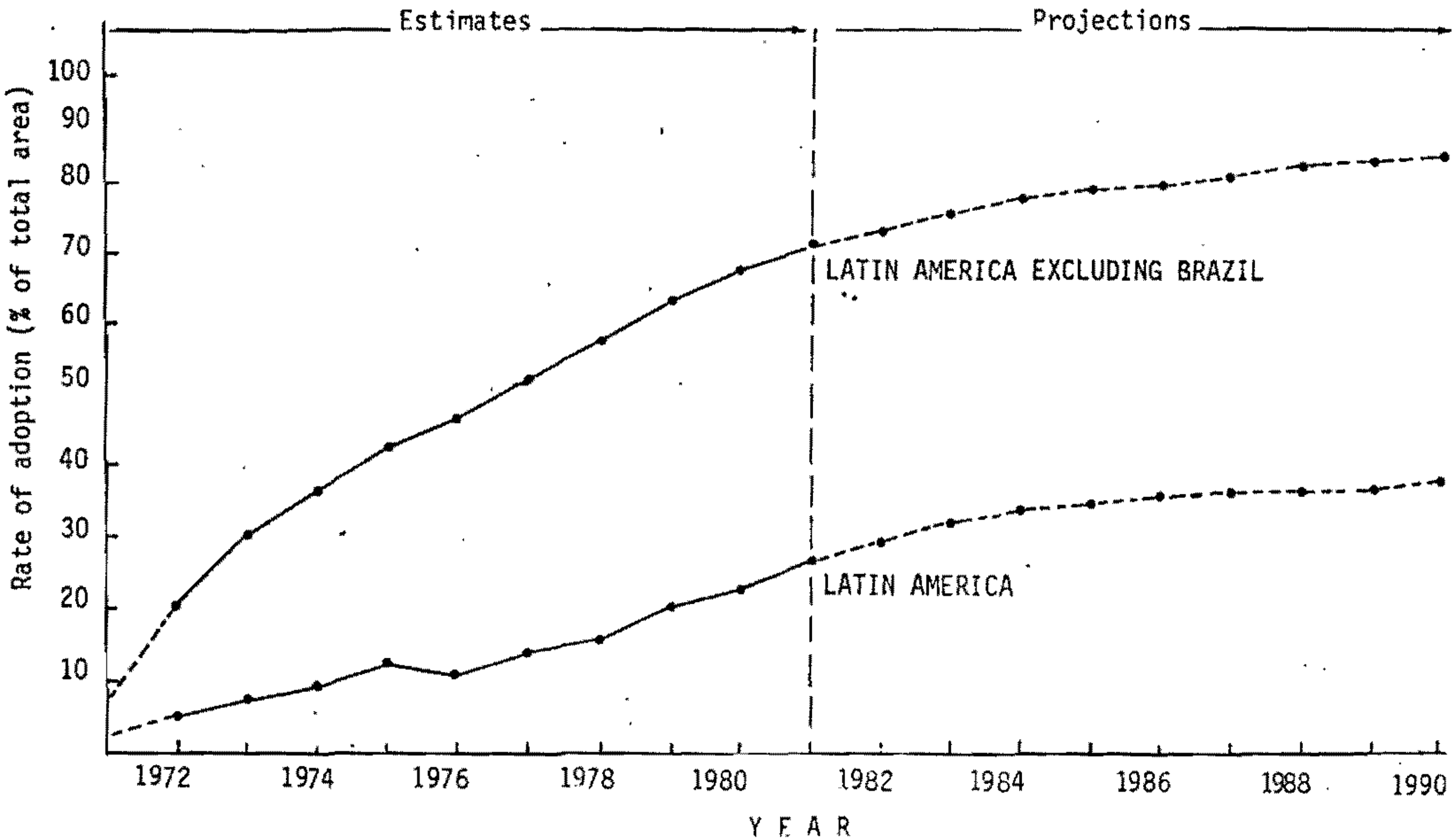
Logistic shapes of growth curves are usually chosen to represent the process of technology adoption following evidence provided by a number of studies which estimated adoption curves (Griliches 1957, Mansfield 1961). According to Herdt and Capule (1983), the logistic shape of adoption curves also is evident in a number of studies on the adoption of modern rice varieties in Asia. The rationale behind these S-shaped curves is that there are a few initial innovators who generate a demonstration effect, leading to a fast increasing rate of adoption. Later on, the process deccelerates, slowly tending to a standstill as fewer late adopters catch up.

Figures A.1 to A.11 of the Appendix contain the logistic adoption curves which were plotted for each individual country. Adoption is expressed as the annual percentage of the cultivated area sown to HYV's.

Based on the country-specific diffusion curves, an aggregate adoption curve has been obtained for Latin America a whole. Figure 1

16/ The curves were plotted without econometric estimations.

Figure 1.



Estimates
Projections
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
LATIN AMERICA EXCLUDING BRAZIL
LATIN AMERICA
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
YEAR

TABLE 13. Spread of HYV's in Latin America[1]. 1969-1981.

Year	Area HYV ('000 ha)		Area all rice ('000 ha)		Percentage of area in HYV's	
	All countries[2]	Excluding Brazil	All countries[2]	Excluding Brazil	All countries[2]	Excluding Brazil
1969-70	53	53	6,226	1,606	0.8	3.3
1970-71	133	133	6,639	1,660	2.0	8.0
1971-72	250	250	6,294	1,531	4.0	16.3
1972-73	345	345	6,032	1,500	5.7	21.7
1973-74	482	482	6,380	1,586	7.6	30.4
1974-75	613	613	6,448	1,784	9.5	34.4
1975-76	935	882	7.344	2.038	12.7	43.3
1976-77	938	872	8,525	1,869	11.0	46.7
1977-78	1,120	1,000	7,938	1,946	14.1	51.4
1978-79	1,206	1,094	7,508	1,885	16.1	58.0
1979-80	1,533	1,315	7,501	2,049	20.4	64.2
1980-81	1,862	1,366	8,213	2,006	22.7	68.1
1981-82	2,286	1,531	8.819	2,181	26.0	70.2

1/ It corresponds to semi-dwarf varieties; it excludes both improved tall and traditional varieties.

2/ It includes the following countries: Argentina, Belize, Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Guyana, Haiti, Jamaica, Mexico, Nicaragua, Panama, Paraguay, Peru, Surinam, Uruguay and Venezuela.

SOURCE: FAO Tapes.
Figures A.1 to A.11 the Appendix.

and Table 13 show the aggregate spread of HYV's in Latin America. The proportion of rice area in HYV's increased from about 1 percent in 1969 to 10 percent in 1974. By 1981, HYV's were sown on 26 percent of the rice area in the 24 countries included in this study. If one excludes Brazil (which is a predominantly unfavored upland ecology), Table 13 indicates that the adoption process had passed the 10 percent mark in 1971, and had reached 70 percent in 1981. As already noticed by Scobie and Posada (1977), this results compares favorably with the Asian experience. According to recent estimates by Herdt and Capule (1983), the rate of adoption of semi-dwarf varieties was 39.5 percent in 1980 for a group of 11 Asian countries (excluding China and Japan).

It was mentioned that an unexpected and unprogrammed spinoff from breeding and selecting material for the irrigated rice system was the adoption of selected improved materials in upland rice production, especially in the most favored upland systems.

Table 14 presents the area sown to HYV's in irrigated and upland conditions in each of 24 Latin American countries during 1981-82.

Out of 2.3 million hectares with HYV's, around 29 percent (661,400 ha) were sown under upland farming conditions. Upland area with HYV's represented 10 percent of the total rice area in upland systems, and as high as 60 percent if Brazil is excluded.

Table 15 indicates that in terms of sub-regions, this spillover into upland rice systems is proportionally higher in Mexico (72 percent of upland rice is obtained from HYV's), Central America (67 percent) and Tropical South America, excluding Brazil (60 percent). The almost nil adoption of HYV's in the Brazilian uplands was explained earlier on by the predominance of unfavored and traditional subsistence farming systems, conditions under which modern varieties present no advantages.

TABLE 14. Irrigated and upland rice area and use of high-yielding or semi-dwarf varieties. 1981-1982.

Country	Irrigated rice area			Upland rice area		
	Total	HYV	HYV/ total	Total	HYV	HYV/ total
	-- '000 ha --		%	-- '000 ha --		%
Argentina	110.0	27.5	25	0	0	0
Belize	1.2	1.2	100	2.2	1.7	77
Bolivia	0.5	0.5	100	58.2	29.1	50
Brazil	740.6	592.5	80	5897.8	163.0	3
Chile	37.0	0.0	0	0	0	0
Colombia	345.9	345.9	100	107.4	64.4	60
Costa Rica	2.0	2.0	100	70.3	70.3	100
Cuba	130.0	130.0	100	0	0	0
Dominican Republic	100.0	83.0	83	3.1	0.0	0
Ecuador	72.4	72.4	100	62.8	12.6	20
El Salvador	1.4	1.4	100	12.5	12.5	100
Guatemala[1]	0	0	0	15.4	3.1	20
Guyana	86.4	24.3	28	35.2	0.0	0
Haiti	31.7	3.7	10	10.5	0.0	0
Honduras	6.0	6.0	100	28.1	17.0	60
Jamaica	1.5	1.4	95	0	0	0
Mexico	96.4	86.4	90	110.6	80.0	72
Nicaragua	22.2	22.2	100	19.5	9.7	50
Panama	5.2	5.2	100	98.2	50.0	51
Paraguay	21.3	20.7	97	11.0	0.0	0
Peru	120.4	103.4	86	40.3	8.0	20
Surinam	35.7	35.7	100	3.1	0.0	0
Uruguay	68.0	0.0	0	0	0	0
Venezuela	60.0	60.0	100	140.0	140.0	100
TOTAL	2,095.8	1,625.4	76.4	6,726.2	661.4	9.8
Percentage	23.8			76.2		
Total excluding Brazil	1,359.2	1,012.6	74.5	828.4	498.8	60.2
Percentage	62.1			37.9		

1/ Data of 1977/78 growing season.

SOURCE: CIAT (1984).

TABLE 15. Irrigated and upland rice area and the use of HYV's in Latin America. 1981-1982. (1.000 ha).

Country or Region	Irrigated rice			Upland rice			Total area		
	Total	HYV's	HYV/Total %	Total	HYV's	HYV/Total %	Total	HYV's	HYV/Total %
Mexico	96.4	86.4	90	110.6	80.0	72	207.0	166.4	80
Central America[1]	38.0	38.0	100	246.2	164.3	67	284.2	202.3	71
Caribbean[2]	119.6	29.4	25	45.7	0	0	165.3	29.4	18
Brazil	740.6	592.5	80	5897.8	163.0	3	6638.4	755.5	11
Tropical South America[3]	886.2	851.6	96	425.9	254.1	60	1312.1	1105.7	84
Temperate South America[4]	215.0	27.5	13	0	0	-	215.0	27.5	13
LATIN AMERICA	2095.8	1625.4	76.4	6726.2	661.4	9.8	8822.0	2286.8	26

1/ Includes Belize, Costa Rica, El Salvador, Guatemala, Honduras, Nicaragua and Panama.

2/ Guyana, Haiti, Jamaica.

3/ Excludes Brazil.

4/ Argentina, Chile, Uruguay.

SOURCE: Table 14.

Contribution of HYV's to Rice Production

Table 16 contains estimates, by country, of average yields achieved with modern and traditional technologies both in upland and irrigated conditions. The main component of modern technology is the use of the semi-dwarf high-yielding varieties. Traditional conditions include improved traditional varieties in those situations where these are available. Data on average irrigated and upland yields has been provided by national research programs. Specific average yields for modern or traditional varieties in either system are CIAT estimates, based on unpublished information and verbal reports. The yield superiority attributed to semi-dwarfs is a result of a number of factors, such as the fact that they may have been sown on superior land, or may use higher levels of inputs, such as fertilizer, irrigation or weed control. However, in the absence of improved genetic potential, the use of better lands or higher input levels may not be justified.

The average yield superiority with modern technology in irrigated systems is around 1.4 ton/ha but varies between 0.1 and 2.8 ton/ha. The lowest yield differential between traditional and modern technology corresponds to Bolivia, where the rice area under irrigation is minimal. But in three out of every five countries, the increase in irrigated yields due to HYV's is above 1 ton/ha.

In upland rice systems, the average increase in yields due to modern technology is 1.7 ton/ha, ranging from 0.4 to 3.0 ton /ha. Again the lowest yield advantage from the adoption of HYV's is observed in Bolivia, where all the rice is obtained with a very traditional manual subsistence system, (slash and burn), using no applied inputs.

Table 17 presents the increase in rice production by country, in 1981-82, which is attributed to the existence of HYV's. These estimates were obtained by multiplying yield increases (due to the use of modern technology) by the number of hectares sown to HYV's, both in irrigated and upland systems. These figures indicate that in 1981, the use of

TABLE 16. Estimated average yields for upland rice irrigated rice areas for tall (traditional and improved) and semi-dwarf varieties. 1981-82.

