RETURNS TO AGRICULTURAL RESEARCH IN COLOMBIA

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INTRODUCTION

This paper summarizes and compares results of four recent studies of the economic returns to varietal research on rice, cotton, wheat and soybeans in Colombia The four programs analyzed have formed a part of a larger national program of agricultural research, extension, and education which has been administered since about 1950 by the Colombian Agricultural Institute (ICA) and its predecessor agencies, the Department of Agricultural Research (DIA) and the Office of Special Studies (OSS)

Our main hypothesis was based on returns calculations previously made for Colombia, the United States, and other countries For Colombia, Harberger had estimated that the average rate of return on all capital had ranged from 8 to 10 5 per cent from 1960 to 1968 and that the opportunity cost of public funds was of the order of 10 per cent in the late 1960's [2/] There were also the rates of return for agricultural research calculated by Griliches [3/] and Peterson [4/] for U S programs and by Ardito for Mexico [5/],

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1/ A revised version of the paper presented in CIAT's Workshop on Methods Used to Allocate Resources in Applied Agricultural Research in Latin America This version was presented at the Conference on Resource Allocation and Productivity in International Agricultural Research held at Airlie House, Virginia, January 26-29, 1975 It benefited from comments of participants to the CIAT workshop and from suggestions made by Norman R Collins and Alain de Janvry

2/ A C Harberger, "La Tasa de Rendimiento del Capital en Colombia", Revista de Planeación y Desarrollo, Vol I, No 3 (October, 1969)

3 / Zvi Griliches, "Research Costs and Social Returns Hybrid Corn and Related Innovations," Journal of Political Economy", Vol 66, No 5 (October, 1958),pp 419-432

4/ Willis Peterson, "Returns to Poultry Research in the United States,"Journal of Farm Economics, Vol 49, No 3 (August, 1967), pp 656-669

5/ Nicolas Ardito-Barletta, "Costs and Social Benefits of Agricultural Research in Mexico" (Ph D dissertation, University of Chicago, 1971)

Ayer and Schuh for Brazil,[6] and Duncan for Australia [7] These clearly established that rates of return to varietal improvement had exceeded 10 per cent and suggested that returns obtained abroad had been somewhat higher than those obtained in the United States Correspondingly, we hypothesized that the estimated rates of return for the four Colombian varietal improvement programs not only exceeded the opportunity cost of capital in the country but also those rates of return (of about 50 per cent) [8] previously reported for similar U S programs

This hypothesis derived additional support from the common-sense notion that, because Colombia had entered the agricultural research field after the United States and other developed countries, it should have been able to draw on a large stock of knowledge about plant breeding techniques and extensive international collections of plant materials in ways which reduced the gestation periods and development costs of its programs Assuming roughly comparable organizations and competencies of the research enterprises in the two countries, this should have increased the cost effectiveness of the research activity and the returns of it Of course, there was also an alternative view -- one which stressed the existence of important socioeconomic and structural constraints in Colombia that could have prevented its earning higher returns to investments in varietal improvement, even if technical break-throughs had been more easily made

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6/ Harry W Ayer and Edward G Schuh, "Social Rates of Return and Other Aspects of Agricultural Research The Case of Cotton Research in Sao Paulo, Brazil," American Journal of Agricultural Economics, Vol 54, No 4 (November, 1972), pp 557-569

7/ R C Duncan, "Evaluating Returns to Research in Pasture Improvement," Australian Journal of Agricultural Economics, Vol 16, No 3 (December, 1972), pp 153-168

8/ See, for example, Willis Peterson, "The Returns to Investment in Agricultural Research in the United States," in Resource Allocation in Agricultural Research, ed by Walter Fishel (Minneapolis University of Minnesota Press, 1971), p 160

These contrasting views of our main hypothesis, together with the nature of the data available for analysis, led us to a methodology which could assist in distinguishing the contributions of biological, socioeconomic, and structural factors to the calculated returns to research "Social benefits" of varietal research were estimated in the usual ways as changes in consumers' and producers' surpluses resulting from shifts in product supplies generated by the use of improved seeds [9/] But the shift in supply itself was taken as the product of two separately estimated variables a difference in yields between two (average) farm plots of one hectare each, one plot being planted entirely to the improved seeds and the other to the unimproved varieties, multiplied by the per cent of cropland actually planted in the improved variety We then associated the first of these variables, the "yield advantage" of the improved variety, with the biological determinants of returns and the second-- equivalently, the rate of adoption-- with the socioeconomic and structural determinants, as well as the biological determinant, recognizing that a large yield advantage can be a primary cause of rapid and high levels of adoption

Because it was our impression at the outset that the technical and biological work of the four Colombian varietal improvement programs had been well done, we felt that our main hypothesis would only be rejected by low rates of adoption, reflecting rather major constraints of a socioeconomic and structural nature The only crop of the four studied which evidenced such constraints was wheat It had been grown under near-subsistence conditions by small, traditional farmers in some of Colombia's poorest agricultural areas Also, for a number of years massive wheat imports had been made under P L 480 These had depressed the relative price of wheat

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9/ By "usual ways" we refer to the methodology followed, for example, by Griliches, op cit, Petersen, op cit, and Ardito, op cit The formula used to calculate social benefits in the cases discussed in this paper was the one developed by Ardito, given non-extreme values of the price elasticities of demand and supply, otherwise the formulas used by Griliches were employed

Our final proposition concerned the way the yield advantage was to be calculated We felt that any simple estimate of the yield advantage based only on comparisons of yields obtained on plots seeded to new varieties and others seeded to unimproved varieties would be biased upwards because of strong, positive interactions of the new variesties with such inputs as chemical fertilizers and water Therefore, in comparing yields and calculating the yield advantages of new varieties, we attempted to factor out the effects of other inputs by estimating a production relation between yields, seed variety, and other variables which may have interacted with the variety of seed employed

The next four sections of this paper take up the cases of rice, cotton, wheat and soybeans, respectively In addition to presenting information relevant to the estimates of the costs and benefits of the varietal improvement programs, some background materials are included in each section which relate to the reasons the particular program was established, the directions it took once established, and those people on the side of production who may have expropriated the surpluses it ultimately generated The final section of the paper then provides a comparative analysis of our main results and summarizes our principal conclusions

RICE 10/

Colombia's rice research program is of relatively recent origin, having been initiated in 1957 by ICA's predecessor agency Its establishment coincided with a sharp rise in rice imports occasioned by an outbreak of the hoja blanca disease, 11/

10/ This section draws heavily on the work by Jorge Ardila, "Rentabilidad Social de las Inversiones en Investigación de Arroz en Colombia"(unpublished M S Thesis, ICA/National University Graduate School, Bogota, 1973)

11/ Until 1957 Colombia's imports of rice were running around 2,000 metric tons annually The 1956 crop was down about 10 per cent from 1955 (from 324,000 tons in 1955 to 300,000 tons in 1956), and the 1957 crop was up less than 8 per cent from 1955, in part because of a fall in yields In 1957 Colombia then imported 10,200 tons of rice In 1958 and 1959 imports returned to "normal" levels Refer, for example, to relevant issues of the FAO Rice Report for these and related data a virus of Latin America--with symptoms like the stripe disease of Japan--which first caused substantial losses in Venezuela in 1956 and in Colombia itself in 1956 and 1957 12/ Correspondingly, the initial objectives of the research program included varietal selection and breeding for higher yields and resistance to the hoja blanca virus

Rice varieties with resistance characteristics were collected throughout Colombia as a first step, in addition, 2,200 varieties were selected and imported from the U S Department of Agriculture's World Collection of Rice in Beltsville, Maryland By 1959 about 400 of these varieties had shown promising resistance to the virus 13/ Because they were mainly japonica varieties previously not consumed in Colombia, the research program adopted an objective of breeding the virus resistance of japonica into the local long-grain varieties 14/ It was estimated that this objective might be satisfied in four to five years As an interim measure, Gulfrose, the one superior-yielding U S variety which had shown some virus resistance, was multiplied and released in 1961

The first improved variety, Napal, to be produced by the Colombian research program was actually released in 1963 or just four years after the program began Napal had the long-grain characteristics of Bluebonnet 50, the most preferred non-traditional variety, but was resistant to hoja blanca 15/ Unfortunately, Napal was subjected to a heavy attack of Bruzone (rice blast disease) in 1965 and thereafter disappeared from commercial production In the same year, Tapuripa, earlier imported

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12/ S H Ou, Rice Diseases (England Commonwealth Mycological Institute, 1972), pp 28-33 Apparently, the attack was least severe where the Colombian red rice was grown, see Philippe Leurquin, "Rice in Colombia A Case Study in Agricultural Development," Food Research Institute Studies, Vol VI, No 2 (1967), p 231

13/ The means by which the disease was transmitted were not identified with the insect, Sogotodes, until 1958

14/ Chemical control of the virus proved somewhat effective--but very expensive--among partially resistant varieties, see G F Galvez, "Hoja Blanca Disease of Rice," The Virus Diseases of the Rice Plant (Baltimore Johns Hopkins Press, 1968), pp 35-49

15/ Bluebonnet 50 was first imported to Colombia in 1954 The history of its introduction and rapid adoption is discussed by Leurquin, op cit, pp 250 and 251 from Surinam, was multiplied and distributed to farmers as an alternative to Bluebonnet 50 and Gulfrose It was long-grained and flinty with some resistance to blast disease and hoja blanca

In 1966 the Colombian rice research program added an objective which reflected leads of the International Rice Research Institute (IRRI) to develop dwarf varieties with a high grain-to-straw ratio and resistance to lodging About 3,000 additional varieties were imported from IRRI, and an order went out to retain only those varieties already in the Colombian collection which outyielded the most prevalent local variety by 100 per cent

A year later (in 1967), ICA's program joined forces with the rice program of the International Center for Tropical Agriculture (CIAT) Personnel, facilities, budgetary resources, and objectives were shared under informal agreements between the two institutions These had the effect of reinforcing the ties of the Colombian program with IRRI as the head of CIAT's rice work had served on IRRI's staff

In 1968, CIAT and ICA introduced IR-8 Its adoption advanced well even though the medium-type chalky grain sold generally at a 30 per cent discount, and showed susceptibility to blast disease IR-8 did prove resistant to hoja blanca Following strong commercial trade interest, CIAT and ICA also introduced IR-22 in 1970 and recommended it to farmers in irrigated tropical areas

Between 1966 and 1970, ICA released independently only one additional rice variety, ICA-10 It never assumed any commercial importance, however, because its yields were inferior to the IRRI varieties --while being superior and/or less variable than either Gulfrose or Napal- and its grain quality was less desirable than Tapuripa

In 1971, CIAT and ICA released the CICA-4 variety It was more disease-resistant and had greater water and air temperature adaptability, good grain appearance and cooking qualities, and slightly superior yields Simultaneously, CICA-4 appeared in Ecuador as INIAP-6, in the Dominican Republic as Advance 72, and in Peru under the name of Nylamp

Yields recorded in commercial field trials of the seven major rice varieties released by the Colombian and joint CIAT-ICA program after 1957 are shown in Table 1, together with data obtained from the same source on yields of the check variety, Bluebonnet 50 The 665 individual trials which are the basis for these yield statistics include all that are available for the 15-year period, 1957-1971 It should be mentioned that ICA's commercial trials or <u>pruebas regionales</u> are conducted on parcels of commercial farms which agree to collaborate with the Institute's programs Farmers run the trials, but materials and instructions are provided by ICA

