ABSTRACT

AN ECONOMIC ANALYSIS OF CORN PRODUCTION IN THE CAUCA VALLEY, COLOMBIA

BY

Douglas Darwin Hedley

This study began as an attempt to understand the reasons for the wide differences between reported farm corn yields and experimental corn yields which has persisted in Colombia for two decades. It was later modified to emphasize the economic aspects of corn production and to relate economically optimum yields to reported yields.

Examination of published statistics from alternative sources yielded estimates of about one metric ton per hectare as the reported corn yield in Colombia. Only the Department of Valle del Cauca, with two tons per hectare, showed a persistently higher corn yield than the national average. However, a field survey conducted in the Cauca Valley in 1967 indicated that corn yields were about 3.5 to 4 tons per hectare in the Cauca Valley.

A study of the research efforts in corn in Colombia indicated that hybrid varieties and improved non-hybrid varieties of corn have been available to Colombian farmers since 1950 with yield potentials of about four tons in 1950 and as high as eight or nine tons per hectare by 1967.

Douglas Darwin Hedley

To understand the reasons for this discrepancy between reported and experimental yields, many inputs in corn production were catalogued and discussed. Using the data from a planting date experiment conducted at an experiment station near Palmira during 1963 and 1964, a quadratic production function was estimated using the ordinary least squares procedure. The variables nitrogen, plant density at harvest, rainfall, irrigation, sunlight and planting time were used to explain corn yields. Water use and sunlight were used to characterize particular planting periods during the year. To compare alternative planting dates, a profit function was constructed, from which economic optima could be found.

It was found that about 60 to 100 kilograms per hectare of nitrogen was adequate, and irrigation during the first 40 to 50 days after planting was optimal. Corn yields were found to be sensitive to sunlight. The only way to change the amount of sunlight was to vary the planting date since sunlight varied a great deal over both crop semesters. Using this knowledge, optimal planting dates were found to be early March and early April for the first crop semester and mid-September and mid-October for the second crop semester. Optimal plant densities appeared to be about 65,000 per hectare for early planting dates and 55,000 per hectare for late planting dates in both semesters.

The likelihood of increasing corn yields to nearer the economic optimum yields was discussed as well as the effect of increasing corn yields on other crops and on beef and milk production in Colombia.

It is expected that land use patterns will change slowly in Colombia and that corn will remain a food grain for many years to come. The study concluded with suggestions and recommendations to farmers concerning corn production practices and to researchers concerning needed research on corn.

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By

Douglas Darwin Hedley

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CHAPTER

INTRODUCTION

The study reported in this thesis examined some of the causes of the marked difference between experimental yields and typical yields of grain corn in Colombia. These differences in yields of corn have persisted for nearly twenty years with no apparent increase in average yields of corn.

The problem of high potential yields versus low farm yields is of considerable importance. Colombia's population has been growing as fast as that of any country in Latin America but neither yields nor production of corn appear to have changed substantially in the past two decades. Table I relates human population to corn yields and total corn production for Colombia in recent years. The importance of corn in the Colombian diet can hardly be over-emphasized. Corn provides twenty percent of total calories, more than any other single crop and is second only to meat as a source of protein. With the development of high lysine varieties of corn, it is becoming an increasingly important source of high quality protein. In terms of land use, corn is also important. It accounts for 800,000 hectares making it the third largest crop in Colombia.

No other crop shows as large a difference between potential and farm yields as does corn.