Country	PIA	Irrigated Yields Y_I^T	Y_I^S	$\bar{Y}_I$	PUA	Upland Yields Y_U^T	Y_U^S	$\bar{Y}_U$	$\bar{Y}$
	%	---- tons/ha ----			%	---- tons/ha ----			tons /ha
Argentina	25	3.5	3.9	3.6	0	-	-	-	3.6
Belize	100	2.5	2.9	2.9	77	1.0	2.3	2.0	2.3
Bolivia	100	2.5	2.6	2.6	50	1.4	1.8	1.6	1.6
Brazil	80	3.0	3.9	3.7	3	0.9	3.5	1.0	1.3
Chile	0	3.5	-	3.5	-	-	-	-	3.5
Colombia	100	3.0	5.1	5.1	60	1.5	4.0	3.0	4.2
Costa Rica	100	3.5	6.1	6.1	100	1.6	2.7	2.7	2.8
Cuba	100	2.5	3.8	3.8	0	-	-	-	3.8
Dominican Rep.	83	1.6	2.8	2.6	0	1.3	-	1.3	2.5
Ecuador	100	2.5	3.9	3.9	21	1.6	3.5	2.0	3.0
El Salvador	100	3.5	5.0	5.0	100	1.6	3.6	3.6	3.7
Guatemala	0	-	-	-	20	1.6	4.6	2.2	2.2
Guyana	28	2.8	3.5	3.0	0	1.5	-	1.5	2.6
Haiti	10	2.8	5.5	3.1	0	2.9	-	2.9	3.0
Honduras	100	1.7	4.5	4.5	60	1.6	3.4	2.7	3.0
Jamaica	95	1.6	3.1	3.0	0	-	-	-	3.0
Mexico	90	2.5	3.9	3.8	72	1.2	2.3	2.0	2.8
Nicaragua	100	3.5	4.1	4.1	50	1.4	3.6	2.5	3.3
Panama	100	3.5	4.1	4.1	51	1.0	3.0	2.0	2.1
Paraguay	97	2.5	2.9	2.9	0	1.8	0	1.8	2.5
Peru	86	4.0	5.2	5.0	20	1.7	3.2	2.0	4.3
Surinam	100	3.0	4.2	4.2	0	-	-	-	4.2
Uruguay	0	5.6	-	5.6	0	-	-	-	5.6
Venezuela	100	2.9	4.0	4.0	100	1.6	2.5	2.5	3.0

PIA = Proportion of irrigated area with semi-dwarf varieties, as in Table 14

PUA = Proportion of upland area with semi-dwarf varieties, as in Table 14

Y_I^S, Y_I^T = Yields of semi-dwarf and traditional varieties respectively, under irrigated system.

Y_U^S, Y_U^T = Yields of semi-dwarf and traditional varieties respectively, in upland rice systems.

$\bar{Y}_I, \bar{Y}_U$ = Average irrigated and upland yields, respectively.

SOURCE: CIAT Reports of the Rice Monitoring Tours.
CIAT (1984)
CIAT estimates

TABLE 17. Increase in rice production in 1981-82 due to HYV and share of CIAT germplasm[1] (paddy rice).

Country	Irrigated rice	Upland rice	TOTAL	CIAT contribution	Adjusted total increase
	------- '000 tons	--------		- % -	'000 tons
Argentina	11.00	-	11.00	100	11.0
Belize	0.48	2.21	2.69	100	2.7
Bolivia	0.05	11.64	11.69	100	11.7
Brazil[2]	533.25	423.80	957.05	100	957.0
Chile	0.00	-	-	-	-
Colombia	726.40	161.00	887.40	100	887.4
Costa Rica	5.20	77.33	82.53	100	82.5
Cuba	169.00	-	169.00	80	135.2
Dominican Rep.	99.60	0.00	99.60	12	11.9
Ecuador	101.36	24.70	126.06	100	126.1
El Salvador	2.10	25.00	27.10	90	24.4
Guatemala	0.00	9.30	9.30	100	9.3
Guyana[2]	17.01	0.00	17.01	0	0.0
Haiti	9.99	0.00	9.99	100	10.0
Honduras	16.80	30.60	47.40	100	47.4
Jamaica	2.10	-	2.10	100	2.1
Mexico	120.96	88.00	208.96	30	62.7
Nicaragua	13.32	21.34	34.66	50	17.3
Panama	3.12	100.00	103.12	100	103.1
Paraguay	8.28	0.00	8.28	100	8.3
Peru	124.08	12.00	136.08	16	21.8
Surinam[2]	47.64	0.00	47.64	0	0.0
Uruguay[2]	0.00	-	0.00	-	0.0
Venezuela	66.00	126.00	192.00	100	192.0
All Latin America	2060.80	1112.92	3173.70		2723.9
% Increase	24	15	20		-
Latin America excluding Brazil	1527.50	689.12	2216.60		1766.9
% Increase	27	40	30		-

1/ Blanks indicate that this type of rice is not planted.

2/ Harvest data 1980-81 for Brazil and Uruguay, 1977-78 for Guyana, and 1979-80 for Surinam.

SOURCE: Tables 14 and 16.

semi-dwarfs along with its input package, meant an additional production in Latin America of approximately 3 million tons of paddy rice, that is, 1.3 additional tons of paddy rice per hectare sown to HYV's. If only the direct contribution of CIAT germplasm is taken into account, Table 17 shows that the diffusion of its HYV's meant an increase in production of 2.7 million tons, or an average yield increase of 1.2 tons per hectare sown to HYV's[17]. An important part of the increase in production (35 per cent) came about as a result of the spillover effect of irrigated HYV's into upland systems (Table 17).

Estimates provided in Table 17 and 18 have been obtained assuming that the shift in the supply of rice did not imply a decrease in the Latin American average price. thus, they correspond to the horizontal shift of the supply curve at constat prices[18]. Data in Table 18 indicates that the largest absolute increase in production during 1981-82 took place in Tropical South America (1.3 million tons of additional paddy rice production), followed by Brazil and Central America. But, the largest relative impacts correspond to Central America (61.7 per cent increase) and next in Tropical South America (42.5 per cent increase). The impact on rice production in Temperate South America and in the Caribbean has been extremely low because the technology is not suited for the ecologies of these areas. Finally, Mexico and Brazil represent itermediate situations, but not included in this analysis is the post 1981 increase in production which has been taking place in temperate Brazil (Rio Grande do Sul).

17/ The relative contribution of CIAT to the estimated increase in rice production by country eas measured in terms of the percentage of the area with HYV's which was sown with varieties directly obtained from the germplasm distributed by the IRTP. The low participation of CIAT germplasm in some countries is due to the existence of active local breeding programs or the adoption of IRRI varieties.

18/ In those countries where rice is a non-tradable commodity (that is, not traded internationally or close self-sufficiency), prices have probably fallen due to technological change, in which case the final increase in rice production was smaller than the current estimates. The estimes of production increases would also differ in those cases where prices would have been higher in the absence of new technology.

TABLE 18. Estimate of the increase in paddy rice production due to HYV's derived from CIAT germplasm in Latin America, by region. 1981 (1000 M.T.).

Country or Region[1]	Observed Production	Estimated Production without HYV's[2]	Additional Production	
			Total	%
Mexico	586.6	523.9	62.7	12.0
Central America	751.6	464.9	286.7	61.7
Caribbean	536.6	524.5	12.1	2.3
Brazil	8,638.0	7,681.0	957.0	12.5
Tropical South America[3]	4,675.1	3,280.7	1,394.4	42.5
Temperate South America	912.2	901.2	12.1	1.3
LATIN AMERICA	16,100.1	13,376.2	2,723.9	20.4

1/ Regions defined as in Table 15.

2/ This is the shift in production at actual prices.

3/ Excluding Brazil.

SOURCE: Tables 17 and Table 5 of the Appendix.

On average, the additional production obtained in 1981 due to the adoption of HYV's which originated in Colombia, represents a 20 per cent increase with respect to a situation of no adoption.

5. THE COSTS AND RETURNS TO INVESTMENT IN RICE BREEDING

The purpose of the following exercise is to determine the aggregate economic impact and returns to investment in rice breeding by CIAT and collaborators in national research programs. No attempt will be made to measure the distribution of benefits between consumers, producers, etc. from the adoption of modern rice varieties for reasons which will soon be explained.

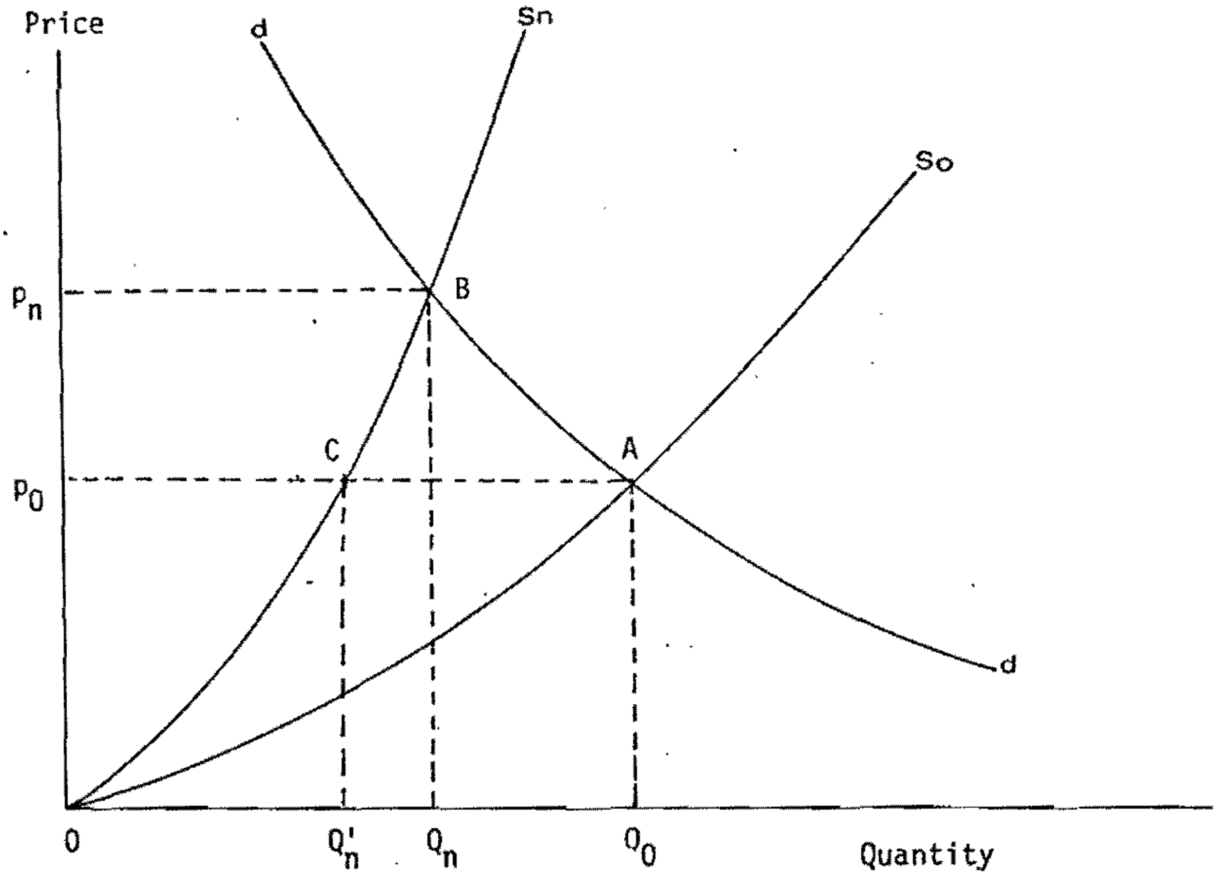
Some Methodological Considerations

Two basically different approaches are used to measure research benefits: one, is the production function approach which involves estimating the marginal productivity of research. The other and most usual approach employs the techniques of cost-benefits analysis, in which the Marshallian concepts of changes in consumer's and producers' surplus, resulting from the shift in the supply curve due to technological change, are used to measure gross research returns[19].

The second approach can be illustrated with the aid of Figure 2. In this graph (which is the one used by Akino and Hayami), d and So represent market demand and supply curves, whereas Sn represents the supply curve which would have existed if the improved rice varieties were not developed. The shift in the supply curve from Sn to So would generate gross benefits of different sizes depending on whether

19/ See, for example, Griliches 1958, Barletta 1967, Ayer and Schuh 1972, Akino and Hayami 1975, Evenson and Flores 1980, Scobie and Posada 1977).

Figure 2



there is autarky or an open economy case. If there are no net imports or exports, the pivotal shift in the supply curve illustrated in Figure 2 would generate annual gross benefits of the size given by the areas (ABC+ AOC). If the country is a net rice importer, gross annual returns are measured by the size of the area AOC.

A whole arsenal of formulae have been developed in the literature, all of them specified in terms of equilibrium price, quantity and three parameters: a demand and supply elasticity and a shift parameter. The differences arise depending on the functional form assumed for the supply and demand curves, and on the type of shift postulated. Lynam and Jones (1984) have pointed out that the different functional forms of demand and supply incorporate a multiplicity of infomation about the technology, farmer responsiveness to price change, input market adjustments and the evaluation of inframarginal production factors.

The authors postulate that of even more potential importance is the specification of the supply shift parameter, which also incorporates a substancial amount of information about the technology and the effect of changes in input mix on costs. Although the shift parameter should be estimated directly from cost functions, this is seldom (if ever) the case because of the constraint imposed by data availability.

Thus, shift parameters are estimated by using a productivity index corrected for increased input use. In the case of Cobb-Douglas production functions and neutral technological change, the production function shift provides an underestimate of the actual shift (Lynam and Jones, p.19).

Akino and Hayami have provided the following approximation formulas for the estimation of the areas represented in Figure 2[20]:

20/ These authors have assumed constant elasticity supply and demand curves as well as neutral technological change.

$$\text{Area ABC} = 1/2\ p_oQ_o \ \frac{\{k(1+\gamma)\}^2}{\gamma + \eta}$$

$$\text{Area AOC} = k\ p_oQ_o$$

Where:
k= rate of shift of the production function, measured as the average yield difference between the improved and unimporved varieties, for the same level of inputs.
h= $(1+\gamma)\ k$, where γ= price elasticity of supply, and h is the rate of shift of the supply function due to varietal improvement.
$p_o\ Q_o$ = observed value of rice output.
η = price elasticity of demand

Estimation of Gross Benefits to Rice Research

In this exercise wer propose to use the model suggested by Akino and Hayami, in order to measure gross returns to varietal improvement of rice in Latin America.