The three rice varieties released prior to 1966 show average yields in these data of 4 1 metric tons per hectare representing a yield advantage over Bluebonnet 50 of about 33 per cent Varieties introduced after 1966, including ICA-10, just double that yield advantage bringing it to 65 per cent above Bluebonnet 50

In view of these yield data, it is interesting to note in Table 2 that the area planted to improved rice varieties did not become a significant proportion of all riceland until the second, or post-1966, stage of the research program Data in the table on the percentage of acreage sown to a given variety were estimated in the following way First, available information on sales of certified seeds by variety were converted to hectare equivalents by dividing by estimates of seeding rates provided by ICA's Director of its National Rice Program Second, lacking data on farm-produced seeds of the improved varities, it was assumed that the proportion of all acreage planted to certified seeds of any variety was equal to the proportion planted to later generation seeds produced outside the seed multiplication and certification program This estimating procedure was followed here, as well as in the cases of wheat and soybeans, to estimate total area planted to improved seeds because it produced the simplest and "best fit" between available data on certified seed sales and "expert opinion "

In order to estimate the shift parameter of each new variety--its yield advantage over Bluebonnet 50--production functions were fit to the <u>pruebas regionales</u> data using

TABLE 1

Colombia Average Rice Yields From Commercial Trials by Variety
1959-1971

Year	Variety							
	Bluebonet 50	Gulfrose	Napal	Tapuripa	ICA-10	IR-8	IR-22	CICA-4
	kilos per hectare							
1959	1,927	a/						
1960								
1961	2,893	3,071						
1962	2,967	4,065						
1963	3,875	5,391	4,420					
1964	4,336	4,138	5,166					
1965	3,462	2,739	4,343					
1966	1,590		2,436	3,645				
1967	2,893			2,690	4,707	6,098		
1968	3,208		5,356	4,600	4,789	5,890		
1969	3,544		5,110	4,625	5,450			
1970	3,339			4,500	3,852	5,180	5,420	6,125
1971	3,164			3,610	4,234	4,748	5,080	4,600
Average	3,099	3,880	4,344	4,025	4,441	5,473	5,250	5,362

a/ Blanks indicate no regional trials were undertaken

Source Jorge Ardila, "Rentabilidad Social de las Inversiones en Investigación de Arroz en Colombia" (unpublished M S Thesis, ICA/National University Graduate School, Bogota, 1973) Table 5

TABLE 2

Colombia Land Area Planted to Six Improved Varieties of Rice as a Percentage of the Total Area Planted in Rice
1964-1973

Year	Variety						All improved varieties
	Napal	Tapuripa	ICA-10	IR-8	IR-22	CICA-4	
	per cent						
1964	2 5	a/					2 5
1965	2 1						2 1
1966		0 1					0 1
1967		3 2	0 1				3 3
1968		21 2	0 6	0 3			22 1
1969		18 0	0 5	3 7			22 2
1970		12 4	0 2	18 2			30 8
1971		6 9		21 1	3 1	5 0	41 1
1972				18 9	10 1	18 3	47 3
1973				20 1	24 3	12 6	57 0

a/ Blanks indicate less than 0 1 percent

Sources Jorge Ardila, "Rentabilidad Social de las Inversiones en Investigación de Arroz en Colombia" (unpublished M S Thesis, ICA/National University Graduate School, Bogota, 1973), Table 11 for the years 1964-1971, also, after 1971, ICA, Director of the National Rice Program standard least-squares procedures. In the final round of estimation, reported yields (kilos per hectare) were taken as a function of 20 variables: size of the trial plot, seeding rate, 7 seed variety variables, 2 variables to distinguish different time periods, 4 variables relating to irrigation and its interactions with seed variety, and 5 variables to differentiate locations and their interactions with variety. Only the first two of these variables entered as continuous arguments. Other continuous variables (relating particularly to "cultural practices") were either discarded or respecified in noncontinuous form in the final results presented in Table 3.

Because CICA-4 was taken as the check variety, the estimated coefficients on the variety variables are to be interpreted as their "yield disadvantage" in kilos per hectare compared with CIAT-4. On interpreting results this way, it is evident that the Colombian rice research program has produced through time continuous and substantial improvements in yields. Again, the superiority of the varieties released after 1966 is evidenced.

The large and significant coefficient on the variable adjusting for the location of the pruebas regionales indicates that the yield advantage of some locations is 1.2 tons. This location effect appears to be somewhat larger for the Napal, Gulfrose, and IR-8 varieties since the location-variety interaction variables for those varieties are positive.[16/] The fact that the corresponding interaction term is negative and about equal to 1.2 tons in the case of CICA-4 leads to a conclusion that it is the only variety which is less location specific.

Results suggest, however, that yields of CICA-4, as well as those of IR-8 and IR-22, are very positively influenced by irrigation. The coefficient on the irrigation variable indicates that yields of all varieties are increased by about 1.2 tons with average irrigation practices. Roughly another ton is added on top of this when irrigation is applied to IR-8, IR-22, or CICA-4 as indicated by the

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16/ The location variable assumed a value of one when a trial fell into areas which could be classified as tropical dry forest, subtropical humid forest, or very dry tropical forest, and zero otherwise. This classification was suggested by the Director of ICA's National Rice Program.

coefficients on the variables of interaction of those varieties with irrigation This evidence from the production functions, coupled with data which show that dryland rice yields increased 7 per cent during the 1961-1972 period while those of irrigated rice increased 133 per cent, 17/ leads to an inference that the newer varieties have benefitted mainly the irrigated rice areas. The other side of the same coin, of course, is that adoption of improved varieties was assisted by the existence of irrigated cropland 18/

Most of ICA's research has been focused on the irrigated rice areas Its largest programs have been located at the Palmira and Espinal experiment stations While about 75 per cent of all riceland is irrigated today (1974) in Colombia, almost 100 per cent has been traditionally irrigated within the areas served by Palmira and Espinal 19/ Underscoring this point is the fact that 84 per cent of the pruebas regionales were performed with irrigation Also, among the 48 locations used for experimentation, upland rice trials were the only type performed in 14 locations while 30 were used only for trials with irrigation This emphasis on the irrigated areas may have been induced by expectations of the sort of variety-irrigation interactions found in the regression results More plausible is the common-sensical explanation that ICA's creditability would have been seriously threatened had it not produced varieties which yielded well in the irrigated areas of Colombia since the controlling interests of the rice growers and commercial trade are found there 20/

17/ FEDFARROZ, Informe de Gerencia al XIII Congreso Nacional, Bogotá, Colombia, 1971, p 32

18/ In 1948 Raul Varela Martínez, Industria y Comercio de Arroz en Colombia (Bogotá Ministerio de Agricultural y Ganadería), p 15 estimated that 18 per cent of all riceland was irrigated and 16 per cent was partly irrigated By 1974, it is estimated that the per cent of riceland irrigated had increased to about 75 per cent

19/ See, for example, Leurquin, op cit , Tables 5 and 11

20/ The exception to this procedure was taken in estimating CICA-4's yield advantage since, given the specification of the regression, the yield advantage of CICA-4 equals simply the negative value of the coefficient on Bluebonnet 50

TABLE 3

Colombia Production Function Estimates for Rice Based on Commercial Trial Data, 1957-1972

Independent variable	Estimated coefficient	Estimated statistics
1 Size of trial plot	- 0 15	- 2 30
2 Seeding rate	2 46	1 58
3 Bluebonnet 50	-1,609 66	- 3 45
4 Gulfrose	-1,486 56	- 1 31
5 Napal	-1,742 79	- 1 83
6 Tapuripa	- 884 31	- 1 80
7 ICA-10	- 536 93	- 1 13
8 IR-8	- 798 97	- 1 54
9 IR-22	- 589 97	- 0 72
10 Irrigation	1,220 20	5 84
11 Irrigation * IR-8 interaction	1,278 09	3 21
12 Irrigation * IR-22 interaction	700 44	0 89
13 Irrigation * CICA-4 interaction	1,061 87	2 11
14 Location	1,185 26	7 12
15 Location *Gulfrose interaction	991 98	0 94
16 Location *Napal interaction	940 33	1 06
17 Location *IR-8 interaction	428 22	1 24
18 Location *CICA-4 interaction	-1,340 16	-3 14
19 Time I	1,228 03	6 74
20 Time II	- 509 78	- 2 20
Intercept	2 028 30	3 64
	R^2 = 0 67	n = 665

Source Jorge Ardila,"Rentabilidad Social de las Inversiones en Investigación de Arroz en Colombia"(Unpublished M S Thesis,ICA/National University Graduate School, Bogotá, 1973), Table 13

Pegression results were used to produce one estimate of the overall shift parameter--the percentage change in rice supply attributable to the yield advantage of all the improved varieties over Bluebonnet 50 It was estimated as a weighted sum--divided by average commercial yields--of the regression coefficient of each improved variety minus the coefficient corresponding to Bluebonnet 50, with weights equaling the percentage of all rice-land planted which was sown in each variety 21/ This estimate is shown in column 2 of Table 4, along with the "simple" estimate of the yield advantage of the improved varieties (shown in column 1 of the table) which is based only on the average annual yield data for each variety obtained in the pruebas regionales and already presented in Table 1 22/

The fact the the simple estimates of the shift parameter exceed the estimates which include just varietal effects from the regression is consistent with the finding that only the improved varieties of rice interacted with other variables of the production function Since those interactions were on balance positive and are included in the simple estimate but not in the varietal-effects estimate, the former overstates the shift parameter by as much as 7 percentage points

The simple and varietal-effects estimates were combined with assumed values of the price elasticities of supply and demand to provide upper and lower bound estimates of gross social benefits of the new seed varieties for the period 1964-1971 23/ Values

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21/ The exception to this procedures was taken in estimating CICA-4's yield advantage since, given the specification of the regression, the yield advantage of CIAT-4 equals simply the negative value of the coefficient on Bluebonnet 50

22/ The varietal effects estimate shown here evidences lower values for the shift parameters than the source (Ardila, op cit , Tables 17 and 20) by reason principally of the omission here of adjustments for "time " Ardila originally added to the yield differentials estimated from the production functions appropriate values of the coefficients on the time variables in each year Since those coefficients are on net strongly positive for the 1964-1971 period, the effect was to increase estimated values of the shift parameters

23/ Calculations based on the varietal effects plus interaction effects shift parameters are not included here but can be inspected in Ardila, op cit , Table 27

TABLE 4

Colombia Alternative Values of the Supply Shift Parameter for Rice Attributable to Improved Varieties, 1964-1971

Year	Estimate	
	Simple	Varietal effects
	1	2
	percent	
1964	1 05	-0 16
1965	1 01	-0 15
1966	0 13	0 03
1967	-0 17	1 07
1968	10 99	5 73
1969	12 81	5 98
1970	14 89	7 42
1971	15 96	10 38

Source Based on Jorge Ardila,"Rentabilidad Social de las Inversiones en Investigación de Arroz en Colombia" (unpublished M S thesis,ICA/National University Graduate School, Bogota,1973), Tables 5, 11, 12, 13, 17, and 20 considered for the price elasticities of supply were 0, 0 2347, and infinity, the intermediate value being derived from the only supply study available for Colombian rice,[24] values considered for the price elasticity of demand were -0 5, -1 372, and -2 0, the intermediate value again having been estimated in another study [25] Maximum gross benefits resulted from using the simple estimates of the shift parameter and price elasticities of demand and supply, respectively, of -0 5 and 0, minumum benefits correspond to price elasticities of demand and supply of -2 0 and infinity and the varietal-effects estimate of the supply shift parameter Both estimates of benefits are shown in Table 5 for the 1964-1971 period