Beyond the limitations and complexities which characterize this type of analysis, there are some additional problems in this particular case which should be brought out.

- Is this the case of an open economy or rather that of autarky? This has implications both for the measurement of the size and distribution of the benefits. We saw in section 2 that countries in the region cover the full spectrum from net importers, self-sufficient to net rice exporters. Given that the region as a whole is a net importer of rice, though net imports represent a very small fraction of total apparent consumption, the region will be treated as an open economy.

In this case, technological change is not taken to imply a price reduction, which would in fact occur in self-sufficient nations. The change in price has important implications in terms of determing who looses or gains due to the adoption of new technology. Changes in prices should be determined on a country by country basis, and is beyond the scope of this study.

- What is the relevant set of prices for the analysis of the region? Again, there is no one annual price which is relevant for all countries. The use of an average C.I.F. import price would overestimate the price for countries which are net exporter or self-sufficient ones.

The average Latin American export price of rice will be used in this study. It is usggested that the choice of this particular price will imply an underestimation of the welfare gains from rice research, because it should be expected that F.O.B. export prices are usually lower than either C.I.F. import prices (this is at least the case in terms of average export and import prices, as can be seen in Table 8), or than domestic prices in self-sufficient countries.

- Which is the shift parameter of the rice production function? Data on average yield differentials between semi-dwarf and traditional rice varieties are not generally available on a year to year basis, but just for 1981-82. Moreover, yield differentials achieved under a constant level of applied inputs are not known.

The following assumption will be made:

(i) the average yield differential estimated for 1981-82 (that is, 1.2 ton/ha), is assumed unchanged during the whole period, given no evidence in favor of a particular trend in yield differentials over time;

(ii) it is assumed that 25 per cent of the estimated yield differential between modern and traditional technologies can be solely explained by genetic differences between modern and traditional rice varieties. This assumption is based on the response functions for rice obtained from 8 Asian countries by Herdt and Capule (1983). According to these results, variety, fertilizer, irrigation and residual unmeasured factors contribute almost equally, to increase production from new rice technology.

Table 19 shows the gross value of the additional rice production in Latin America obtained from the adoption of modern technology. These estimates correspond to (Q_0 - Q'_0) of Figure 2 for each year valued at the average annual export price of rice in Latin America. Values are measured in constant 1981 dollars. The value of additional milled rice made available in 1981 due to modern technology is about US$824 million. But, as we already mentioned earlier, only part of this increase in output can be attributed to the existence of HYV's.

In order to isolate the increase in output or shift in the production function, which is owed exclusively to a change in the rice varieties available, the annual shift parameters (k) have to be determined. These are presented in Table 20. It is worth noticing that the k parameter is not the same every year, in spite of the assumption about a constant yield differential over time. The reason for this is the changing proportion of rice area sown to HYV's durint the period under study[21].

Costs of Rice Genetic Research and Net Returns

Table 21 presents estimated research costs, including all CIAT and IRTP budgets in connection with rice research, plus an estimate of annual research costs of breeders in national programs which collaborate with CIAT via IRTP. The latter have been estimated on the basis of the number of rice breeders per country and a fixed cost per breeder which would cover both direct and indirect research costs.

21/ k has been defined as $\frac{Q_0 - Q'_n}{Q_0}$ in terms of Figure 2, which is equivalent to: $\frac{(Y^s - Y^t) \cdot p_a}{\bar{Y}}$

Where:

Y^s, Y^t=are the average yield of semi-dwarf and traditional varieties, respectively.

$\bar{Y}$= average observed yield when semi-dwarf are sown in the proportion p_a of the rice area.

TABLE 19. Estimates of the quantity and gross value of additional rice production in Latin America, due to HYV's.[1] 1970-1082 (1981 US$).

Year	Actual production paddy rice[2]	Additional production due to HYV's		Value of additional Milled rice[5]
		Paddy rice[3]	Milled rice equivalent[4]	
	----------- 1000 MT		------------	1000 US$ of 1981
1970	11,832	158	103	33,949
1971	10,752	298	193	61,625
1972	10,904	411	267	105,198
1973	11,778	574	373	201,383
1974	12,220	729	474	323,078
1975	14,041	1,113	723	409,146
1976	15,401	1,116	726	289,674
1977	15,086	1,333	866	294,007
1978	13,379	1,435	933	335,787
1979	14,387	1,824	1,186	443,327
1980	16,406	2,216	1,440	588,096
1981	16,100	2,724	1,771	823,869

1/ These estimates only refer to HYV's derived from CIAT germplasm.

2/ Taken from FAO Production Yearbooks.

3/ This is estimated by multipying each year the area with HYV's (Table 14) by 1.19 (yield increase due to CIAT germplasm and the technological package that goes with it).

4/ A conversion factor of 0.65 is used to express paddy rice in milled rice equivalent.

5/ Annual milled rice production multiplied by the average annual export prices received by Latin American exporters during the priod 1970-1981.(in US$ of 1981) (Table 18). If the production of additional rice bran is valued by its maize equivalence (in terms of calories),it would increase the estimates in this column by approximately 5 percent.

TABLE 20. Estimates of the shift parameter due to HYV's in Latin America. 1969-1981.

Year	Increased production due to HYV's[1] (ΔQ)	Observed production (with HYV's)[2] (Q_o)	Shift parameter $K = \frac{\Delta Q \times 0.25}{Q_o}$
	----------- '000 tons -----------		
1969	63	10,273	0.002
1970	158	11,832	0.003
1971	298	10,752	0.007
1972	411	10,904	0.010
1973	574	11,778	0.012
1974	729	12,220	0.015
1975	1,113	14,041	0.020
1976	1,116	15,402	0.018
1977	1,333	15,086	0.022
1978	1,435	13,379	0.027
1979	1,824	14,387	0.032
1980	2,216	16,406	0.034
1981	2,724	16,100	0.042

1/ See Table 19. Figures correspond to paddy rice.

2/ FAO Production Yearbooks.

TABLE 21. Costs of rice research of CIAT and of national organizations. Latin America, 1968-81 (constant 1981 US$ thousands).

Year	International cooperation CIAT[1]	National organizations[2]	Total
1968	108		108
1969	740		740
1970	1,086	8,280	9,366
1971	1,572	8,280	9,852
1972	1,796	8,280	10,076
1973	1,043	8,280	9,323
1974	612	8,280	8,892
1975	787	8,280	9,067
1976	806	8,280	9,086
1977	967	8,280	9,247
1978	696	8,280	8,976
1979	926	8,280	9,206
1980	1,020	8,280	9,300
1981	1,477	8,280	9,757

1/ Personal communication, Director of Administration and Finance, CIAT, December 1983.

2/ This estimate is based on the number of rice breeders working in the countries which collaborate with IRTP. These were 69 in 1982, and were assumed the same since 1970. An annual cost per breeder of US$120 thousand was considered which includes direct and indirect research costs as in the international centers.

The flow of costs estimated for the period 1970-1981 represent an annual figure of 9 to 10 million dollars, of which CIAT annual research costs do not exceed 1.5 million dollars.

Table 22 presents the flows of gross and net benefits for the period 1968 to 1981 in constant 1981 US dollars. Gross benefits have been estimated by the size of the area AOC of Figure 2, using the formula of Akino and Hayami, on the basis of the data presented in Tables19 and 20. Net benefits are calculated by subtracting the flow of research costs from the flow of gross benefits. Only supply shifts that took place after 1973 are included - that is, two years after the release of the first variety (CICA 4) produced by the Colombian research program.

It is assumed that there are no additional extension costs involved in transferring semi-dwarf varieties to farmers, as compared to traditional varieties, and that the seed costs of the modern varieties is not higher either.

Three measures of teh efficiency of the investment in rice genetic research are presented in Table 22. These are Net Present Value, Benefit-Cost Ratio and Internal Rate of Return. The Benefit-Cost Ratio is calculated as the ratio of the present value of gross Benefits to the presente value of Research Costs.

For the first two measures, both costs and benefits are discounted up to 1981 (inclusive) values, on the basis of a real social opportunity cost of funds in Latin America of 10%. The Internal Rate of Return is a measure of the profitability of the investment of funds allocated to rice research.

Given that full adoption of current HYV technology may not been completed by 1981, Table 7 of the Appendix presents the returns when future costs and benefits for the period 1982-1990 are also included. These values correspond to the expected costs and adoption of CIAT's

TABLE 22. Research costs, gross and net benefits and returns to investment in research on high yielding rice varieties, by CIAT and national institutions in Latin America. 1968-1982. (Constant 1981 US$ millions).

Year	Total Costs[1]	Benefits[2]	
		Gross	Net
1968	0.1		-0.1
1969	0.7		-0.7
1970	9.4		-9.4
1971	9.8		-9.8
1972	10.1		-10.1
1973	9.3	76.3	67.0
1974	8.9	81.2	72.3
1975	9.1	103.3	94.2
1976	9.1	71.9	62.8
1977	9.2	73.2	64.0
1978	9.0	84.5	75.5
1979	9.2	111.9	102.7
1980	9.3	148.1	138.8
1981	9.8	204.5	194.7

1981 Net Present Value (i - 10%)	1,140
Benefit-Cost Ratio (i = 10%)	6.6
Internal Rate of Return (%)	98.3

1/ It includes research expenditures by CIAT, by CIAT/IRRI's co-sponsored IRTP, and by National Programs.

2/ The average Latin American export prices of rice for each year, at constant 1981 US$, were used to estimate benefits.

current technology and exclude both costs and returns of upland rice research. Future supply shifts assume that the total rice area will remain constant, and that adoption will continue along the adoption curves that have been estimated in this study.

In both cases (the project through 1981, and through 1990, respectively), the returns to research in HYV's are substantial. According to the results presented in Table 22, the internal rate of return is close to 90%, which means that, on average, every dollar invested generates another 90 cents per year from the time it is invested until the cutoff date.

Final Comments

Some of the factors which need to be considered in reflecting on the benefit-cost analysis above are:

a. The investment project which has been evaluated corresponds to the research that has been carried out in Latin America on HYV's for irrigated conditions by CIAT and collaborating national programs. Thus, for example, the production increase arising from HYV's used in some countries, which have no relationship with IRTP germplasm, were excluded from the flow benefits.

b. The size of the benefits were estimated using the average export price for Latin America, assuming an open economy case.

c. Research costs included in the evaluation are probably overestimated for national organizations, due to the assumptions that were made made regarding the number of breeders over time and the cost per breeder. With respect to IRRI costs, it has been assumed that the IRRI lines which are tested by IRTP in Latin America are a "free good" to this region, and only those costs incurred by IRRI in support of the Latin American IRTP network have been included.

d. The distributional effects of research, and particularly the impact on consumers, have not been included in this study. It is considered that such calculations should be carried out country-by-country, in order to measure the price effects of the supply shifts in some countries.

e. The internal rates of returns obtained in this exercise are very high. It is useful to remember that for conventional development project, a 15-20% internal rate of return is considered good (Arndt and Ruttan, 1977, p.4) for rice research in Colombia during 1957-1974 was 94%. Akino and Hayami (1975, p.8) report values up to 75% for rice research in Japan, and Ardila (1973) reports rates from 58% to 82% for rice in Colombia up to 1971.

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APPENDIX

Appendix
Table 1

Rice Milled

PRODUCTION, TRADE AND APPARENT CONSUPTION

COUNTRY	1965/67 PRODUCTION	1965/67 +IMPORT -EXPORT	1965/67 APPARENT CONSUMPTION	1965/67 APPARENT PER CAPITA CONSUMPTION	1965/67 SELF SUFFICIENCY INDEX	1968/70 PRODUCTION	1968/70 +IMPORT -EXPORT	1968/70 APPARENT CONSUMPTION	1968/70 APPARENT PER CAPITA CONSUMPTION	1968/70 SELF SUFFICIENCY INDEX
	1000 MT			KG		1000 MT			KG	
BRAZIL	4371	-186	4185	58	104.44	4463	-108	4356	55	102.47
MEXICO	253	10	263	7	96.29	249	-39	210	5	118.38
	4624	-176	4448	41	103.96	4712	-146	4506	39	103.20
BOLIVIA	35	1	36	9	96.37	50	-0	49	12	100.68
COLOMBIA	436	0	437	27	99.92	476	-7	469	27	101.45
CUBA	47	195	242	34	19.43	152	187	340	43	44.84
DOMINICAN RP	111	11	122	39	90.94	127	7	134	39	94.94
ECUADOR	146	-6	141	31	104.08	141	2	143	29	98.59
PARAGUAY	11	0	11	6	100.00	20	-0	20	10	100.16
PERU	244	54	298	29	81.83	285	28	314	28	90.94
VENEZUELA	134	-41	93	12	144.71	155	-31	124	15	124.91
TROPICAL SOUTH AMERICA	1164	215	1379	25	84.43	1406	187	1593	27	88.29
COSTA RICA	56	6	61	47	90.44	61	2	63	44	97.09
EL SALVADOR	35	-5	30	12	116.34	35	-12	23	8	152.90
GUATEMALA	10	0	11	3	97.22	13	1	14	3	96.20
HONDURAS	7	4	12	6	62.50	9	9	17	7	53.22
NICARAGUA	40	11	51	35	78.73	51	-4	47	30	108.57
PANAMA	96	-2	94	86	101.76	100	0	100	83	99.86
CENTRAL AMERICA, PANAMA	245	15	260	23	94.23	268	-6	263	22	102.18
BARBADOS	0	8	8	34	0.00	0	7	7	30	0.00
GUYANA	169	-105	64	110	263.32	126	-77	48	76	260.76
HAITI	49	0	49	13	99.91	52	0	52	13	99.99
JAMAICA	1	31	32	20	2.78	0	28	28	14	1.47
TRINIDAD ETC	7	31	38	43	17.61	7	28	35	37	19.16
CARIBBEAN	226	-35	191	27	118.25	184	-14	170	23	108.07
TROPICAL LATIN AMERICA	6259	18	6277	31	99.71	6571	21	6591	31	99.68
ARGENTINA	141	-49	92	4	153.37	224	-77	147	7	152.20
CHILE	52	20	72	9	72.03	45	34	78	9	57.10
URUGUAY	63	-29	34	13	184.66	82	-42	40	15	204.43
TEMPERATE SOUTH AMERIC	256	-58	198	6	129.02	351	-85	266	8	132.05
LATIN AMERICA	6514	-39	6475	30	100.60	6921	-64	6857	30	100.94

SOURCE: FAO Tapes.