Costs of the research program for the same period, also shown in Table 5, include direct costs, indirect costs, and complementary costs, definitions given these terms being those earlier used by Ardito [26] Direct costs of the rice program were available only after 1964 For this reason available cost data were regressed on the number of employees assigned to the rice program and ICA's total expenses for all research programs, the resulting regression coefficients and available data on the two independent variables of the regression were then used to estimate the direct cost data for the missing years, 1957-1965 Complementary costs associated with the new program--those it incurred with other collaborating programs--were estimated for this study by the Director of the National Rice Program Included were costs associated with the entomology, plant physiology, plant pathology, soils, and extension programs Indirect costs were taken to include staff training costs, [27] opportunity costs of the services of fixed capital and land, management costs, and the costs of "international cooperation" including a prorated share

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24/ Nestor Gutierrez and Reed Hertford, Una Evaluación de la Intervención del Gobierno en el Mercado de Arroz en Colombia, Folleto Técnico No 4 (Colombia Centro Internacional de Agricultura Tropical, 1974), Table 3

25/ Ibid , Table 4

26/ Ardito, op cit

27/ One staff member of the rice program was trained through the Ph D ,and four others were trained through the M S Costs of training personnel of the National Federation of Rice Growers at the National University/ICA Graduate School were also included

TABLE 5

Colombia Estimated Benefits and Costs of the Rice Research Program, 1957-1980

Year	Estimated benefits		Estimated costs
	Maximum	Minimum	
	1	2	3
	1,000 (1958) pesos		
1957	a/		15
1958			193
1959			235
1960			286
1961			429
1962			441
1963			252
1964	3,733	- 563	445
1965	4,750	- 699	538
1966	553	127	519
1967	- 827	5,157	867
1968	61,659	27,291	937
1969	60,872	23,675	2,074
1970	69,444	27,883	2,779
1971	107,470	52,225	4,165
1972-1980	107,543	52,225	4,202 b/

a/ Blanks indicate no benefits

b/ Figures for subsequent years were estimated by assuming 4,202 grew 10 per cent annually

Sources

Cols 1 and 2 Based on preceding tables

Col 3 Jorge Ardila, "Rentabilidad Social de las Inversiones en Investigación de Arroz en Colombia" (unpublished M S thesis, ICA/National University Graduate School, Bogota, 1973), Tables 44 and 46 of personnel costs of Rockefeller Foundation staff stationed in Colombia from 1958 through 1968 and, most importantly, the total costs of the CIAT rice program from 1969 to 1972 estimated by the head of that program This latter item was the major cost The simple sum of total costs for the 1957-1971 period equaled 14 2 million 1958 pesos, and the costs of international cooperation were calculated at 5 0 million pesos or 35 per cent of the total 28/ All costs for the rice program in 1971 represented about 12 per cent of ICA's total expenses for research

Recognizing that the current stock of new varieties will continue to produce into the future, costs and benefits of the Colombian rice program were projected forward for nine years to 1980 using assumptions, when necessary, which would bias downward the estimate of internal rates of return On the cost side, for example, it was assumed that the real value of the cooperative CIAT-ICA rice program would increase at a rate of about 10 per cent per year, primarily on the grounds that programs which are relatively new and reputedly successful tend to grow 29/ On the side of the projection of gross benefits, it was assumed that the value of production during the 1972-1980 period will average 581 million pesos, a sum which equals the value of the rather good 1971 crop (in 1958 pesos), that the adoption rate of the new rice varieties after 1973 will stabilize at the estimated 1973 level of 57 per cent, 30/ that the per cent of riceland planted to IR-8 will trend downward linearly to 0 by 1980, that the percentages

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28/ Costs of international cooperation are still probably understated since benefits derived from the "capital stock" of IRRI and other institutions have not been charged to the Colombian program More is said about this elsewhere in this paper

29/ Since this assumption was made, ICA's budget has been severely cut and CIAT's rice program has been phased down Nonetheless, we hold to the initial assumption in order not to overstate the final estimate of the internal rate of return

30/ This is a more moderate assumption than that caused by Ardila, op cit, Table 35 who assumed that the percentage of area sown in improved rice would fall between 72 per cent and 84 per cent by 1980 The data of the U S Department of Agriculture, Economic Research Service, Development and Spread of High-Yielding Varieties of Wheat and Rice in the Less Developed Nations, FAER No 95, 1974, Table 38, indicating that adoption rates in the Philippines, Malaysia, and India are topping out at rates well under 60 per cent, plus the analysis by Robert Evenson, "The 'Green Revolution' in Recent Development Experience," American Journal of Agricultural Economics, Vol 56, No 2 (May, 1974), pp 387-394, suggest that the use of improved varieties may never reach 70 per cent in Colombia and that an assumption of 57 per cent is more conservative and probable of all riceland sown to IR-22 and CICA-4 will be equal after 1973, and that the increase in the shift parameter these assumptions would imply will about equal increases in commercial yields over the period 1971-1980 31/

The resulting internal rate of return corresponding to the stream of maximum gross benefits was found to be 82 3 per cent, the rate estimated on the basis of the minimum gross benefits stream was 60 1 per cent 32/

COTTON 33/

Cotton has turned in a striking growth performance in Colombia Since the mid-1930's, yields have about quadrupled--in fact, their pattern of change has been broadly similar to that of the United States Currently, Colombian cotton yields are comparable to U S yields and roughly twice as high as average yields for all South America (Table 6) In an earlier comparative analysis of changes in cotton yields, it was concluded that Colombia ranked fourth in yield increases in the 1950-1960 period among those 24 countries of the world which produced 97 per cent of all cotton in 1960 34/ Production after the mid-1930's increased at least 15 times or from about 30,000 bales in 1937-38 to over 500,000 bales in the early 1970's 35/

31/ The increases in yields would be 14 and 11 per cent, respectively, for the maximum and minimum values of the shift parameters

32/ Ardila, op cit , placed a range on the internal rate of return of 53 0 to 53 4 per cent The minimum (and the maximum) reported here would have been lower and lower that Ardila's estimates had the additional costs of the new varieties to farmers been netted out of "gross benefits" Data on those costs were simply judged to be too weak to include, however

33/ This section is based largely on the work by Andrés Rocha, "Evaluación Economica de la Investigación sobre Variedades Mejoradas de Aldogón en Colombia" (unpublished M S thesis, ICA/National University Graduate School, Bogotá, 1972)

34/ Leurquin, "Cotton Growing in Colombia Achievements and Uncertainties," Food Research Institute Studies, Vol VI, No 2 (1966), p 145

35/ These and other production and trade data cited in this section were obtained from the relevant number of Cotton-World Statistics published by the Secretariat of the International Cotton Advisory Committee, Washington, D C

TABLE 6

Comparative Cotton Yield Statistics
1934-35/1938-39 to 1973-74

Year	Colombia		United States	South America
	All crops	Cotton		
	1	2	3	4
	index	pounds per acre		
1934-35 to 1938-39	a/	133	212	181
1947-48	100	152	267	163
1950-51	115	167	269	175
1951-52	102	150	269	203
1952-53	109	227	280	197
1953-54	119	317	324	212
1956-57	143	319	409	178
1959-60	152	377	462	207
1962-63	176	398	457	231
1965-66	158	352	526	244
1966-67	164	470	480	232
1967-68	176	516	447	267
1970-71		463	437	222
1973-74 b/		470	519	249

a/ Blanks indicate no data available
b/ Preliminary

Sources
Col 1 U S Department of Agriculture, Economic Research Service, Changes in Agricultural Production and Technology in Colombia, FAER No 52, 1969, Table 30

Col 2-4 Secretariat, International Cotton Advisory Committee, Cotton-World Statistics (Washington, D C), various issues

Yields and production advanced most rapidly in two different but not widely separated periods of time 1951-1954 and 1957-1959 Yields about doubled in the first period Although they did increase in the second, production evidenced a much larger increase of 167 per cent Developments in both periods appear to have been the direct result of changes in government policies

The first period of rapid development followed the reopening of the Colombian Ministry of Agriculture in 1948 and new policy pronouncements emphasizing the need to substitute imports of food and fibers with local production In the case of cotton, this involved some protection--notably a requirement that the textile industry consume stated allotments of national cotton--which resulted in an 82 per cent increase in the farm price between 1948 and 1951 [36/] When the local textile industry was faced with the prospect of consuming larger quantities of national cotton, it promoted the establishment, in 1948, of the Cotton Development Institute (IFA) to improve the quality and uniformity of local cotton through research and the control of ginning [37/] IFA, eventually a government institute with its own budget, also assumed responsibilities for cotton extension, seed distribution, and credit

The second surge in production, occurring at the end of the 1950's, paralleled changes in exchange policies The official exchange rate in Colombia was 2 5 pesos per U S dollar from 1951 through May, 1957 The free rate was 3.0 to 3 5 pesos through 1954 and then edged up to 6 9 pesos by mid-1957 On June 18, 1957, the official rate was increased to 7 6 pesos Through the 1951-1957 period, the Colombian textile industry was permitted to import raw cotton and capital items at the official exchange rate As a result, imports steadily built up to a level of 77,000 bales in 1957, production stood at 95,000 bales in that same year In 1958, following reforms, production jumped

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36/ U S Department of Agriculture, Economic Research Service, Changes in Agricultural Production and Technology in Colombia, FAER No 52, 1969, p 76 In the same source it is shown that the price of rice rose 41 per cent, and the price of sugarcane rose 49 per cent Pice and sugarcane compete with cotton for the same farmlands in many areas of Colombia

37/ Leurquin, "Cotton Growing in Colombia. ," pp 158 and 159 to 220,000 bales and, in 1959, reached 256,000 bales Imports fell to 36,000 bales in 1958 and to slightly less than 2,000 bales in 1959, at which time Colombia also showed its first exportable surplus of cotton in several decades During the early 1960's, exports averaged about 100,000 bales and by 1968 had reached a level of almost 300,000 bales

As producers of cotton attained national prominence and power for satisfying domestic consumption and exporting a growing surplus, the National Federation of Cotton Growers (FNA) began to absorb IFA's functions In 1968, IFA was dissolved completely, and its research and extension activities were passed on to the ICA Others of its activities were absorbed by the Ministry of Agriculture

IFA's inheritance was meager when it assumed responsibilities for organized cotton research in 1948 On the advice of an English mission, some cotton research was begun in the Cauca Valley in 1928 but was later suspended when attention there turned to the prospects for sugarcane research by a visiting mission from Puerto Rico Some research was established later (1934) in Armero, State of Tolima, to introduce and test U S Uplands and some Peruvian varieties Most progress, however, up until 1948 had been made in improving the perennial tree cotton A station near Barranquilla on the north coast is reported to have obtained yields of 350-400 kilos per hectare or at least twice the then prevailing average yield 38/ Nonetheless, one of the first things IFA did was to close that station as the quality of the tree cotton was considered inferior to imported cotton and tree cotton had become infested with diseases which threatened the introduction of annual varieties

From the beginning, the Institute's sole research objective was the introduction, testing, and manipulation of improved U S cotton varieties No attempt was made to produce a national variety until 1961, and that effort appears to have languished until IFA's research was absorbed by ICA in 1968

ICA stated the first objective of its cotton research program to coincide identically with IFA's but added a second objective--the development of a national cotton variety through selection and hybridization ICA also improved the design of research,

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38/ Ibid, p 154

expanded experimentation beyond the three locations used by IFA (at Buga, Espinal and Codazzi), and undertook more trials on a commercial scale as pruebas regionales