Appendix
Table 2

Rice Milled

PRODUCTION, TRADE AND APPARENT CONSUPTION

COUNTRY	1971/73 PRODUCTION	+IMPORT -EXPORT	APPARENT CONSUMPTION	APPARENT PER CAPITA CONSUMPTION	SELF SUFFICIENCY INDEX	1974/76 PRODUCTION	+IMPORT -EXPORT	APPARENT CONSUMPTION	APPARENT PER CAPITA CONSUMPTION	SELF SUFFICIENCY INDEX
	1000 MT			KG		1000 MT			KG	
BRAZIL	4445	-54	4391	52	101.23	5266	-18	5247	57	100.35
MEXICO	265	1	266	6	99.54	362	22	384	8	94.38
	4710	-53	4657	36	101.14	5628	3	5631	40	99.94
BOLIVIA	49	-1	48	12	101.01	70	2	71	17	97.67
COLOMBIA	650	-7	643	35	101.15	1021	-50	971	48	105.18
CUBA	216	246	462	58	46.70	289	218	508	60	56.96
DOMINICAN RP	141	19	161	41	88.00	171	59	230	52	74.47
ECUADOR	135	0	135	26	99.92	214	-13	201	35	106.38
PARAGUAY	28	-0	27	13	101.65	35	-1	35	18	101.85
PERU	336	-27	309	26	108.64	347	73	420	32	82.54
VENEZUELA	134	-4	130	14	103.01	188	-33	155	15	121.28
TROPICAL SOUTH AMERICA	1689	226	1914	30	88.22	2335	256	2591	38	90.13
COSTA RICA	62	6	67	44	91.37	102	-6	96	57	106.19
EL SALVADOR	28	-1	27	9	103.60	28	3	31	9	90.72
GUATEMALA	20	2	22	5	90.58	22	2	24	5	90.95
HONDURAS	11	3	14	6	81.51	18	5	23	9	79.83
NICARAGUA	51	-7	44	26	115.36	49	-3	46	24	106.94
PANAMA	92	7	99	75	92.99	110	0	110	75	99.96
CENTRAL AMERICA, PANAMA	263	10	273	21	96.45	329	1	330	23	99.69
BARBADOS	0	7	7	28	0.00	0	7	7	28	0.00
GUYANA	111	-64	47	73	235.84	162	-76	85	124	189.08
HAITI	63	1	64	15	98.56	78	7	84	19	92.12
JAMAICA	0	35	35	20	0.54	1	45	46	25	2.34
TRINIDAD ETC	8	29	37	37	20.68	13	36	48	46	26.70
CARIBBEAN	182	8	190	24	96.15	253	17	270	33	93.65
TROPICAL LATIN AMERICA	6844	190	7034	30	97.29	8545	276	8821	34	96.87
ARGENTINA	182	-50	132	6	137.92	211	-67	144	6	146.68
CHILE	45	11	59	7	76.19	45	36	80	9	56.59
URUGUAY	84	-62	32	12	263.93	123	-88	35	12	352.44
TEMPERATE SOUTH AMERIC	311	-88	223	7	139.47	380	-121	259	7	146.65
LATIN AMERICA	7155	102	7258	29	98.59	8925	156	9080	33	98.29

SOURCE: FAO Tapes.

Appendix
Table 3

Rice Milled

PRODUCTION, TRADE AND APPARENT CONSUPTION

COUNTRY	1977/79 PRODUCTION	1977/79 IMPORT -EXPORT	1977/79 APPARENT CONSUMPTION	1977/79 APPARENT PER CAPITA CONSUMPTION	1977/79 SELF SUFFICIENCY INDEX	1980/82 PRODUCTION	1980/82 IMPORT -EXPORT	1980/82 APPARENT CONSUMPTION	1980/82 APPARENT PER CAPITA CONSUMPTION	1980/82 SELF SUFFICIENCY INDEX
	1000 MT			KG		1000 MT			KG	
BRAZIL	5175	50	5225	52	99.04	6013	151	6165	57	97.54
MEXICO	318	-10	308	6	103.27	368	65	433	7	85.05
	5493	40	5533	36	99.28	6381	216	6598	39	96.72
BOLIVIA	62	-0	62	14	100.18	61	1	62	13	98.33
COLOMBIA	1073	-19	1055	49	101.77	1228	-23	1205	52	101.91
CUBA	291	159	449	51	64.70	316	208	524	56	60.36
DOMINICAN RP	222	24	246	51	90.30	270	33	302	58	89.20
ECUADOR	189	7	196	31	96.55	260	2	262	38	99.21
PARAGUAY	40	0	40	16	99.38	44	-0	44	16	100.22
PERU	351	76	428	30	82.17	411	127	538	35	76.42
VENEZUELA	358	-7	351	30	102.01	427	-19	408	31	104.68
TROPICAL SOUTH AMERICA	2586	240	2826	30	91.51	3016	328	3344	41	90.19
COSTA RICA	124	-40	84	46	147.46	113	-33	80	41	141.17
EL SALVADOR	31	2	33	9	93.22	32	3	35	8	91.13
GUATEMALA	20	7	26	5	75.09	29	4	32	5	88.00
HONDURAS	19	7	26	9	73.42	24	4	28	9	86.76
NICARAGUA	43	4	47	22	92.25	95	22	116	50	81.46
PANAMA	112	-8	104	65	108.02	117	0	118	68	99.83
CENTRAL AMERICA, PANAMA	383	-29	313	20	109.19	410	-1	409	23	100.16
BARBADOS	0	6	6	26	0.00	0	7	7	29	0.00
GUYANA	196	-83	113	163	172.91	187	-66	121	152	154.66
HAITI	71	26	96	20	73.38	62	24	86	17	72.04
JAMAICA	1	34	35	18	3.05	1	50	51	25	2.11
TRINIDAD ETC	14	34	48	46	28.67	18	44	62	57	29.23
CARIBBEAN	281	17	299	34	94.16	267	59	326	35	81.95
TROPICAL LATIN AMERICA	8709	268	8977	32	97.01	10075	602	10677	36	94.36
ARGENTINA	204	-136	68	3	298.24	213	-95	118	5	180.88
CHILE	88	6	94	10	93.89	71	24	95	9	74.38
URUGUAY	152	-122	30	11	501.18	225	-193	31	11	714.78
TEMPERATE SOUTH AMERIC	444	-252	192	5	230.76	509	-264	244	6	208.17
LATIN AMERICA	9154	16	9170	31	99.82	10584	338	10922	35	96.90

SOURCE: FAO Tapes.

Appendix
Table 4

RICE, PADDY — PRODUCTION, RELATIVE IMPORTANCE IN THE REGION AND PER CAPITA PRODUCTION LEVELS (CIAT)

COUNTRY	PRODUCTION 1000 MT 1960/62	1970/72	1980/82	PERCENTAGE OF TOTAL % 1980/82	PER CAPITA PRODUCTION KG 1980/82
BRAZIL	5248	6969	9251	56.815	85
MEXICO	317	393	567	3.480	9
	5565	7362	9818	60.295	58
BOLIVIA	32	78	94	0.577	19
COLOMBIA	503	851	1889	11.601	82
CUBA	255	346	436	2.987	52
DOMINICAN RP	114	212	415	2.549	79
ECUADOR	161	206	400	2.455	58
PARAGUAY	17	44	68	0.416	25
PERU	355	551	632	3.883	41
VENEZUELA	85	181	657	4.033	50
TROPICAL SOUTH AMERICA	1522	2469	4641	28.501	57
COSTA RICA	58	67	174	1.071	89
EL SALVADOR	24	45	49	0.299	12
GUATEMALA	14	30	44	0.270	7
HONDURAS	15	16	37	0.227	12
NICARAGUA	37	79	146	0.895	63
PANAMA	105	131	181	1.110	105
CENTRAL AMERICA, PANAMA	252	387	630	3.871	32
GUYANA	231	184	287	1.763	363
HAITI	55	84	95	0.583	18
JAMAICA	4	0	2	0.010	1
TRINIDAD TOB	11	11	28	0.170	26
CARIBBEAN	301	280	411	2.526	44
TROPICAL LATIN AMERICA	7640	10498	15500	95.193	98
ARGENTINA	174	330	328	2.016	13
CHILE	98	77	109	0.667	11
URUGUAY	58	130	346	2.123	122
TEMPERATE SOUTH AMERICA	330	536	783	4.807	20
LATIN AMERICA	7970	11034	16283	100.000	89 ??

COLUMNS MAY NOT ADD EXACTLY DUE TO ROUNDING
SOURCE: FAO Tapes.

Appendix
Table 5. Area, production and yield of rice in Latin America, 1981-1982 harvest.

Country	Area (000 ha)[a]			Production (000 ton)			Yield (t/ha)		
	Irrig.	Upland	Total	Irrig.	Upland	Total	Irrig.	Upland	Average
Argentina	110.0	-	110.0	400.0	-	400.0	3.6	-	3.6
Belize	1.2	2.2	3.4	3.5	4.3	7.8	2.9	2.0	2.3
Bolivia	0.5	58.2	58.7	1.3	91.4	92.7	2.6	1.6	1.6
Brazil[b]	740.6	5897.8	6638.4	2747.6	5890.4	8638.0	3.7	1.0	1.3
Chile	37.0	-	37.0	131.2	-	131.2	3.5	-	3.5
Colombia	345.9	107.4	453.3	1754.9	161.0	1915.9	5.1	1.5	4.2
Costa Rica	2.0	70.3	72.3	12.2	189.8	202.2	6.1	2.7	2.8
Cuba	130.0	-	130.0	496.9	-	496.9	3.8	-	3.8
Ecuador	72.4	62.8	135.2	282.5	127.2	409.7	3.9	2.0	3.0
El Salvador	-	13.9	13.9	-	50.1	50.1	-	3.6	3.6
Guatemala	-	15.4	15.4	-	33.3	33.3	-	2.2	2.2
Guyana[b]	86.4	35.2	121.6	259.2	52.8	312.0	3.0	1.5	2.6
Haiti	31.7	10.5	42.2	190.0	30.1	220.1	6.0	2.9	5.2
Honduras	6.0	28.1	34.1	27.0	75.2	102.2	4.5	2.7	3.0
Jamaica	1.5	-	1.5	4.5	-	4.5	3.0	-	3.0
Mexico	96.4	110.6	207.0	366.9	219.7	586.6	3.8	2.0	2.8
Nicaragua	22.3	19.5	41.8	90.5	48.1	138.6	4.1	2.5	3.3
Panama	6.0	98.2	104.2	24.5	193.1	217.6	4.1	2.0	2.1
Paraguay	21.3	11.0	32.3	61.8	19.8	81.6	2.9	1.8	2.5
Peru	120.2	40.3	160.5	595.6	80.6	686.2	5.0	2.0	4.3
Dominican Rep.	100.0	3.1	103.1	258.1	4.0	262.1	2.6	1.3	2.5
Surinam[b]	35.7	-	35.7	150.0	-	150.0	4.2	-	4.2
Uruguay[b]	68.0	-	68.0	381.0	-	381.0	5.6	-	5.6
Venezuela	60.0	140.0	200.0	240.0	350.0	590.0	4.0	2.5	3.0
TOTAL	2095.1	6724.5	8819.6	8479.2	7620.9	16100.1	4.0	1.1	1.8

a/ Blank space indicates no planting.

b/ Data from Brazil and Uruguay (80-81), Guyana (77-78) and Surinam (79-80).

SOURCE: CIAT (1984).

Appendix
Table 6 . Estimate of future supply shifts from the adoption of HYV's. 1982-1990

Year	Total rice area	Area with HYV's	Production increase of Paddy rice (ΔQ)	Production without HYVs	Production with HYVs (Q_0)	$K = \frac{\Delta Q}{Q_0} \times 0.25$
	-- '000 has --		-----------	'000 tons	-----------	
1982	8819.6	2,586	3,077	13,376	16,453	0.047
1983	8819.6	2,857	3,400	13,376	16,776	0.051
1984	8819.6	2,957	3,519	13,376	16,895	0.052
1985	8819.6	3,053	3,633	13,376	17,009	0.053
1986	8819.6	3,073	3,657	13,376	17,033	0.054
1987	8819.6	3,087	3,674	13,376	17,050	0.054
1988	8819.6	3,093	3,681	13,376	17,057	0.054
1989	8819.6	3,097	3,685	13,376	17,061	0.054
1990	8819.6	3,099	3,688	13,376	17,064	0.054

SOURCE: Figure 1 and Table 15.A constant future rice area is assumed,and a constant yield increase of 1.19 ton/ha,as in 1981.

Appendix
TABLE 7. Annual research costs, gross and net benefits and return to investment in research on rice HYV's in Latin America[1], 1968-1990. (Constant 1981 US$ millions).

Year	Total Costs[2]	Benefits[3]	
		Gross	Net
1968	0.1		- 0.1
1969	0.7		- 0.7
1970	9.4		- 9.4
1971	9.8		- 9.8
1972	10.1		-10.1
1973	9.3	76.3	67.0
1974	8.9	81.2	72.3
1975	9.1	103.3	94.2
1976	9.1	71.9	62.8
1977	9.2	73.2	64.0
1978	9.0	84.5	75.5
1979	9.2	111.9	102.7
1980	9.3	148.1	138.8
1981	9.7	294.5	194.7
1982	5.8	259.7	253.9
1983	5.8	281.8	276.0
1984	5.8	287.3	281.5
1985	5.8	292.8	287.0
1986	5.8	298.4	292.6
1987	5.8	298.4	292.6
1988	5.8	298.4	292.6
1989	5.8	298.4	292.6
1990	5.8	298.4	292.6

1981 Net Present Value (i = 10%)	2,764
Benefit-Cost Ratio	12.7
Internal Rate of Return (%)	98.7

1/ Benefits from adoption of HYV's which are related to IRTP germplasm. The average Latin American export prices are used in these estimates.

2/ It is assumed that costs beyond 1981 are 60% of 1981 costs, and represented only costs associated with breeding for irrigated conditions.

3/ Rice area beyond 1981 is fixed at the 1981 level, but adoption of HYV's continues along the estimated aggregate adoption curve. The world price of rice is taken to be the average export price of rice in Latin America for the period 1973-1983, that is US$528/ton, in constant 1981 US$.

SOURCE: Appendix, Table 6, Figure 1. Tables 19 and 20.

Figure A.1

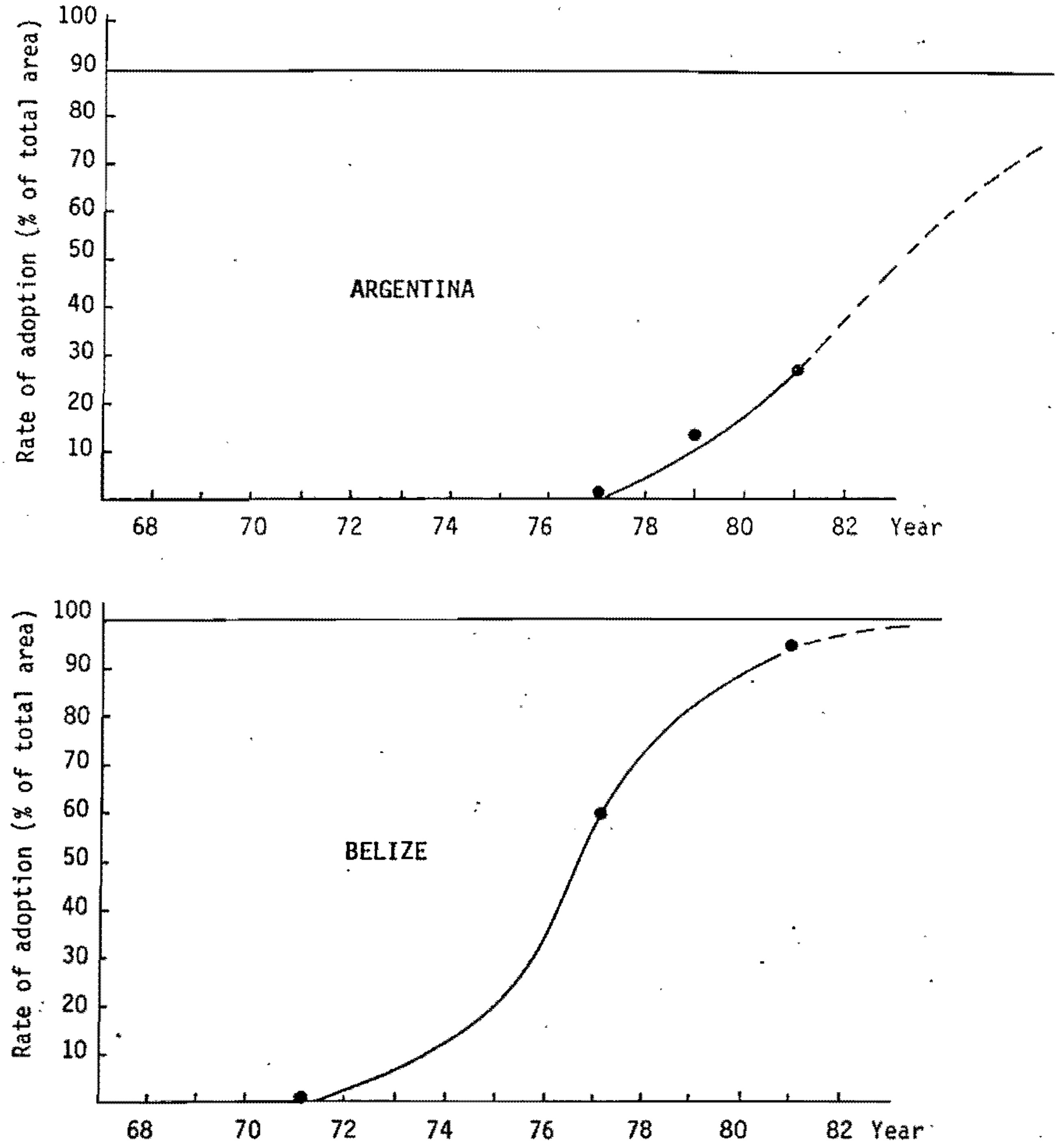
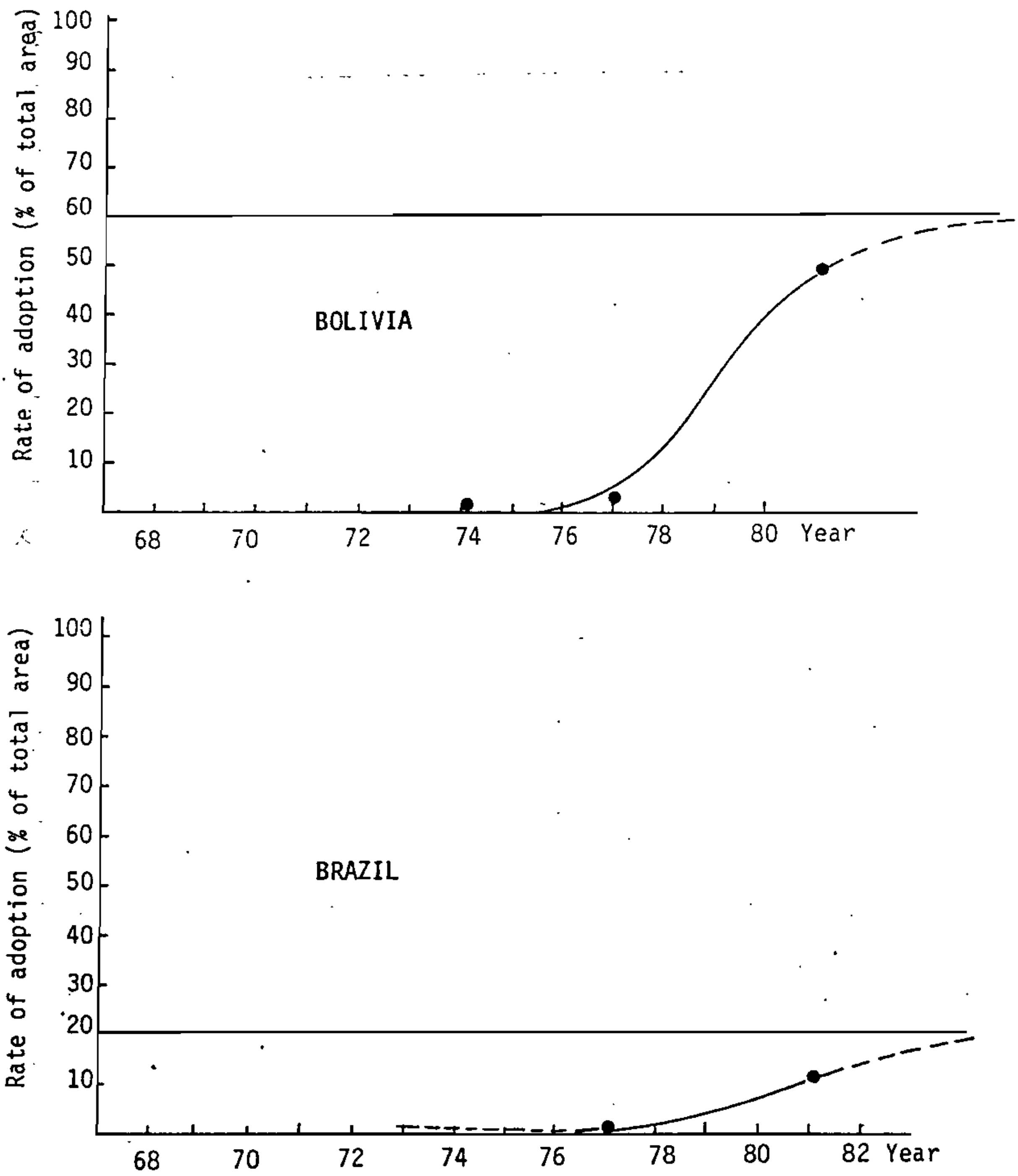
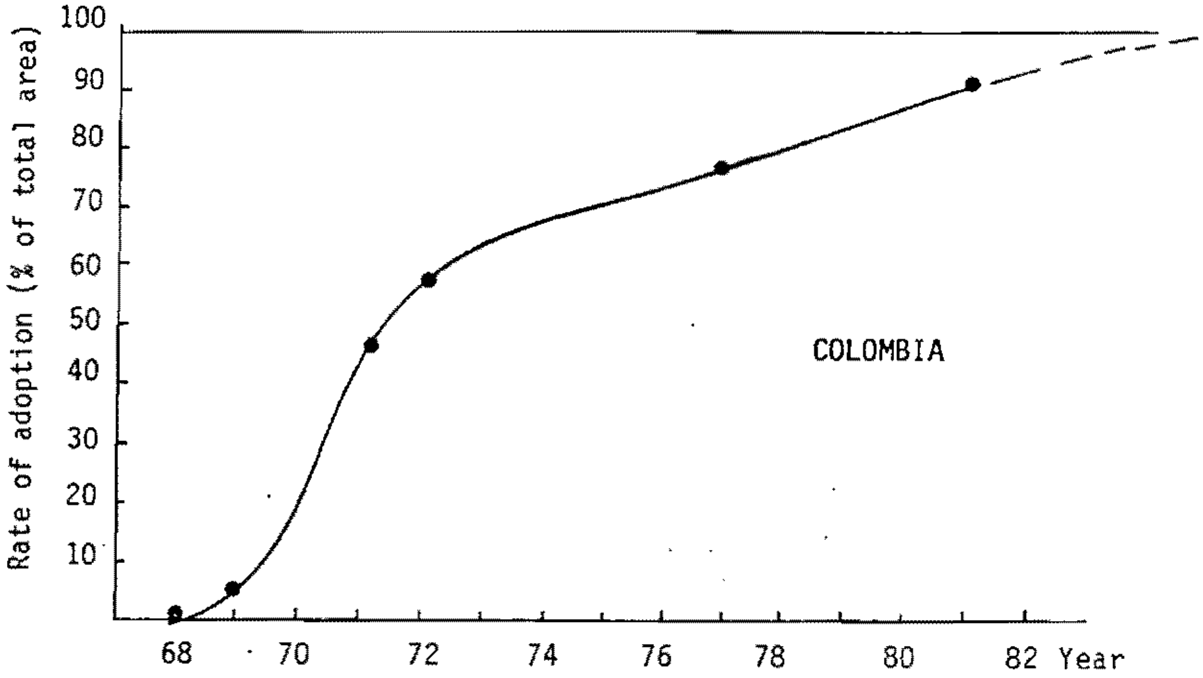

ARGENTINA
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
68
70
72
74
76
78
80
82
Year
BELIZE
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
68
70
72
74
76
78
80
82
Year