Actually the first U S cotton variety was introduced into Colombia well before the establishment of IFA Deltapine 12 was imported by cotton producers in 1941 and came into general use in Tolima State during the 1940's The year before, a Brazilian variety had been introduced, Expresso do Brazil, it likewise gained acceptance in Tolima during the 1940's In the late 1940's and the 1950's, Deltapine 15, Earlystaple, Coker 124, and Deltapine Smoothlead were introduced These so-called "T" type cottons came to account for about 93 per cent of all cotton production by 1959, Deltapine was certainly the most important among them Another 6 per cent of production, mostly in the Cauca Valley, was a longer, finer "V" type cotton. The remainder was "L" type tree cotton from the north coast and a short, staple length "S" type cotton (Lengupa) from Peru [39/] For 1961-62, IFA reported data showing that 92 per cent of all production was from the Deltapine 15 variety, 5 per cent from Coker 124, and the balance from Deltapine Smoothleaf, Deltapine 16, tree cotton, Lengupa, Delfos, Plains, and unspecified varieties [40/] By 1971, Deltapine 15 was no longer in use but Deltapine 16 accounted for 42 per cent of all cotton acreage and Deltapine Smoothleaf for 38 per cent, Acala 1517 BR-2 for 8 per cent, and Stoneville 213 for 8 per cent, with the remaining 4 per cent being accounted for by Deltapine 45 and Coker 201 [41/]

Because of the different nature of the cotton research program--namely, its emphasis on the selection and multiplication of promising U S varieties rather than on the development of improved national varieties--contributions of research to yield increases and the specification of the shift parameter were envisaged differently than in the case of the Colombian rice program Specifically, the shift parameter was seen

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39/ U S Department of Agriculture, Foreign Agricultural Service, The Cotton Industry of Colombia, FAS M-113, 1961, p 8

40/ Instituto de Fomento Algodonero, Colombia Su Desarrollo Agrícola (Bogotá, Editorial Andes, 1962), pp 51 and 52

41/ U S Department of Agriculture, Foreign Agricultural Service, Cotton in Colombia, FAS-M 239, 1971, p 11 to include three different factors

First, if the cotton program successfully encountered and released U S varieties which out-yielded the Deltapine 12 and Expresso do Brazil varieties in general use when IFA was established, there would have occurred an increase in yield--analagous to the shift parameter defined for rice--and equal in a given year to

$$\sum_{i}^{n} \left(\frac{R_{di} - R_a}{R_t}\right) P_{1i}, \qquad (2)$$

where

R_{di} = yield of the ith improved variety

P_{1i} = percentage of cotton land planted to the ith variety

R_a = average yield for Deltapine 12 and Expresso varieties

and

R_t = average commercial yield of all cotton

A second element to consider would be the change in yields which would have occurred had new varieties been introduced and diffused by farmers in the abasence of an organized research establishment, i e ,

$$\sum_{i}^{n} \left(\frac{R_{di} - R_a}{R_t}\right) P_{2i}, \qquad (3)$$

where P_{2i} is the per cent which would have been planted in the ith cotton variety This expression would be subtracted from (2) in calculating the net shift parameter attributable in a given year to the cotton research program It was hyphesized that (3) would be positive valued in view of certain characteristics of the Colombian cotton industry For example, the demand curve facing producers has been highly elastic because of the existence of an export market Also, Colombian cotton production appears to have been concentrated in the hands of a small group of farmers As of 1958, 422 farmers accounted for 61 per cent of total production,[42] in 1967, 343 producers were reported to have accounted for 40 per cent of all output[43] The elastic demand curve would have served as insurance to individual innovators that prices and profits would not be eroded from increased production brought about by the diffusion of their innovations Also, because the industry was one of a few large farmers, it is more probable that a single individual or small group could have anticipated large enough rewards from search and research efforts to justify undertaking them

A third and final factor to be considered in the specification of the shift parameter is the yield change which might have been brought about through the introduction by unorganized research efforts of varieties different from those observed to have been in use This yield change can be expressed as

$$\sum_{n+1}^{m} \left(\frac{R_{di} - R_a}{R_t} \right) P_{3i}, \qquad (4)$$

where P_{3i} denotes the adoption rate of the ith improved variety not currently in use, all other variables are defined as above This factor, like (3), would be subtracted from (2) in the complete specification of the shift parameter (k) in any given year, i e ,

$$k = \sum_{1}^{n} \left(\frac{R_{di} - R_a}{R_t} \right) (P_{1i} - P_{2i}) - \sum_{n+1}^{m} \left(\frac{R_{di} - R_a}{R_t} \right) P_{3i} \qquad (5)$$

42/ Idem, The Cotton Industry of Colombia, p 9

43/ U S Department of Agriculture, Economic Research Service, Agricultural Production and Trade of Colombia, ERS-Foreign 343, 1973, p 31 It is interesting to note that, at prevailing average yields, this would have implied that each large cotton producer was harvesting about 550 acres, given total production for Colombia of 465,000 bales in 1967 The data for 1958 imply that each of the 422 farmers was harvesting in that year only about 200 acres of cotton, suggesting that large cotton producers were major contributors to the increase in production which occurred between 1958 and 1967

It was assumed that the last element considered, (4), would be so small that it could be neglected This was equivalent to assuming that the organized research efforts of IFA and ICA left no stones unturned that would have been by the less organized, independent efforts of individual farmers

Note that what is then left in (5), namely,

$$k = \sum^{n}\left(\frac{R_{di} - R_a}{R_t}\right) \quad (P_{1i} - P_{2i}) \qquad (5')$$

could be zero valued in either of two circumstances (a) if $(R_{di} - R_a)$ were negatively correlated with $(P_{1i} - P_{2i})$ or (b) if R_{di} were equal for all varieties (although greater than R_a) since Sum $(P_{1i} - P_{2i}) = 0$ by definition

The first of these two possibilities requires that farmers undertaking research independently would have been more effective in securing the adoption of the higher yielding, improved varieties than IFA and ICA That, in turn, would require that farmers would have been more effective at identifying new varieties, importing them into the country, testing them, multiplying the most promising types, and releasing them to fellow farmers Both organizations of research might have been equally fast testers of new imported varieties But is has already been assumed that IFA and ICA were as efficient at identifying new varieties as individual farmers would have been Further, because of their "official" status, the two institutes probably were able to import new varieties more easily and rapidly into Colombia, likewise, they were able to exercise absolute control over the distribution of improved seeds 44/ Thus, it seems unlikely that a farmer-based research effort would have outperformed IFA and ICA and that the shift parameter in (5') have been zero valued in any year as a result of a negative correlation between $(R_{di} - R_a)$ and $(P_{1i} - P_{2i})$ 45/

44/ IFA controlled all cotton gins

45/ Note, however, that one of the implications is that it was the special privileges and franchises IFA and ICA possessed as official government agencies--not "pure differences" in the organization of research--which lead to this conclusion

That the shift parameter in (5') might also be zero valued if yields of improved varieties were equal can be understood intuitively in the following terms IFA's and ICA's programs were founded on a premise that yield differences existed among improved U S cotton varieties when cultivated in Colombia A claim was made that it would be worthwhile to identify the value of these differences and key programs of seed multiplication and distribution on them in order to increase any positive correlation between $(R_{di} - R_s)$ and $(P_{1i} - P_{2i})$ in (5') If, on the other hand, yields of all U S varieties harvested in Colombia were equal, then there would be no payoff to a program of varietal selection and distribution Any farmer individually could import a variety of U S cotton selected at random and hope to obtain as good results as he would have obtained through an organized program of research like IFA's and ICA's 46/

In order to explore this possibility more carefully, all available data were obtained on the IFA and ICA commercial trials which were comparable in design to those earlier reported for rice The trials covered the period 1953-1972 and included 523 individual experiments They are summarized in Table 7 which presents mean values of yields obtained for each of 10 cotton varieties Additional trial data were destroyed when IFA's research was absorbed by ICA Presumably they included information on the two check varieties, Deltapine 12 and Expresso do Brazil

It is evident from the data of Table 7 that gross differences in yields are not appreciable and that it would be difficult to reject the hypothesis that they were all, in fact, equal For this reason a more refined test was made by estimating production functions from the trial data In the final round of estimates, 23 variables

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46/ There is another instance in which the IFA and ICA type of program would not pay, namely, when the distribution of yields by variety is the same in the United States and Colombia

TABLE 7

Colombia Average Yields of Seed Cotton by Variety Obtained from Commercial Trials Conducted in the 1953-1972 Period

Variety	Number of observations	Yield
		kilos per hectare
Deltapine 15	193	2,312
Deltapine Smoothleaf	71	2,369
Stardel	18	2,296
Stonville 213	39	2,375
Coker 124 B	12	2,634
Acala BR-2	48	2,287
Deltapine 45	9	2,693
Deltapine 45 A	40	2,575
Deltapine 16	42	2,457
Coker 201	27	2,568
Total/average a/	523	2,366

a/ Excludes 24 trials on other varieties

Source Andrés Rocha, "Evaluación Economica de la Investigacion sobre Variedades Mejoradas de Algodon en Colombia" (unpublished M S thesis, ICA/National University Graduate School, Bogota, 1972), Table 10

TABLE 8

Colombia Production Function Estimates for Cotton Based on Commercial Trial Data, 1953-1972

Independent variable	Estimated coefficient	Estimated standard error of coefficient
1 Nitrogen	2 58	0 53
2 Irrigation	606 56	48 71
3 Parcel type	-471 41	61 41
4 Rain deficiency	-1,150 22	47 60
5 Stardel	-241,43	89 09
6 Coker 124 B	-214 75	109 08
7 Alcala BR-2	-331 64	59 23
8 Location 1	381 53	88 86
9 Location 2	189 13	80 78
10 Location 3	600 73	94 34
11 Location 4	1,094 14	149 39
12 Location 5	349 18	91 05
13 Location 6	-649 88	116 08
14 Location 7	-408 99	181 04
15 Location 8	991 48	71 77
16 Location 9	408 49	62 74
17 Location 10	1,167 86	77 85
18 1953	-218 53	106 79
19 1954	-268 37	81 12
20 1967	-428 55	156 78
21 1970	363 15	61 72
22 1971	366 96	70 66
23 1972	452 88	75 20
Intercept	2,081 20	Unavailable
	R^2 = 0 82	n=523

Source Andres Rocha,"Evaluacion Economica de la Investigacion sobre Variedades Mejoradas de Algodon en Colombia"(unpublished M S Thesis,ICA/National University Graduate School, Bogota, 1972),Table 3 entered the regression, their estimated coefficients and related statistics are shown in Table 8 The first variable measures the quantity of nitrogen applied per hectare, the second indicates simply whether or not irrigation was applied, the third adjusts for the fact that some of the trials were undertaken on plots which were "small" by pruebas regionales standards, the fourth is an index used by attending agronomists for the lack of rainfall, variables 9 through 17 adjust for the location of the experiments, and 18 through 23 adjust results for abnormal years

Regression results indicated that only 3 varieties out of the 10 tested yields significantly different from Deltapine 15 were--Stardel, Coker 124B, and Alcala BR-2, in each case their adjusted yields were lower than those for Deltapine 15 and lower by rather similar and "small" amounts On the basis of these results, it is concluded that no significant, positive benefits were derived from the Colombian cotton research programs 47/

WHEAT 48/

In an earlier study of production trends of Colombia's major crops, it was claimed that "the wheat situation in Colombia contains a number of paradoxes Despite good experimental development and government programs to expand production, both acreage and output have declined sharply in recent years"49/ Other more refined data now