Figure A.2

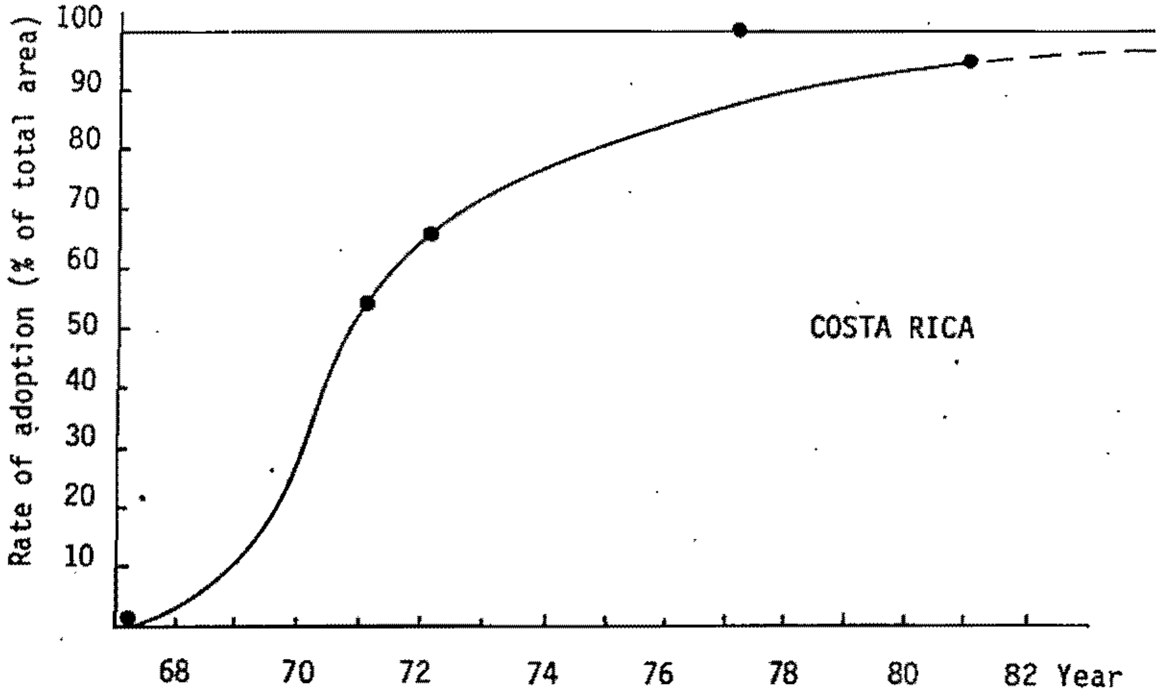


BOLIVIA
BRAZIL
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
68
70
72
74
76
78
80
82
Year

Figure A.3



COLOMBIA
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
68
70
72
74
76
78
80
82 Year



COSTA RICA
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
68
70
72
74
76
78
80
82 Year

Figure A.4

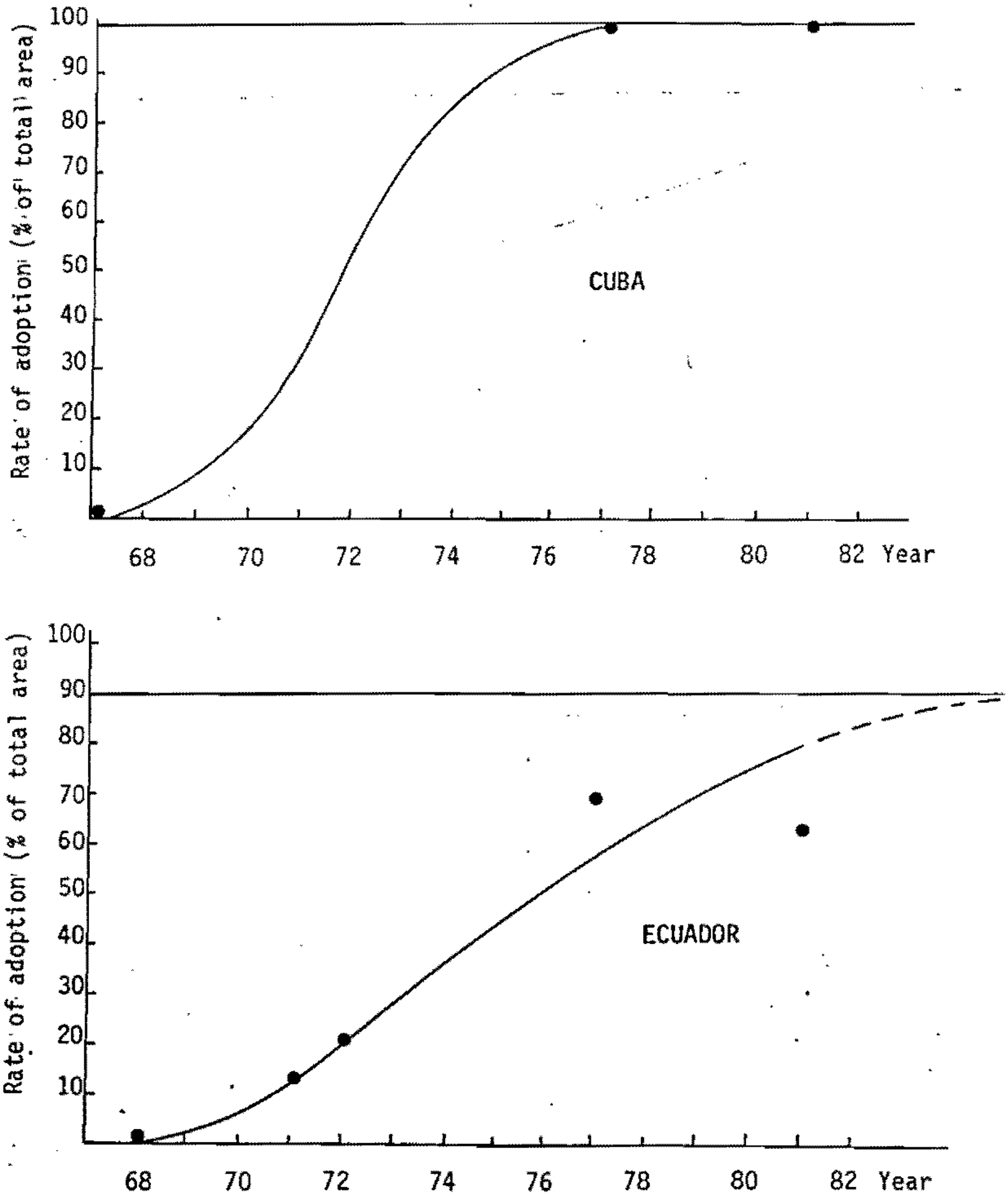
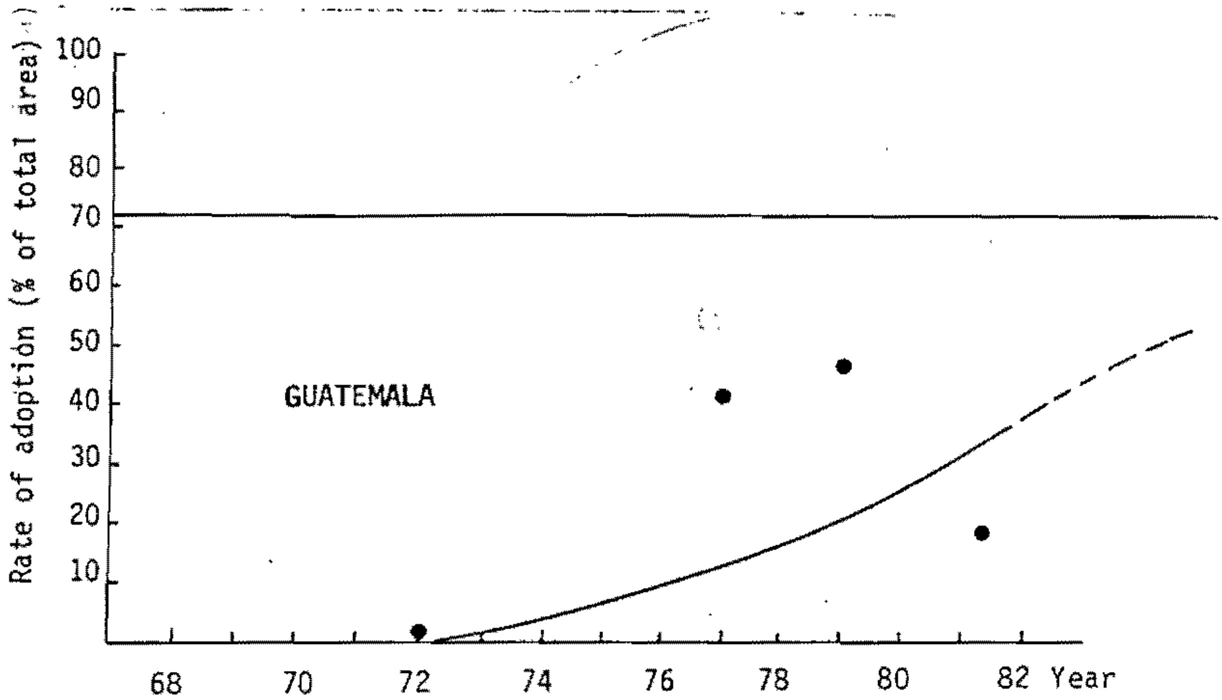
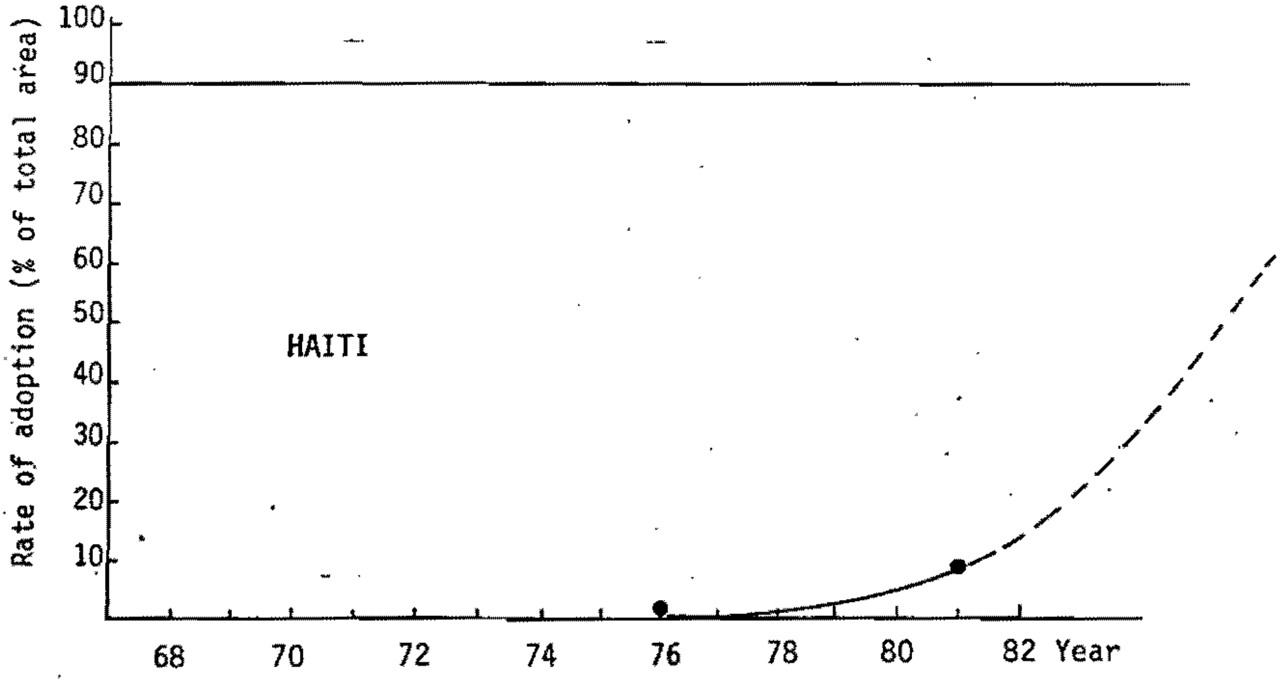

Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
CUBA
68
70
72
74
76
78
80
82 Year
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
ECUADOR
68
70
72
74
76
78
80
82 Year

Figure A.5

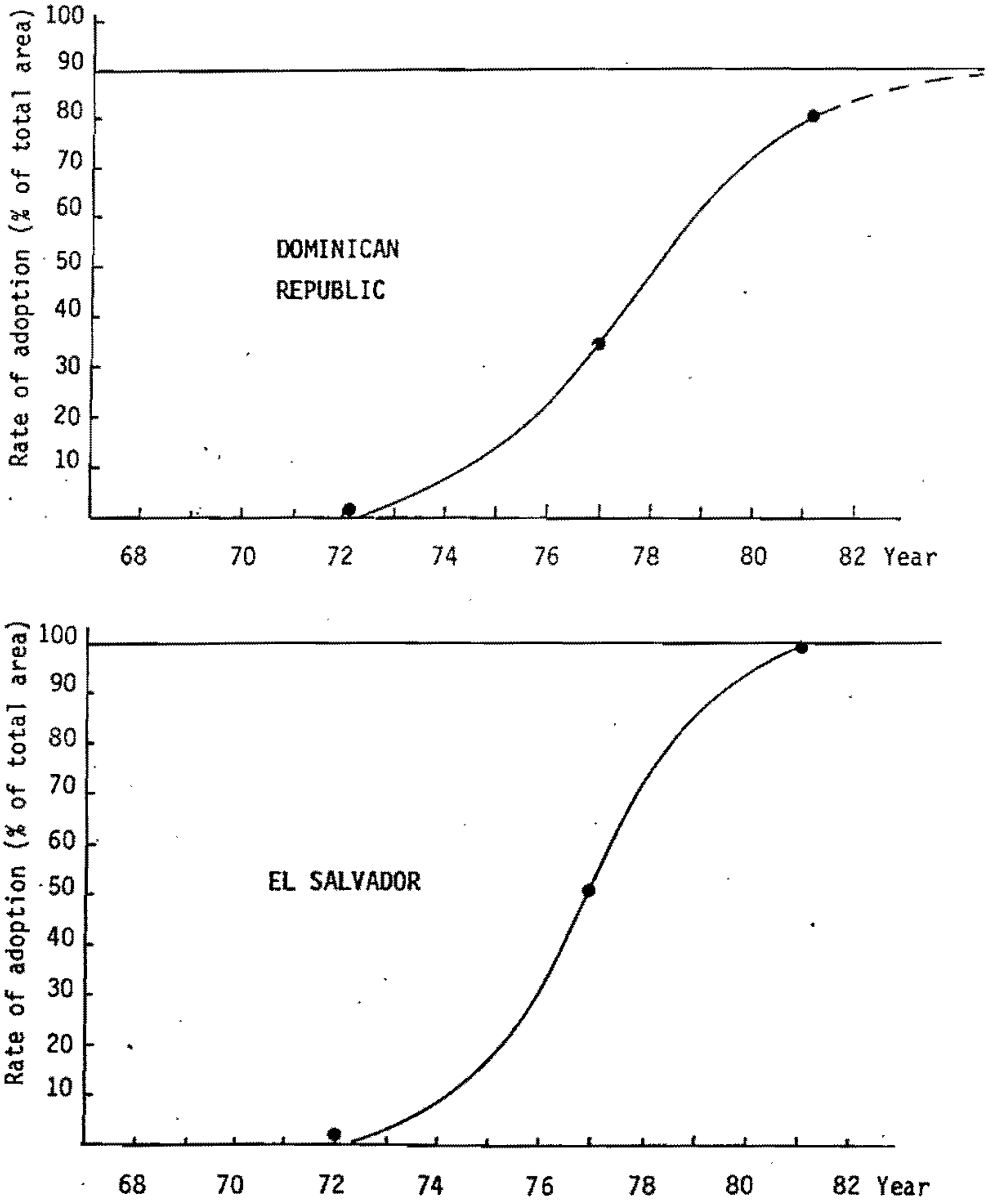


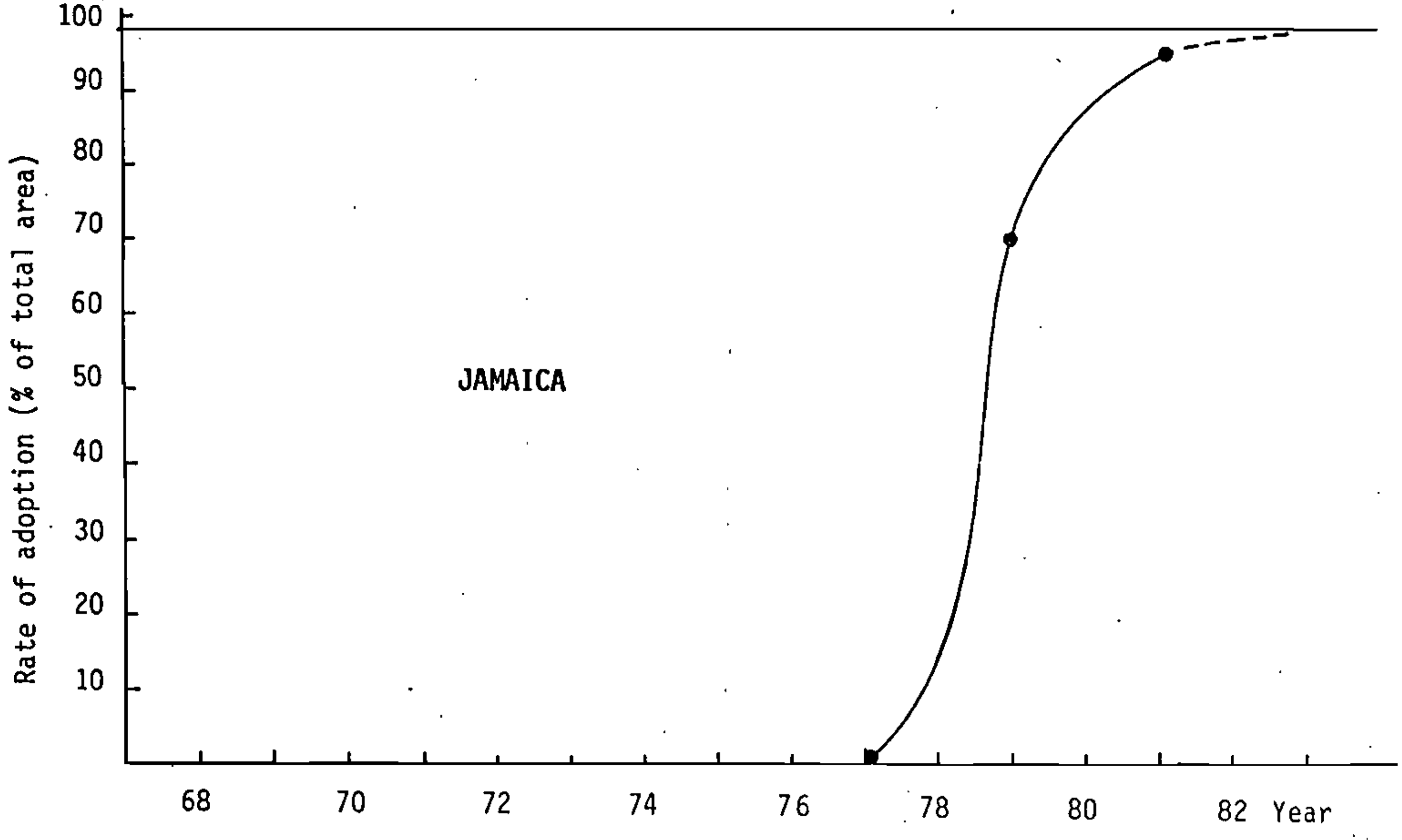
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
GUATEMALA
68
70
72
74
76
78
80
82 Year



Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
HAITI
68
70
72
74
76
78
80
82 Year

Figure A.6

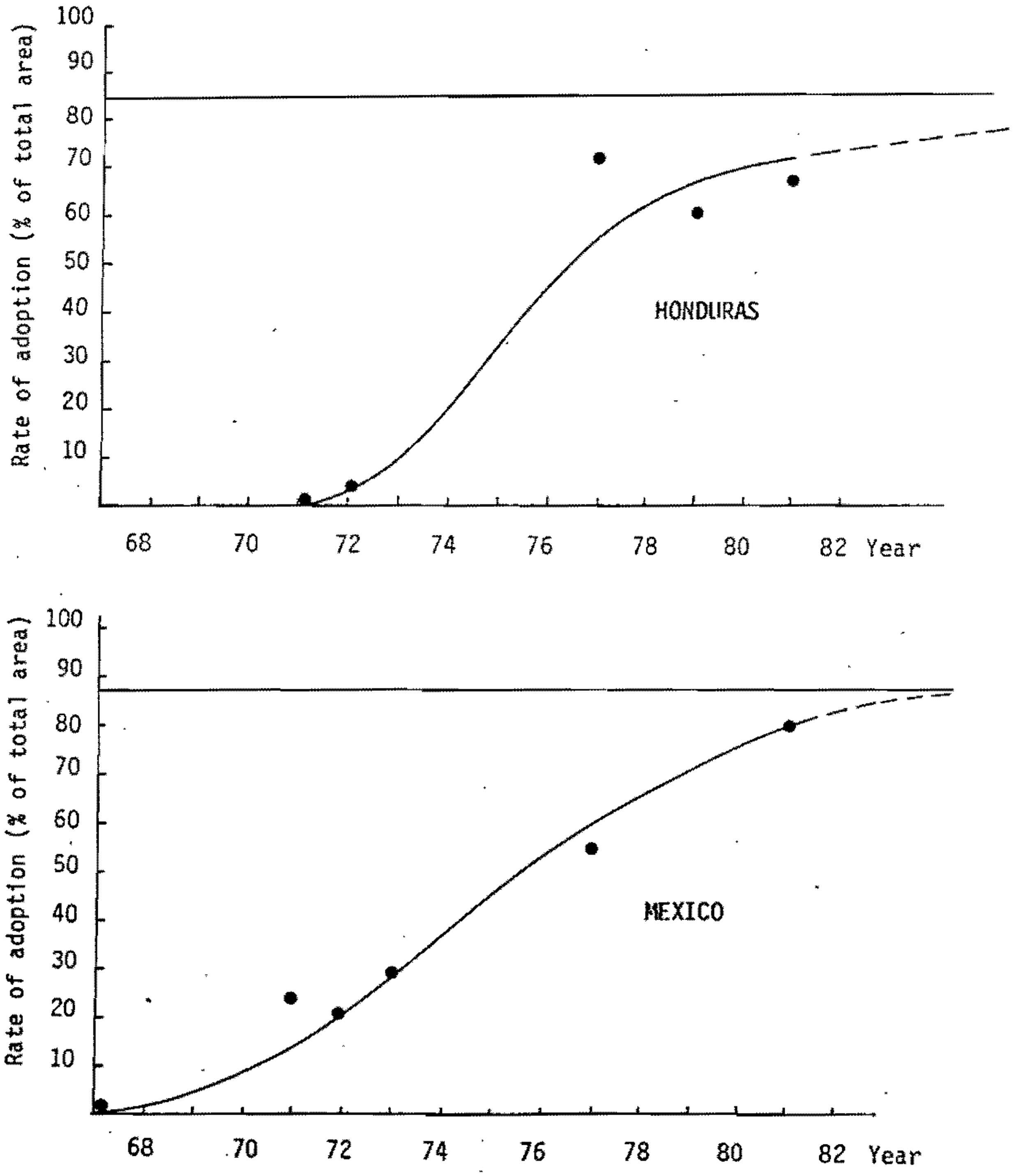

Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
DOMINICAN
REPUBLIC
68
70
72
74
76
78
80
82 Year
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
EL SALVADOR
68
70
72
74
76
78
80
82 Year



Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
JAMAICA
68
70
72
74
76
78
80
82 Year

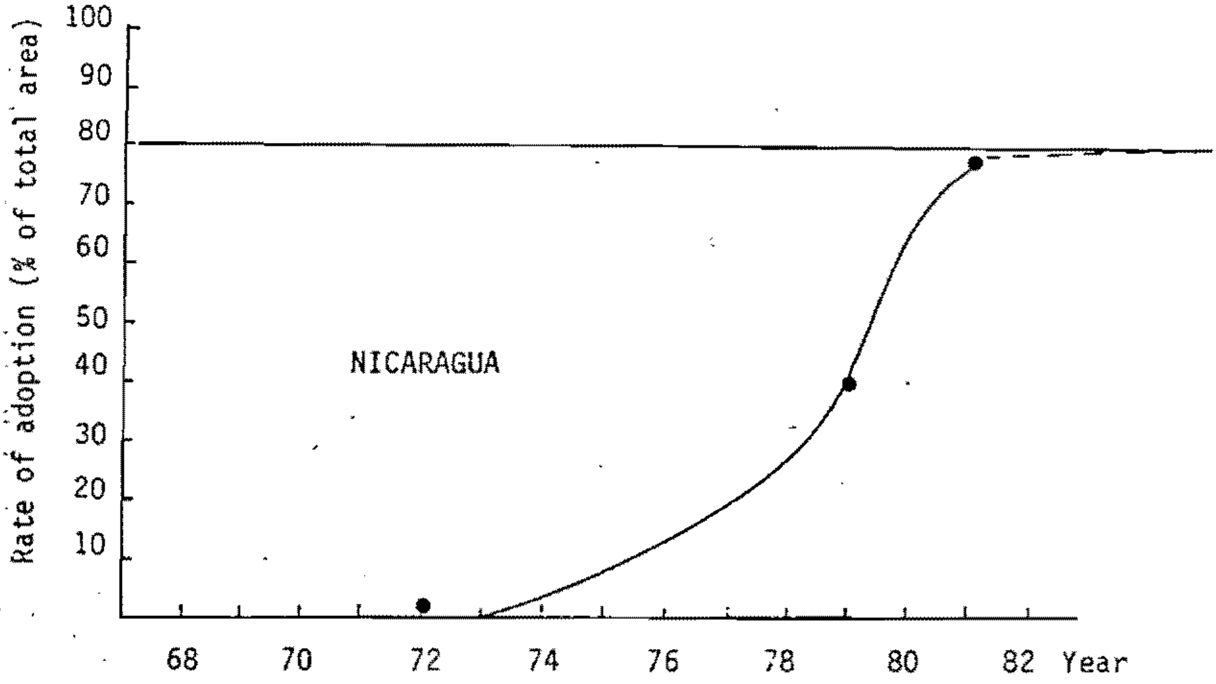
Figure A.7

Figure A.8



Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
HONDURAS
68
70
72
74
76
78
80
82 Year
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
MEXICO
68
70
72
74
76
78
80
82 Year

Figure A.9


NICARAGUA
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
68
70
72
74
76
78
80
82 Year