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47/This is not to deny the role of improved U S varieties in increasing Colombian cotton yields There are several references to their importance in the available literature One of the strongest is International Bank for Reconstruction and Development, The Agricultural Development of Colombia (Washington,D C ,1956),p 86 " it is the policy and program of the Cotton Institute to provide the full seed requirements for the entire cotton crop annually Largely as a result thereof, the average yield per hectare of the cotton crop has doubled in four years "

48/ This section is based on the research of Carlos Trujillo, "Evaluación Economica de la Investigacion en Trigo" (unpublished M S Thesis,ICA/National University Graduate School, Bogota, 1974)

49/ U S Department of Agriculture, Changes in Agricultural Production , p 12 available--developed, in part, on the premise that the answers to some of the paradoxes might be the result of data errors--continue to show that both acreage and production have declined over the past 20 years The area cultivated in wheat fell steadily from 175,000 hectares in 1953 to about 70,000 hectares in 1973, over the same period production was halved Yields increased by about 25 per cent in the 1953-1958 period but stabilized at just above 1,000 kilos per hectare until 1972 In the most recent two years for which information is available (1972 and 1973), yields may have again increased-- by about 20 per cent 50/ Still, the average yield increase over the whole 20-year period has been rather unimpressive

The best explanation currently available for the fall in acreage planted is that increasing P L 480 sales have served to dampen incentives of Colombian farmers to either maintain or increase farmland devoted to wheat production 51/ The quantity of wheat imported has increased over the 1953-1973 period from a third to almost three times the quantity of total wheat production 52/ The modest rise in yields may be attributable to the same forces and a shift in the regional distribution of wheat production from the higher-than-average-yield State of Boyaca to the State of Nariño in Southern Colombia where farms are small and poor and yields have traditionally stood below the national average (Our impression is that production possibilities are limited in Nariño., In the Espiga de Oro maximum wheat yield trials, for

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50/ Data on production, land area planted, and yields of wheat prior to 1971 are from Roger Sandilands, Algunos problemas en la selección de datos estadísticos para trigo, cebada y papa, Informe Tecnico No 14, ICA (Bogota, 1974) Data for 1971-1973 are from the National Department of Statistics, DANE, Bogota

51/ Many of the important issues involved are discussed by Leonard Dudley and Roger J Sandilands, "The Side-Effects of Foreign Aid The Case of P L 480 Wheat in Colombia", National Department of Planning (Bogota, 1972, mimeo)

52/ The wheat import data are from the Food and Agriculture Organization of the United Nations, Trade Yearbook, various issues example, sponsored by the Agricultural Credit Bank in 1967, the average yields reported by the 10 best wheat farmers in Boyaca and Cundinamarca were about 10 per cent higher than yields obtained by the best farmers in Nariño)53/

The wheat improvement program is one of Colombia's oldest, dating from 1926 with the establishment of the La Picota experiment station in central Colombia (State of Cundinamarca) for the purposes of improving yields and other characteristics of wheat, barley, oats, and rye Through 1951, at least half of the total costs of the activities of La Picota were absorbed by wheat In 1947, "cold climate" wheat research expanded out from La Picota to two more locations-- one at Bonza in Boyaca and another at Isla in Cundinamarca A few years later, additional locations for research were acquired at Tabaitata (Cundinmarca) and Obonuco (Nariño) Following the addition of the Surbatá Station in Boyaca in 1959 for cold climate wheat research, activities were consolidated there, in Tibaitata, and in Obonuco--in just three locations

Colombia's wheat research has received important assistance from a number of different foreign and national organizations In 1948, program personnel were sent to Mexico to study methods of wheat breeding with staff of the OSS in Mexico City, then supported by the Rockefeller Foundation Later, in 1950, Rockefeller personnel were assigned to collaborate with the Colombian research program, the Foundation's assistance continued until the mid-1960's In 1953, wheat seed distribution and multiplication programs received a lift from the Colombian Agricultural Credit Bank which ultimately assumed responsibility for them In 1955, the National Federation of Rice Growers provided some support for research on the potential for wheat production in the warmer tropical areas traditionally destined to rice production, similar support was received in the same year from INA, the National Marketing Institute PROCEBADA, a federation of barley producers, contributed to the budget of the wheat program in the 1959-1961 period for purposes of supporting an expansion of the pruebas regionales

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53/ Trujillo, op cit , Table C 5

effort, support was received for the same purpose from FENALCE, a federation of Colombian cereal producers In the 1967-1971 period, the wheat program benefited from inputs provided by personnel of the University of Nebraska Mission, financed by a consortium of international assistance agencies, including USAID and major U S foundations

Data compiled on the costs of the wheat improvement program reflect these injections of complementary support from outside and provide a profile of the development of the program Table 9 presents data on the direct, complementary, and indirect costs of the program--comparable in all respects with the cost data earlier shown for the rice improvement program-- plus data on the additional cost to farmers of the improved wheat seeds which were adopted after 1952 It is seen that, beginning in 1927, total costs built up slowly to a level by 1935 which was subsequently maintained for about 15 years Following establishment of the joint Colombian-Rockefeller Foundation program, direct, complementary, and indirect costs again built up to a level which was maintained until 1964 with the exception of three years--1959, 1963, and 1964, the latter two of which were years of reorganization of the research agency Investments began to drift upwards after 1964 and then increased sharply during the period of the University of Nebraska Mission's presence, falling off after the Mission began to leave Colombia in 1971 From 1968 through 1971, total costs of the program represented only 5 per cent of ICA's research budget but fully 3 per cent of the value of wheat production In these latter terms, wheat research had become an expensive program

Activities of the research program revolved around four kinds of wheat (1) cold climate, (2) warm climate, (3) Triticales, and (4) Durums By all odds, the first has been the most important in terms of the time and the resources that have been devoted to it

When the research program began in 1927, some promising cold climate wheats were introduced from the United States and tested over a six-year period, resulting in the release of 15 to farmers from the La Picota experiment station in 1933 By the early

TABLE 9

Colombia Cost of the Wheat Research Program by Major Category 1927-1973

Year	Costs				Total costs
	Direct a/	Complementary b/	Indirect c/	Added costs of new seeds d/	
	1,000 (1972) pesos				
1927	184	e/	9		193
1928	236		9		245
1929	287		11		298
1930	338		12		350
1931	389		15		404
1932	441		17		458
1933	492		48		540
1934	543		52		595
1935	598		58		656
1936	653		63		716
1937	708		69		777
1938	709		78		787
1939	709		108		817
1940	710		120		830
1941	711		135		846
1942	670		143		813
1943	630		156		786
1944	589		170		759
1945	548		189		737
1946	508		207		715
1947	467		239		706
1948	416		255		671
1949	365		279		644
1950	315		351		666
1951	403		394		797
1952	492	88	440		1,020
1953	580	117	315	655	1,667
1954	609	74	349	2,638	3,730

(Continued on next page)

TABLE 9--continued

Year	Costs				
	Direct a/	Complementary b/	Indirect c/	Added costs of new seeds d/	Total costs
	1,000 (1972) pesos				
1955	758	93	385	242	1,478
1956	1,169	238	511	1,680	3,598
1957	1,117	232	562	282	2,193
1958	996	271	584	1,058	2,909
1959	841	265	483	1,170	2,759
1960	1,202	319	500	2,182	4,203
1961	914	388	510	3,002	4,814
1962	828	277	396	2,599	4,100
1963	615	280	280	2,717	3,892
1964	1,229	487	1,146	2,628	5,490
1965	1,889	658	585	5,548	8,680
1966	2,427	592	957	4,129	8,105
1967	2,150	993	2,307	8,731	14,181
1968	2,919	915	1,261	7,050	12,145
1969	3,045	1,314	2,768	5,623	12,750
1970	2,352	1,446	3,106	3,343	10,247
1971	2,020	1,603	3,260	2,901	9,784
1972	1,501	1,467	2,407	1,507	6,882
1973	1,570	1,385	2,354	1,626	6,935

a/ Salaries, supplies, and office materials directly related to the wheat varietal improvement program

b/ Represents costs of the plant pathology, soils, entomology, biometrics, extension, and plant physiology programs incurred on behalf of the wheat improvement program

c/ Includes costs associated with the use of experiment station facilities, agricultural machinery, and land as well as costs of administration and training of program staff

d/ Equals the difference between the average price of certified wheat seeds and the price received by farmers times the quantity sold of certified seeds, for the period 1927-1949, improved varieties relevant to this study were not planted

e/ These costs were included in direct costs (1927-1951)

Source Carlos Trujillo, "Rendimiento Economico de la Investigacion en Trigo" (Unpublished M S Thesis, ICA/National University Graduate School, Bogota, 1974), Tables 4 1, 4 2, 4 3, 4 4, and 4 5

1940's, the number had increased to 24 The best seven of these included Klein, General San Martin, Klein 40, Marzuolo, Pentad, Florence, Barcino Barbado, and Bola Picota Because the latter two were in most widespread use by the mid-1940's, they are considered as check varieties in this analysis. The first reference to their yields indicated that between 850 and 1,500 kilos per hectare could be expected from them, while the other five of the best seven available varieties could be reasonably expected to produce 1,800 to 2,800 kilos per hectare under experimental conditions 54/

The vast majority of promising wheats were obtained by crossing local criolla varieties This led to a conclusion in the early 1940's that available foreign varieties were inferior to local Colombian wheats and resulted in the program's turning inwards until the arrival of foreign personnel in the early 1950's When, with Rockefeller Foundation support, the OSS was established in Colombia, 11,000 varieties were immediately imported from the Rockefeller Mexican program Selections were made from these imports primarily on the basis of their resistance to the yellow, black stem, and leaf rusts These rusts had become the major preoccupation of the Colombian wheat improvement team as a result of data produced in 1949 which showed that wheat yields were being cut 6 per cent by leaf and stem rusts and by 14 to 41 per cent as a result of yellow rust 55/

The first commercial release of a new wheat variety after the establishment of the joint Colombian-Rockefeller Foundation program was of Menkemen 52 Distributed in 1953, it was the product of crossing varieties from the Mexican collection, including

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54/ Estación Agrícola Experimental La Picota, Informe de labores de la sección experimental e industrial realizadas en 1936 (Bogota, 1937), also, ibid , 1941 (Bogotá,1942)

55/ Estación Francisco José de Caldas, Influencia de las royas sobre el rendimiento del trigo, Proyecto I-SF-1949 (Bogota, 1951)

Mentana and Kenya It reduced time to maturity by 35 days, was somewhat resistant to the major rusts, had strong stems, and outyielded Bola Picota by 30 per cent. Two years later a second variety, Bonza 55, was released It was the product of two Rocamex varieties, Yaqui and Kentana. Because it was especially resistant to yellow rust of Nariño State, it was most widely distributed there A third variety, Nariño 59, was released in 1959, again, it was particularly well-adapted to the State of Nariño, being resistant to its variety of yellow rust Three years later (1962), several new varieties produced by the joint Colombian-Rockefeller Foundation program were released, including Miramar 63, Bonza 63, Crespo 63, Napo 63, Tiba 63, and Tota 63 At the time this release was made, the industry was advised that the research program would attempt to make "batch releases" (i e , releases of more than one variety) in the future in order to reduce susceptibility to new wheat rusts Millers are reported to have reacted adversely to this announcement on the grounds that a single mill could not handle more than two varieties of wheat, an appeal was made to the research team to revise its strategy As it turns out, the wheat program for cold climates made only one more additional release anyway, in 1968, Sumamuxi 68, Zipa 68, and Samacá 68 were distributed simultaneously.