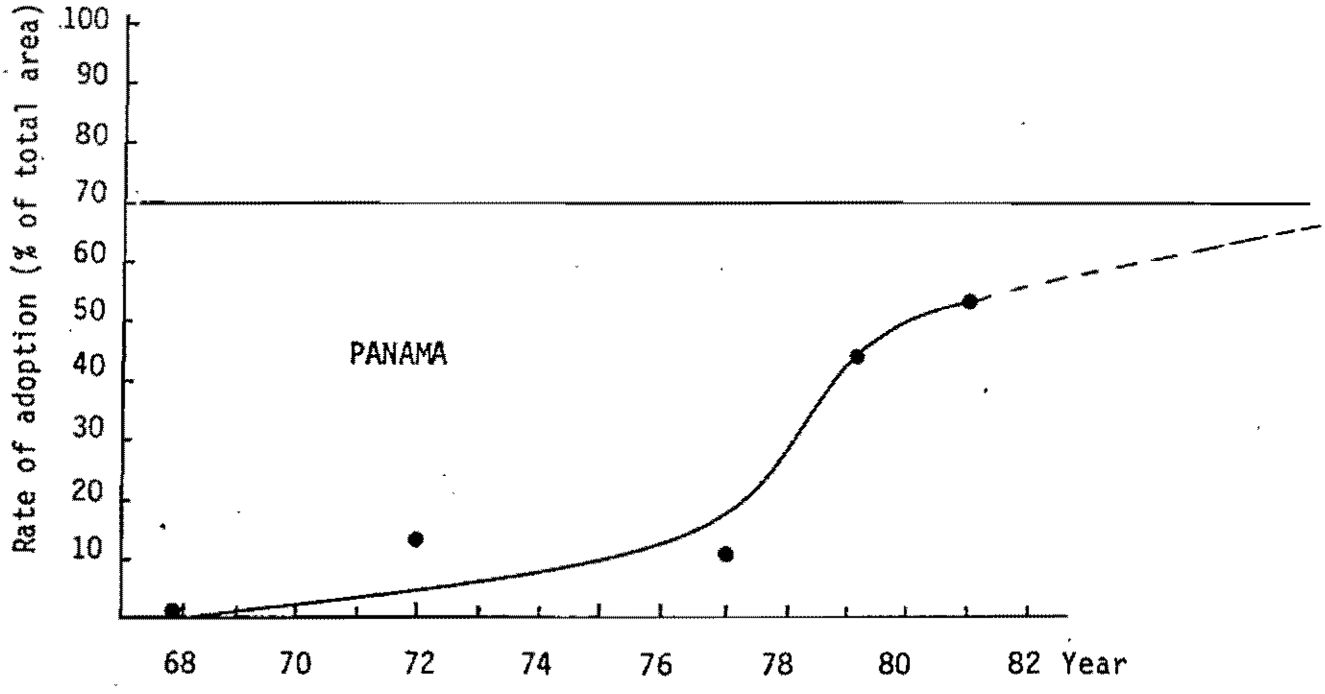

PANAMA
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
68
70
72
74
76
78
80
82 Year

Figure A.10

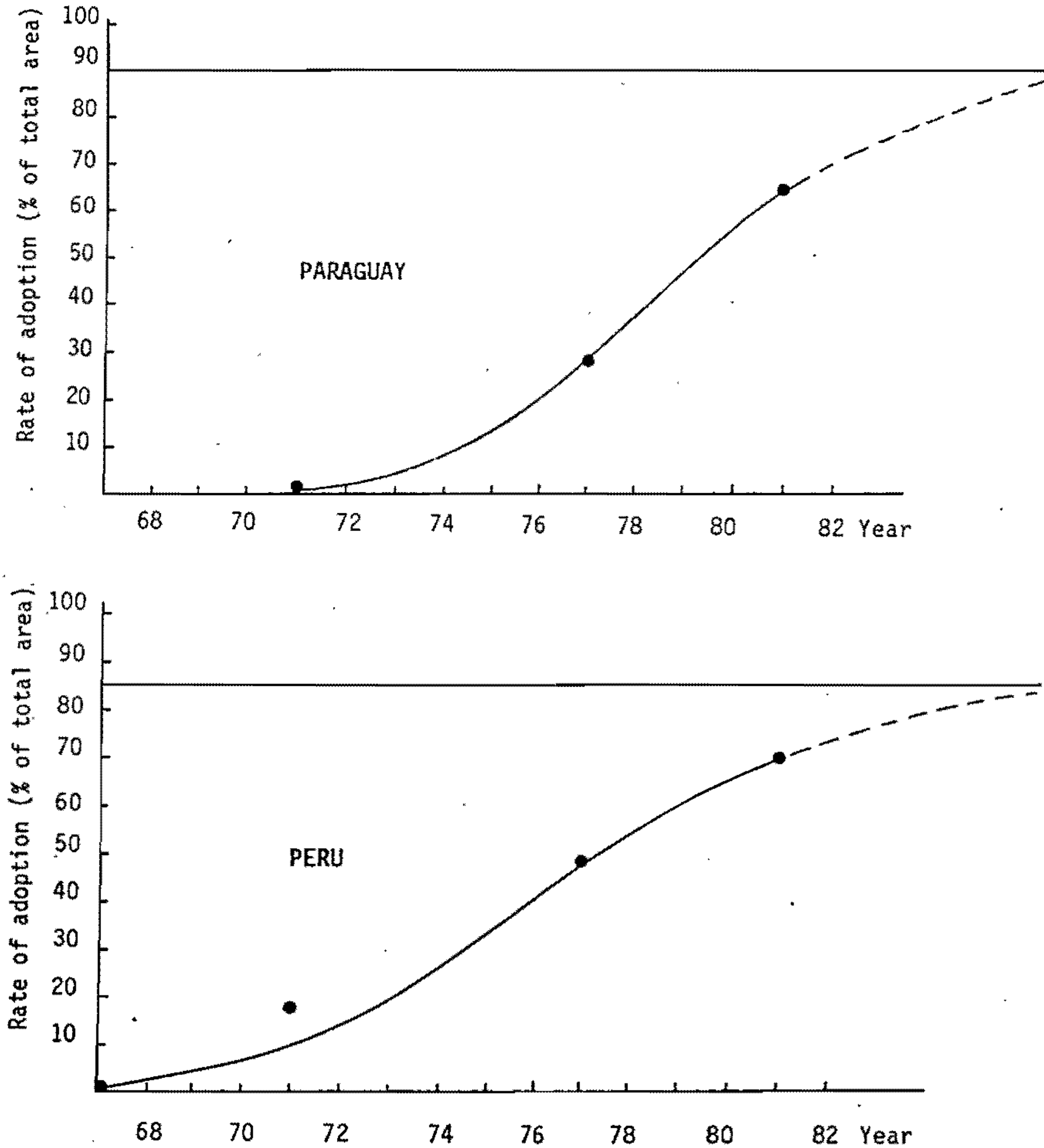
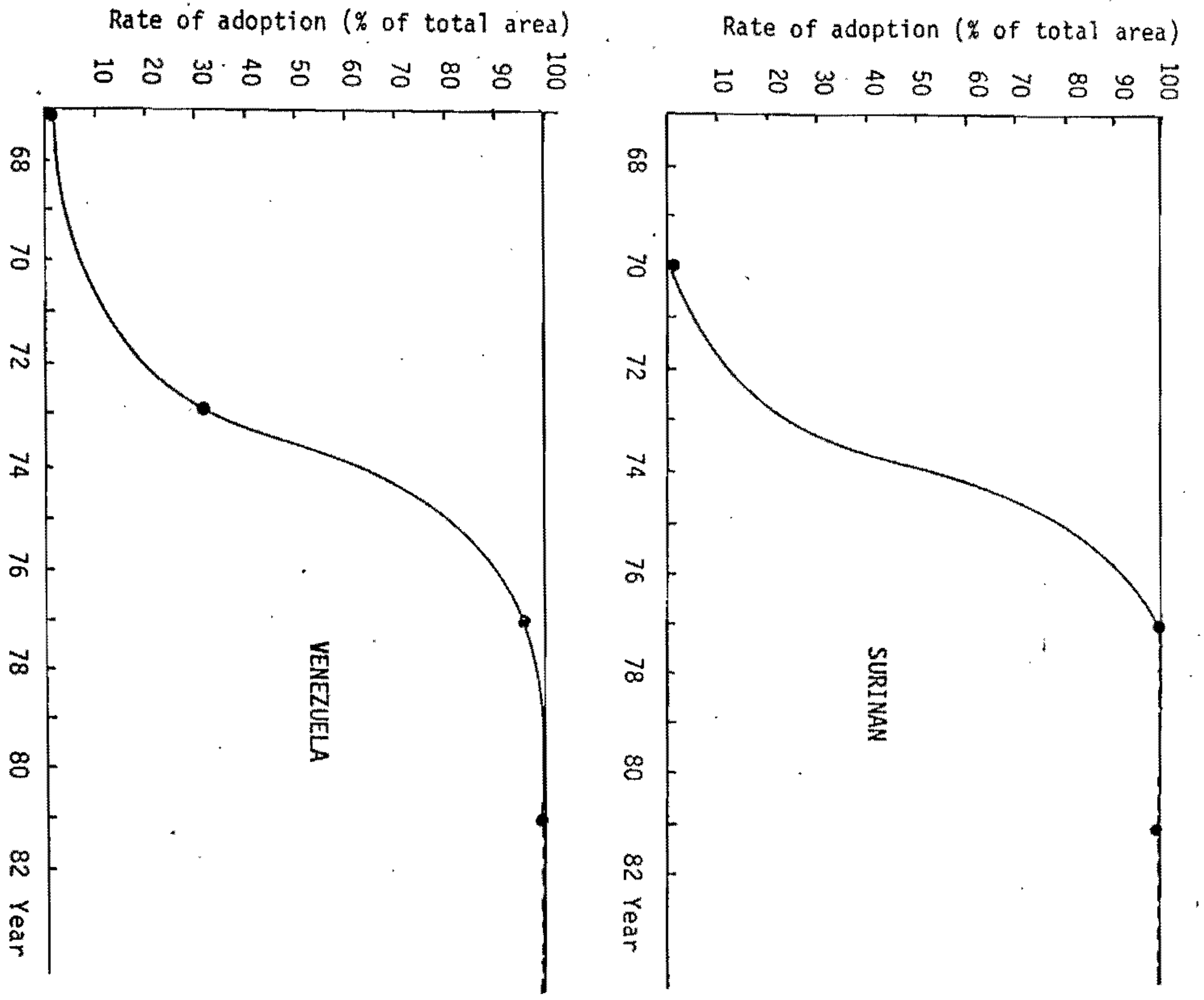

PARAGUAY
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
68
70
72
74
76
78
80
82 Year
PERU
Rate of adoption (% of total area)
100
90
80
70
60
50
40
30
20
10
68
70
72
74
76
78
80
82 Year

Figure A.11



SURINAN
Rate of adoption (% of total area)
10
20
30
40
50
60
70
80
90
100
68
70
72
74
76
78
80
82 Year
VENEZUELA
Rate of adoption (% of total area)
10
20
30
40
50
60
70
80
90
100
68
70
72
74
76
78
80
82 Year

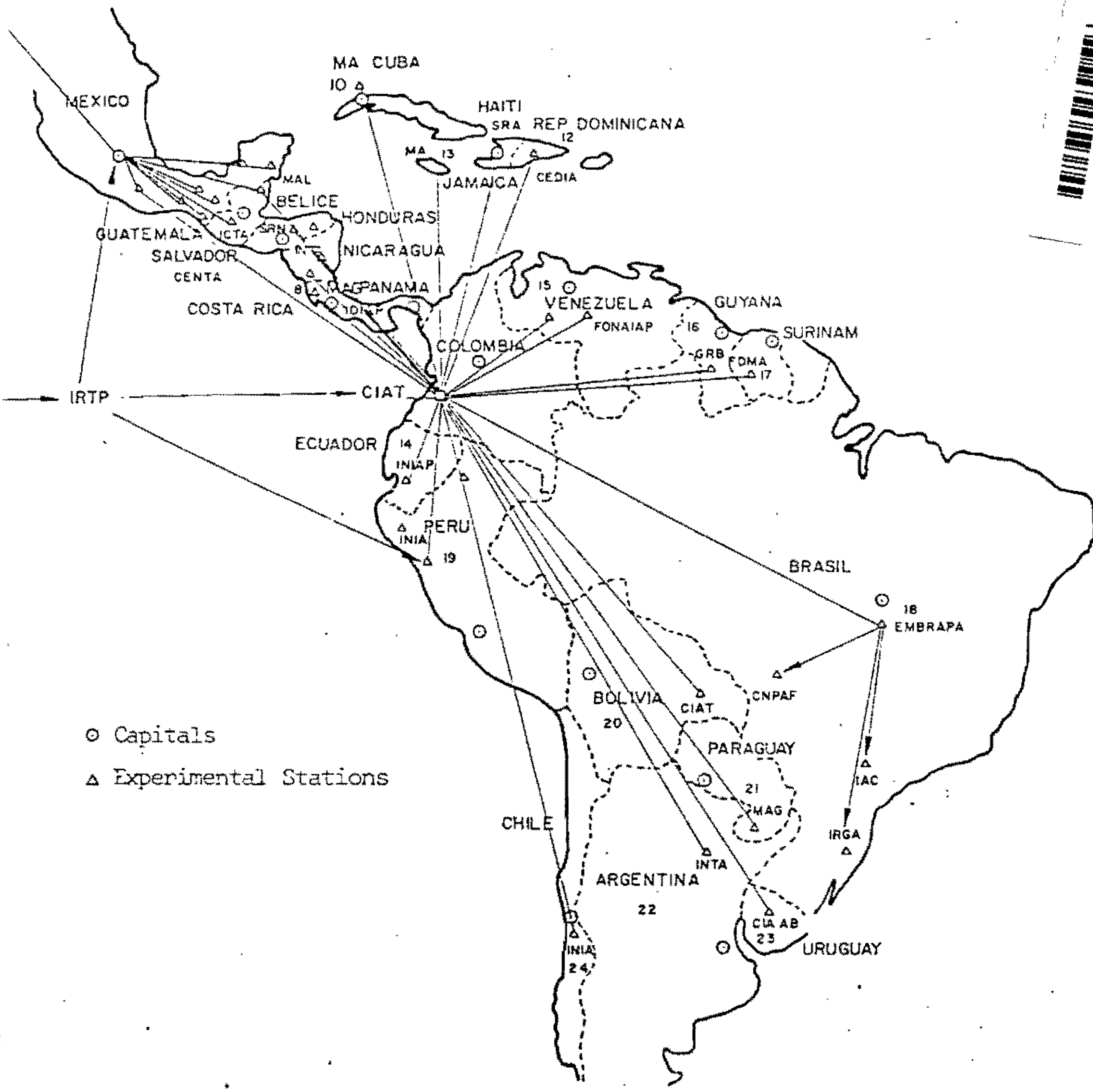


FIGURE A.12 IRTP NETWORK IN LATIN AMERICA.