The Colombian wheat plant began to change as the result of the introduction of dwarf varieties from Mexico in 1958 The effort to incorporate the smaller plant type characteristics did not, however, gain force and importance until about 1964 By 1970, 60 per cent of all materials in the Colombian wheat research program included dwarf wheats Of the 13 improved varieties released to farmers after establishment of the joint Colombian-Rockefeller Foundation program, small plant characteristics were incorporated in 9 varieties, Bonza 63, Miramar 63 and 64, Napo 63, Tiba 63, Tota 63, and the 3 varieties released in 1968 In this regard it is important to mention that practically none of Colombia's wheat is irrigated and that fertilizer use is negligible

In 1971, ICA published the data shown in Table 10 comparing yields obtained under experimental conditions on small plots of lands for 12 improved varieties and Bola Picota The reported yield advantage relative to the Bola Picota variety was in excess of 500 per cent for the highest yielding wheats but not less than 250 per cent for any improved variety. By international standards, these yields of the Colombian varieties also appeared to be quite good Referring to Table 11 and data published on the results of the International Wheat Trials of 1968, three of Colombia's most recently released wheats outyielded the best of the Mexican wheats, Azteca 67 The average level of these yields, however, is extremely high even by experiment station standards in Colombia (e g , those reflected in Table 10)

With reference to the second category of wheat research, namely, that undertaken on "warm climate" varieties, it is worth mentioning that large areas of wheat had existed in the clima cálido or warmer climates since the Colonial Period However, these wheat areas were practically eliminated in the mid-1930's as a result of attacks by stem rust Thus, in 1955 when the first rust-resistant varieties were available, the Federation of Rice Growers persuaded the research agency to experiment with Bonza and Menkemen in the Cauca Valley and Tolima State Although the rust resistance of the new wheats was confirmed in these early experiments, they were not continued because of the unpromising levels of wheat yields obtained It was felt at the time that, in order for wheat to compete with rice, 2,500 to 3,000 kilos of wheat per hectare would be required Commercial yields averaged 1,500 kilos, and maximum experimental yields did not exceed 2,750 kilos per hectare 56/

56/ Mario Zapata, "Informe General del Programa de Trigo en Clima Cálido," (Bogota, 1969, mimeo)

TABLE 10

Colombia Comparative Wheat Yields for 13 Varieties Obtained Under Experimental Conditions, 1970

Variety	Area planted	Reported yields	Reported yields compared with Bola Picota yield
	hectares	kilos per hectare	percent
Menkemen 52	0 095	2,820	427
Bonza 55	0 123	2,360	358
Nariño 59	0 106	1,700	258
Bonza 63	0 153	2,220	336
Miramar 64	0 101	2,535	384
Crespo 63	0 163	1,570	238
Napo 63	0 274	2,770	420
Tiba 63	3 740	3,017	457
Tota 63	0 200	2,680	406
Zipa 68	0 134	3,000	455
Samacá 68	0 050	3,700	561
Sugamuxi 68	0 223	2,300	348
Bola Picota	0 132	660	100

Source Colombian Agricultural Institute (ICA), _Informe del Programa Nacional de Trigo_ (Bogotá, 1970), Appendix 4

TABLE 11

Colombia Comparative Wheat Yields Obtained for Colombian and Mexican Varieties in the International Nursery Trials,1968

Variety	Country of origin	Reported yields kilos per hectare
Sugamuxi 68	Colombia	6,232
Crespo 63	Colombia	6,215
Samacá 68	Colombia	6,217
Azteca 67	Mexico	6,110
Tota 63	Colombia	6,054
Napo 63	Colombia	6,044
Tiba 63	Colombia	5,894
Penjamo 62	Mexico	5,833
Centrifén	Chile	5,755
Norteño	Mexico	5,538
Lerma Rojo 64 x Sonora 64	Mexico	5,349
Sonora 64 x TZ PP Nai 60 (B)	Mexico	5,249
Bonza 63	Colombia	5,233
Jaral	Mexico	5,166
Zipa 68	Colombia	5,166

Source Colombian Agricultural Institute (ICA), Informe del Programa Nacional de Trigo (Bogota, 1968), p 13

The wheat program first experimented with rye as a rust-resistant, high-protein, water-saving alternative to wheat in 1937, and experiments with triticales were initiated in La Picota in 1946 Interest in triticales appears to have languished until very recently (1970) The wheat program has also evidenced interest through time in the Durum wheats Work actually began on Durum in 1952 and was stepped up somewhat in the mid-1960's However, successes have not been reported primarily because of the high humidity which prevails in Colombia's wheat areas, the short daylength, and the sometimes heavy rainfalls which occur when the grains are maturing

Again, as in the cases of rice and cotton, available data on the pruebas regionales were collected in an attempt to quantify the shift parameter and gross social benefits attributable to the Colombian wheat research program The collection of these data was much more difficult in the case of wheat, however, because the information had been scattered by changes in the affiliation of the research program with outside agencies In the final analysis, results of only 1,016 individual trials were obtained for the 1953-1973 period, many more were undertaken on the major improved varieties

Most of the results obtained (about 80 per cent) related to six varieties Bonza 63, Crespo 63, Menkemen 52, Napo 63, Nariño 59, and Tota 63 By region, the bulk of the data related to two states, Cundinamarca and Nariño Only about 5 per cent are from the State of Boyaca The Director of the National Wheat Program has stated that this does not reflect any slighting of the Boyaca wheat regions because there are many in Cundinamarca and Nariño which are fully representative of the areas in Boyaca Given that wheat production in Boyaca has declined most sharply, the facts here are important, although difficult to establish and qualify Finally, it should be noted that most of the pruebas regionales data obtained (70 per cent) were for five years including 1963, 1964, 1968, 1971, and 1972

Table 12 summarizes the data collected for 13 improved wheat varieties and 2 check varieties, Bola Picota and "150 " Mean yields in kilos per hectare are reported by variety, together with the estimated standard error of yields, the range of trial yields corresponding to a 5 per cent level of probability, and the coefficient of variation of yields When compared with the data of Table 10, it can be seen that these data assign rather different relative yield ranks to specific varieties For example, in Table 12 the yield Menkemen 52 puts it in twelfth place among the improved varieties, while its yield in Table 10 ranks it in third place Also, the average level of yields reported in Table 12 is lower than the averages of Tables 10 and 11, and the yield advantage of the improved varieties is noticeably less than indicated by Table 11

The range in yields of most improved varieties in Table 12 includes the upper bound yields reported for Bola Picota and "150" The only exceptions to this are the Samacá 68 and Bonza 63 improved varieties, lower bound yields for which are well above the upper bound yields of the two check varieties, indicating a significant yield advantage The yield advantages of Samacá 68 and Bonza 63, as a percentage of the average yields of "150" and Bola Picota, are 83 and 75 per cent, respectively, the corresponding value for all improved varieties shown in Table 12 is 50 per cent

In order to adjust these estimates of the gross yield advantage of the improved wheat varieties for the effects of other determinants of yields, production functions were estimated from the commercial trials data. The final version of the production function is shown in Table 13 Thirty-nine variables entered 12 represented zero-one adjustment variables for the location of the trials, 14 adjusted for the effects of variety, 4, measured as indices above a certain threshold level and zero otherwise, accounted for major diseases reported (vaneamiento, foot and root rot, stem rust, and dwarfing virus), 1 adjusted for seeding rates of 80 kilos per hectare (only two rates were actually reported--80 and 111 kilos per hectare), 2 each were used to adjust for soil type and reported weather, and 1 variable each adjusted for how well the soil had been worked prior to planting, for weed growth, and for the application of lime Coefficients on the noncontinuous variables shown in Table 13 need to be read with some

TABLE 12

Colombia Comparative Wheat Yields for 15 Varieties Obtained in Commercial Trials 1953-1973

Variety	Number of observations	Output per hectare: Mean	Standard error	Range at 5 percent probability: Lower bound	Upper bound	Coefficient of variation of yields
		kilos				percent
"150"	8	1,624	1,022	771	2,476	62 9
Bola Picota	8	1,194	895	448	1,941	74 9
Samacá 68	47	2,584	1,592	2,117	3,051	61 6
Bonza 63	106	2,460	1,197	2,230	2,690	48 7
Miramar 63	29	2,348	1,218	1,885	2,812	51 9
Zipa 68	31	2,190	1,382	1,684	2,697	63 1
Bonza 55	77	2,172	1,504	1,831	2,513	69 2
Crespo 63	129	2,115	1,369	1,876	2,353	64 7
Tiba 63	51	2,110	1,265	1,754	2,466	59 9
Nariño 59	119	2,106	1,351	1,861	2,352	64 1
Napo 63	136	2,097	1,340	1,869	2,324	63 9
Sugamuxi 68	12	1,973	1,157	1,238	2,708	58 7
Tota 63	104	1,893	1,283	1,643	2,142	67 8
Menkemen 52	138	1,836	1,237	1,627	2,044	67 4
Miramar 64	21	1,643	1,496	960	2,326	91 1
All varieties	1,016	2,099	1,340	2,027	2,175	66 1

Source Carlos Trujillo, "Rendimiento Economico de la Investigacion en Trigo" (unpublished M S thesis, ICA/National University Graduate School, Bogota, 1974), Table 5 7 care Since the regression package reparameterized all variables by imposing a restriction that the sum of the regression coefficients equal zero, an estimate of the corrected mean yield associated with a given noncontinuous variable should be calculated by adding its estimated coefficient to the overall mean value of yields, which was 2,099 kilos per hectare

The statistical significance of the variety variables entering the regression was surprisingly low Only the estimated coefficients on the Bonza 63 and Crespo 63 varieties were very positive and significant In an independent estimate made of the partial contribution of the variety variables as a group to the explanation of the variance of yields, their significance was found to be less than that of any other single variable or group of variables (e g , the variables adjusting for location)

Also, the values of the estimated yield advantages of most of the improved varieties are lower on the basis of the regression of Table 13 than on the basis of the unadjusted estimated of mean yields earlier presented in Table 12 The largest and most significant yield advantage of any improved variety in the regression--that of Bonza 63-- is only 36 per cent more than the adjusted yield of Bola Picota, or roughly half the value implied by the unadjusted yield estimates of Table 12

Table 14 presents summary statistics on the use of the improved varieties of wheat Underlying these summaries are data for each improved variety used in weighting shift parameters taken from the estimated production function to arrive at an average annual estimate of the percentage yield increase over average commercial yields attributable to improved wheats Two estimates of these weights were considered, and their implications for overall rates of adoption are reflected in Table 14 in the "upper bound value" and the "most probable value" of the per cent of wheatland planted to improved varieties The first simply assumed that the total use of an improved variety in any year equaled two times its reported sales in certified form and that the average seeding rate was 120 kilos per hectare for all varieties As can be seen in the table, this assumption results in levels of adoption in the late 1960's which are

TABLE 13

Colombia Production Function Estimates for
Wheat Based on Commercial Trials

Independent variable	Estimated coefficient	Estimated t statistic
1. Vaneamieanto	- 13 8	- 6 98
2 Foot Rot	- 11 1	- 5 75
3 Stem Rust	- 8 6	- 3 18
4 Dwarfing Virus	- 15 8	- 3 73
5 Plot Size	- 48 5	- 5 88
6 Seeding rate	- 225 0	- 3 69
7 Good soils	482 7	8 10
8 Poor soils	- 340 2	- 4 31
9 Poor prior soil preparation	- 157 1	- 2 68
10 Heavy weed growth	- 300 6	- 6 79
11 Unfavorable weather	-1,333 9	- 10 20
12 Favorable weather	895 4	8 43
13 Lime applied	154 1	2 35
14 Location 1	- 732 0	- 3 21
15 Location 2	3,672 8	16 40
16 Location 3	692 4	7 37
17 Location 4	1,604 9	9 24
18 Location 5	- 466 9	- 2 29
19 Location 6	-1,084 6	- 4 44
20 Location 8	- 349 1	- 3 12
21 Location 9	- 644 9	- 5 38

(Continued on next page)

TABLE 13--continued

Independent variable	Estimated coefficient	Estimated t statistic
22 Location 10	- 831 1	- 6 60
23 Location 11	- 812 2	- 1 94
24 Location 12	- 856 6	- 3 05
25 Location 13	49 1	0 56
26 Menkemen 62	- 113 2	- 1 20
27 Bonza 55	98 8	0 89
28 Nariño 59	163 8	1 70
29 Miramar 63	- 375 5	- 2 17
30 Bonza 63	340 5	3 27
31 Miramar 64	- 300 3	- 1 46
32 Crespo 63	210 9	2 12
33 Napo 63	131 7	1 44
34 Tiba 63	- 169 2	- 1 28
35 Tota 63	- 80 7	- 0 77
36 Zipa 68	- 152 8	- 0 92
37 Samacá 68	196 9	1 22
38 Sugamuxi 68	210 3	0 80
39 Bola Picota	- 303 5	- 0 91
Intercept	2,460 8	15 73
	R^2 = 0 53	n= 1 016

Source Carlos Trujillo, "Rendimiento Economico de la Investigación en Trigo" (unpublished M S thesis, ICA/National University Graduate School, Bogota, 1974), Table 5 14

TABLE 14

Colombia Selected Data on Employment of
Improved Wheat Varieties, 1953-1973

Year	Total certified seed sales	Wheat land in improved varieties	
		Upper bound value	Most probable value
	tons	percent	
1953	147	1 4	0 9
1954	1,039	8 9	5 6
1955	113	0 9	0 5
1956	639	5 2	3 3
1957	599	5 5	3 4
1958	1,610	22 0	13 7
1959	3,050	43 4	27 1
1960	2,149	28 7	17 9
1961	2,830	33 7	21 1
1962	2,470	31 7	19 8
1963	2,100	31.8	19 9
1964	1,864	27 0	16 9
1965	2,782	38 6	24 1
1966	3,113	45 0	28 1
1967	3,795	66 6	41 6
1968	4,494	83 2	52 0
1969	2,809	72 0	44 6
1970	1,694	56 5	35 1
1971	1,641	56 9	35 3
1972	1,528	40 4	25 3
1973	1,429	33 0	20 5

Source Carlos Trujillo, "Rendimiento Economico de la Investigacion en Trigo" (unpublished M S thesis, ICA/National University Graduate School, Bogota, 1974), Tables B 3, 5 17, and 2 10 high by known standards for unirrigated wheat The second estimate--and the one used in this study--maintained the assumptions that the total seed use of any variety would equal two times its certified sales and that seeding rates averaged 120 kilos per hectare, but set the germination rate of certified seeds at 86 per cent and the corresponding rate for seeds retained and planted by farmers from prior harvests at 39 per cent These low rates of germination, based on several ICA studies,[57/] were not encountered for either rice, cotton, or soybeans Since the sum of the two germination rates is 125 per cent, the effect of this procedure was to assume that the real, post-germination rate of employment of an improved variety was 1 25 times the quantity of it sold in certified form

Estimates of the yield advantage of each improved variety taken from the regression, divided by average commercial yields in each year and weighted by the appropriate adoption rate, produced two streams of gross benefits for the 1953-1973 period of the Colombian wheat improvement program In each case it was assumed that the c i f import price of wheat was the relevant "price" at which to value the crop[58/] However, in one of the estimates, it was assumed that the price elasticity of supply of wheat equaled 0.55 and that the price elasticity of demand was -0 04 These values of the price elasticity parameters were derived from estimates of two independent studies[59/] For the second estimate of gross benefits, it was recognized that wheat was imported throughout the 1953-1973 period and that the value of gross benefits should thereby not include a surplus to consumers

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57/ Trujillo, op cit , Table 2 10

58/ Because of the overvaluation of the Colombian peso, this assumption results in an underestimate of the gross benefits of research It was found, however, that the estimated internal rate of return to the wheat improvement program would increase by only 4 per cent if instead the (higher) price received for wheat by farmers was used

59/ The price elasticity of demand estimate is from ICA, Un método de proyectar la producción y demanda para productos agrícolas en Colombia, Boletín de Investigación No 15 (Bogota, 1971), the price elasticity of supply estimate is from Roger Sandilands and L Dudley,"The Side-Effects of Foreign Aid The Case of P L 480 Wheat in Colombia," National Department of Planning, Bogota, 1972 (mimeo)

The two estimates of gross benefits, as well as total costs earlier shown in Table 9, were then projected through 1976 on assumptions similar to those used in the case of rice The internal rate of return estimated for the "closed economy" case corresponding to the stream of new program benefits (gross benefits minust costs) for the 1927-1976 period was 11 9 per cent When allowance was made for the fact that wheat was imported, the estimated internal rate of return was reduced to 11 1 per cent

SOYBEANS 60/

Soybean production in Colombia has experienced very rapid growth in recent years The total area cultivated was only 16,000 hectares in 1962, production stood at 25,000 tons, and yields were 1,500 kilos per hectare in the same year By 1972, or just 10 years later, the area harvested had increased to 58,000 hectares, production was 116,000 tons, and yields had risen by a third to 2,000 kilos 61/ This rapid development is attributed to the fact that soybeans are excellent in rotation with several major crops (cotton, in particular) and that the demand for soybeans has been strengthened by a fast-growing poultry industry The crop is cultivated in Colombia only in the Cauca Valley, and its location there has been attributed to the nearness of the feed industry An equally important explanation, however, is that available high-yielding, disease-resistant soybean varieties produced by the ICA experiment station at Palmira have been adapted to conditions of the Cauca Valley

ICA did not initiate activities in soybean research until 1960, and the work was restricted to the Palmira station In about seven years, however, the research effort succedded in producing three new varieties with superior yield potential and resistance

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60/ Based on the research by Gabriel Montes, "Fvaluación de un Programa de Investigación Agrícola El Caso de la Soya" (unpublished M S thesis, Faculty of Economics, University of the Andes, Bogota, 1973)

61/ Ibid, Table 4

to major diseases, the principal one being cercóspora, a fungus which attacks and destroys almost all parts of the soybean plant Table 15 summarizes experimental data relating to yields of four soybean varieties obtained for this study Unfortunately, data generated from commercial fields or pruebas regionales were unavailable, thus, the information used in Table 15 and elsewhere in this section relates to small experimental plots of the Palmira station 62/ The ICA Pelican, Lili, and Taroa varieties were successive releases of the experiment station The Mandarin variety was imported earlier from the United States and by 1967 had come to occupy about four-fifths of all soybean acreage In terms of the data previously shown for cotton, rice, and wheat, the yield superiority of the improved varieties in Table 15 is not particularly outstanding

Nonetheless, adoption of the new varieties has been nothing short of spectacular Table 16 presents the percentages of soybean acreage planted to each of the four main varieties grown in the 1967-1971 period These data were estimated using a procedure analagous to the one followed for other crops included in this paper, i e , total acreage planted to a variety in a given year was taken equal to two times certified seed sales of that variety divided by an estimate of the seeding rate The important point to note about the data of Table 16 is that roughly three-quarters of the area planted in soybeans was in the Mandarin variety in 1968 and 1969, while by 1971--just two years later-- Mandarin had practically disappeared, and ICA Pelican and Lili varieties had come to be used on 84 per cent of all acreage

The major reasons for the rapid and high levels of adoption of the improved varieties were at least the following two First, there was a severe outbreak of the cercóspora fungus on the Mandarin variety in 1969 ICA found itself in 1970 in the enviable position of having two high-yielding, fungus-resistant varieties available

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62/ The use of experimental data is somewhat less troublesome in the case of soybeans because of the high level of technology and improved practices used by farmers in the Cauca Valley

TABLE 15

Colombia Average Soybean Yields From Lxperimental Trials by Variety 1967-1971

Year	Unimproved variety, Mandarin	Improved varieties		
		ICA-Pelican	ICA-Iili	ICA-Taroa
	kilos			
1967	2,068	2,406	a/	2,490
1968	2,329	2,373	2,700	2,650
1969	1,756	2,138	2,525	2,400
1970	1,751	2,373	2,300	2,500
1971	1,828	2,578	2,410	3,034
Average	1,946	2,455	2,483	2,622

a/ No experiment reported

Source Gabriel Montes, "Evaluación de un Programa de Investigación Agrícola, el Caso de la Soya" (unpublished M S thesis, Faculty of Economics, University of the Andes, Bogota, 1973), Table 3

TABLE 16

Colombia Land Area Planted to Improved Varieties of Soybeans as a Percentage of the Total Area Planted in Soybeans, 1967-1971[a/]

Year	Variety					Total
	Mandarin	ICA-Pelican	ICA-Lili	ICA-Taroa	Other	
	per cent					
1967 b/	89	1	c/		10	100
1968	77	13			10	100
1969	71	18	5		6	100
1970	35	29	24		12	100
1971	2	43	41	2	12	100

a/ Estimates derived from data on certified seed sales, assuming that the total use of a variety of seeds equaled two times its sales in certified form

b/ Only data on ICA-Pelican use were available The Mandarin estimate was derived on the assumption that "other" varieties occupied 10 per cent of all acreage planted in 1967 as they did in 1968

c/ Blanks indicate less than 0 5 per cent

Source Gabriel Montes, "Evaluación de un Programa de Investigación Agrícola El Caso de la Soya" (unpublished M S thesis, Faculty of Economics, University of the Andes, Bogota, 1973), Table 6 for distribution and plerty of seed Second, it was easy for this news to get around, the only Colombian farmers interested in soybean production are located in a relatively small geographic area with some of the best communication and infrastructure facilities that exist in the country The farmers themselves are among Colombia's most modern

As in the cases of cotton, rice, and wheat, an attempt was made to generate more refined estimates of the yield superiority of the new soybean varieties by means of the identification of a relation between yields and their major determinants, including seed variety Final results of this effort are shown in Table 17 reporting on a re - gression of experimental yields on three independent variables for the major improved seed varieties (observations on the check variety, Mandarin, were included in the re- gression, of course), the number of tiemes the experiment was weeded, kilos per hectare of active herbicide and insecticide ingredients applied, millimeters of rainfall, the presence of cercospora fungus measured as an index with a range of 0 to 5, and an index (likewise with a 0 to 5 range) which reflected essentially the ratio between the ob- served plant density and the seeding rate Sigrs of all estimated coefficients are those which were hypothesized at the outset, and the significance of most coefficients is seen to be high One exception, the estimated coefficient for rainfall, reflects the fact that rainfall variability was limited because most experiments were under - taken ina small geographic area The statistical strength of the plant density/seeding rate variable is attributable to the fact that it is capturing the effects of several unspecified cultural practices used in the experiments [63/] The fact that the coefficients on the improved varieties increase in value from Pelican (the first released) through Lili to Toran (most recently released) indicated substantial progression in ICA's re- search program A test of the null hypothesis that the estimated coefficient on the

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63/ This variable may thereby have adjusted to some extent estimated coefficients on the improved varieties for the experimental nature of the data-- the high levels of technology and intensive use of improved cultural practices

TABLE 17

Production Function Estimates for Soybeans
Based on Experimental Data
1967-1971

Independent variable	Estimated coefficient	Estimated t statistic
1 ICA-Pelican	268 44	3 06
2 ICA-Lili	418 31	3 93
3 ICA-Taroa	436 95	4 37
4 Number of weedings	86 93	2 43
5 Herbicide use	78 45	2 35
6 Rainfall	113 11	1 75
7 Cercospora	-107 30	-3 68
8 Plant density/Seeding rate	200 80	4 58
Intercept	692 08	a/
	R^2 = 0 70	n=68

a/ Unavailable

Source Gabriel Montes, "Evaluación de un Programa de Investigación Agrícola El Caso de la Soya" (unpublished M S Thesis, Faculty of Economics, University of the Andes, Bogota, 1973), Table 8

Pelican variety equaled that of the Lili variety was rejected at the 99 per cent level of significance Similarly, the hypothesis that the coefficients estimated for the Lili and Taroa varieties are equal was rejected at the 95 per cent level

The yield advantage of the improved varieties taken from the production function, divided by commercial yields and weighted by the percentages of the land area planted in each variety, led to a "varietal effect" estimate of the shift parameter The yield advantage of the improved varieties estimated directly from the data of Table 15, likewise divided by commercial yields and weighted by the percentages of the land area planted in each variety, led to a "simple" estimate of the shift parameter associated with the soybean research program These two estimates of the shift parameter were combined with plausible values for the price elasticities of demand and supply--respectively, -0 77 [64/] and infinity--to yield a range of gross benefits in each year for the 1967-1971 period These two streams of gross benefits are shown in Table 18 along with estimates of the costs of the soybean research program which include the same categories of expenses included in the cases of the other three commodities considered in this paper Costs and benefits were projected nine years beyond 1971 on the assumption that in real terms they would both remain about constant The resulting internal rate of return for the smaller benefit stream was 79 per cent, while the rate for the larger one was 96 per cent These rates did not change appreciably when program costs were assumed to increase 10 per cent per year after 1971

COMPARISONS AND CONCLUSIONS

At the outset we hypothesized that net internal rates of return to varietal improvement of rice, cotton, wheat, and soybeans in Colombia had been higher than the opportunity cost of public funds (10 per cent) and, in fact, higher than return rates of

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64/ The price elasticity of demand estimate was suggested by the results of James P Houck, "A Statistical Model of Demand for Soybeans," The Journal of Farm Economics, Vol 46, No 2 (May, 1964), pp 371 and 372 the order of 50 per cent calculated for similar programs in the United States Among the four programs, somewhat lower estimated returns were expected for wheat because its domestic price had been under pressure from P L 480 imports, and production had relocated in less productive areas of Colombian agriculture

To more carefully examine this latter possibility--as well as the roles of socioeconomic and structural constraints generally on the estimated returns to research--the total shift in product supplies caused by the use of improved varieties generated through research was divided into two parts an estimate of the "yield advantage" of the new over the old varieties and an estimate of the rate of adoption of the new varieties Low returns attributable to socioeconomic and structural constraints were then associated mainly with low rates of adoption, the role of the biological determinants of the return to research was associated principally with the calculated yield advantage of the improved varieties The yield advantage was estimated with regression techniques which were designed to factor out assumed positive interaction between the improved varieties and such inputs as fertilizers and water

Our main results are summarized in Table 19 Estimated net internal rates of return were found to exceed 50 per cent in the cases of soybeans and rice Returns calculated for the wheat improvement program turned out to be much lower-- in fact, well below the 50 per cent level, and gross returns to cotton research were found to have been negligible In all cases, the estimated yield advantage was smallest when interactions of the improved varieties with other variables were factored out

The very high rates of return estimated for soybean research were explained by a large shift in product supply caused principally by the rapid uptake of the new varieties and their virtual displacement of the unimproved Mandarin seed The calculated yield advantage of the new varieties was not spectacular The striking adoption of the improved soybeans was attributed to the strength of product demand, derived in the main from a fast-growing poultry industry, the geographic concentration

TABLE 18

Colombia Estimated Benefits and Costs of the Soybean Research Program, 1960-1980

Year	Gross benefits		Total costs
	Based on "varietal effect" shift parameters	Based on "simple" shift parameters	
	1,000 (1958 pesos)		
1960	a/		40
1961			41
1962			37
1963			39
1964			33
1965			37
1966			40
1967	49	62	57
1968	1,288	2,230	98
1969	3,102	6,187	179
1970	7,847	16,300	463
1971	10,217	28,643	267
1972-1980	10,217	28,643	267

a/ Blanks indicate no benefits during this period

Source Gabriel Montes, "Evaluación de un Programa de Investigación Agrícola El Caso de la Soya" (unpublished M S, thesis, Faculty of Economics, University of the Andes, Bogota, 1973), Tables 14 and 21 of production in a small area (the Cauca Valley) which facilitated the rapid diffusion of information concerning the improved varieties, the expected severity of the attacks by the cercospora virus to which the improved varieties were resistant, and the fact that soybean producers figure among Colombia's most modern farmers That soybean yields have been practically equal in Colombia and the United States in recent years (Table 19) reinforces our characterization of the industry as a modern one

The Colombian cotton industry has evidenced similar characteristics Yields of cotton in Colombia have not only equaled U S yields but even surpassed them in some recent years Adoption of the improved U S varieties of cotton was practically instantaneous as a result of the government's ownership of gins and control over seed distribution Yield increases since the early 1950's, when improved varieties came into widespread use, have been spectacular Still, in spite of these similarities with the case of soybeans, it was concluded that returns to the cotton research program had been negligible

This apparent contradiction was explained in terms of the organization of the research effort The Colombian textile industry, long accustomed to importing U S cotton, partly as a result of a preferential rate of exchange, was made "to buy Colombian" by a change in government policy Textile firms then sponsored establish - ment of research which would lead ultimately to the local production of U S varieties of cotton The final organization of the research program involved merely the importation, local testing, and the distribution to farmers of the highest yielding U S varieties This organization was justified on a premise that yields obtained locally from the U S cotton would vary by variety, thus, there would be a payoff to identifying those kinds of cotton which yielded best under local conditions

Our data did not sustain the premise, however Information compiled on about 500 commercial field trials undertaken in Colombia on over 10 varieties of improved U S cotton indicated that differences in yields by variety were minimal Thus,

TABLE 19

Colombia Selected Comparative Data on the Rice, Cotton, Wheat and Soybean Varietal Improvement Programs

Concept	Unit	Rice	Cotton	Wheat	Soybeans
1. Estimated net internal rates of return	per cent	60-82	0[a]	11-12	79-96
2 Estimated value of the supply shift parameter, 1971	per cent	10-16	[b]	16	17-35
3 Estimated yield advantage, 1971	per cent	25-39		46	17-36
4. Land area planted to improved varieties, 1971	per cent	41	100	35	98
5 Average yields, 1971 Colombia/United States	ratio	0 68	1 03[c]	0 53[c]	1 01[c]
6 Total research costs/ value production, 1968-1971	per cent	0 5	0.1	3 0	0 1

(Continued on next page)

TABLE 19--continued

a/ Since gross benefits were negligible, this net rate should be negative

b/ Blanks indicate no data available

c/ 1970-1972 average

Sources

1-4 Based on summary of previous tables in this study

5 For Colombia

Jorge Ardila, "Rentabilidad Social de las Inversiones en Investigación de Arroz en Colombia" (unpublished M S thesis, ICA/National University Graduate School, Bogota, 1973)

Gabriel Montes, "Evaluación de un Programa de Investigación Agrícola El Caso de la Soya" (unpublished M S thesis, Faculty of Economics, University of the Andes, Bogota, 1973)

Andres Rocha, "Evaluación Economica de la Investigacion sobre Variedades Mejoradas de Algodon en Colombia" (unpublished M S thesis, ICA/National University Graduate School, Bogota, 1972)

Carlos Trujillo, "Evaluación Económica de la Investigacion en Trigo" (unpublished M S thesis, ICA/National University Graduate School, Bogota, 1974)

For the United States

U S Department of Agriculture, Agricultural Statistics, 1973, p 441

6 Ardila, op cit , Montes, op cit , Rocha, op cit , and Trujillo, op cit

the main research activity--local testing of imported varieties-- appears to have not been necessary U S varieties could just as well have been selected at random for distribution in Colombia Therefore, even though the widespread use of U S cotton increased yields, resulting surpluses were not attributed as benefits to the cotton research program

As already mentioned earlier in this section, net internal rates of return found for the rice research program were high by any standard of comparison Yet, in light of the comparative data of Table 19, they are a puzzle Although the ranges of estimated rates of return for the rice and soybean program overlap, for example, we see that the range of the calculated supply shift parameter for rice is significantly lower than the corresponding range for soybeans, principally because of differences in the levels of adoption of the improved rice and soybean varieties Also, it can be observed that estimated rates of return to rice were much higher than those for wheat, even though the calculated values of their supply shift parameters were roughly comparable Why then were estimated net rates of return to the rice research program so very high?

An important answer lies with the cost side of the net rates of return calculations and with the organization of the rice improvement program We believe that the direct costs of rice research to Colombia were effectively reduced by the program's having tapped into the accumulated stock of plant breeding capital--general knowledge, improved breeding techniques, and plant materials--available in the two international centers, CIAT and IRRI, and in the World Collection of Rice Without that accumulated capital, the costs of achieving comparable shifts in the supply of rice would have been higher and the corresponding net rates of return would have been lower

This characteristic of the rice program was also found in the wheat research program In fact, wheat had a longer history of using the accumulated foreign stock of plant breeding capital than did rice Linkages with the Rockefeller Foundation-

Mexican program dated from around 1948, and additional collaborative support was provided the program during the late 1960's and early 1970's by the University of Nebraska Mission to Colombia Judged from a purely technical and biological point of view, these foreign inputs were associated with success as they were in the case of rice The estimated yield advantages of the improved wheat varieties were found to be large, even after the effects of variables which interacted with the new wheat varieties had been factored out If they were included, the improved wheats could be shown to outyield the unimproved varieties by more than 250 per cent' Also, in international nursery trials the Colombian wheats easily outyielded the Mexican wheats from which they were largely derived

Thus, the low estimated returns to the wheat research program were not the result of obvious technical failures in plant breeding Rather, part of the explanation for the low returns lies with patterns of on-farm adoption of the improved seeds The uptake of the new wheat varieties was notoriously slow From the time the first improved varieties of wheat were sold commercially in 1953 until they were in use on roughly one-quarter of all wheatland, fully 12 years elapsed Rates of adoption peaked at 50 per cent in 1968 and then began a downward trend Current (1974) levels of use of the improved varieties are estimated to barely include a fifth of all cropland planted to wheat The slow uptake of the new seeds and the low levels and distressing trends in their use were attributed primarily to socioeconomic and structural constraints on production, especially the depressed domestic market results from continued P L 480 imports at levels which represented a large multiple of national production

Two additional explanations for the low estimated rates of return to wheat research should also be stressed, however One is that it became a very expensive program in later life--in the middle and late 1960's Annual investments averaged fully 3 per cent of the total value of wheat production, a figure which was not even remotely approximated by investments made in the other three varietal improvement programs

(Table 19) A second explanation relates to the program's long gestation period The Colombian wheat program dates from 1927 Yet, our review of that history indicated that a well-organized research effort probably did not get underway until 1948, and the first improved varieties were not released on a major scale until 1953 Thus, investments (albeit at reduced levels) were being made for almost a quarter of a century before offsetting benefits were realized This affected adversely the calculated net rates of return for wheat research

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