TABLE I. COLOMBIA: POPULATION, CORN PRODUCTION, AND YIELDS OF CORN, 1950 TO 1965

Year	Population[1]	Production of Corn[2]	Yields of Corn[2]
	in 1000's	metric tons	kilograms per hectare
1950	11,334[3]	620,000	950
1951	11,615	845,000	1,100
1952	11,986	928,000	1,100
1953	12,369	770,000	1,100
1954	12,765	750,000	1,200
1955	13,172	769,999	1,200
1956	13,593	790,000	1,450
1957	14,028	746,450	1,210
1958	14,476	852,407	1,220
1959	14,938	891,202	1,220
1960	15,416	938,482	1,164
1961	15,908	1,060,016	1,311
1962	16,417	1,116,495	1,313
1963	16,941	1,019,217	1,237
1964	17,482[4]	1,105,027	1,301
1965	17,787[4]	965,971	1,084

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[1] Source: United Nations, "Estimates of Mid-Year Population 1946 to 1965," Demographic Yearbook, 1965, Table 4, pages 132, 133. Except for 1964, the estimates for population are of questionable reliability. The estimate for 1964, although provisional, is based on a census report.

[2] Source: Caja de Credito Agrario, "Calculos de Produccion Agricola Nacional," Carta Agraria, Anexos 80, Febrero de 1962, 165 Julio de 1965 y 193, Octubre de 1966, Bogotá. (Government Agricultural Credit Bank, "Estimates of National Agricultural Production," Carta Agraria, issues 80, February 1962, 165, July 1965, and 193, October 1966, Bogotá).

[3] This estimate is for July 5, 1951; all others are for July 15.

[4] Published by the Economic Commission for Latin America.

Various alternative ways of increasing Colombian food supplies were examined before starting this study. The possibilities considered were:

1) imports,

2) opening of new lands,

3) more intensive use of existing lands,

4) increases in yields on land presently used for food production,

or a combination of the above methods.

Increasing imports of food supplies would be difficult for Colombia in view of her present foreign exchange problem. The scarcity of foreign exchange in Colombia has to a large extent been caused by the low prices of Colombia's chief export, coffee. No improvement in the foreign exchange problem is expected in the near future since nearly one year's supply of coffee is being held in stocks and Colombian coffee exports are only about two-thirds of the amounts available for export. Although it is impossible to deny that imports of food will be necessary, and in fact will be made, it is fair to say that strongly increased imports of food supplies do not represent a very practical solution to the Colombian food supply problems.

The unused lands in the Eastern Plains of Colombia appear to offer useful opportunities for increasing food production. The agricultural potential of this area is only presently being determined. However, because of its remoteness, transportation is virtually non-existent. Hence for the near future, cultivation of these lands would not seem to be the answer to the problem of the Colombian food supply. Nonetheless, grazing of cattle does offer some promise of immediate but extensive use of the area.

More intensive use of land that is already provided with services and markets, to a considerable degree, could apparently increase food production substantially at a low real cost to Colombia. While there has been a considerable increase in crop production in areas such as the Cauca Valley, nonetheless, a large portion of these areas is still devoted to extensive cattle raising.

The best opportunity to give sustained improvement to Colombian food production appears to be to increase yields on land presently used for crops. While it is not normally expected that farm yields will be equal to experimental yields, there is a truly vast difference between experimental and average farm yields in Colombia which would not be expected on the basis of experience elsewhere. For example, Davidson and Martin,[1] using Australian data, found farm yields to range from 57 to 93 percent of experimental yields, while in Colombia, farm yields of corn have been 20 percent or less of experimental yields for the past several years. Hence the possibilities of increasing on farm corn yields appear to be good.

Increased yields and more intensive use of land seemed to be realistic methods for increasing food supplies in Colombia at present. Later, as the agricultural potential of the Eastern Plains is established, and services and markets are built up, these areas may be used to provide an important addition to crop production in Colombia.

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[1] Davidson, B. R. and Martin, B. R., "The Relationship Between Yields on Farms and in Experiments," Australian Journal of Agricultural Economics, 9:129-140, 1965. Table II, page 133.

Objectives:

The plan of the study is directed toward fulfilling the following objectives:

(1) to compare reported farm yields to attainable yields of corn under experimental conditions over the past fifteen years;

(2) to identify and study some of the agronomic and economic factors which could account for the difference between farm and experiment station corn yields in Colombia;

(3) to combine economic and agronomic information into estimated production relationships from which inferences may be drawn that would permit farmers to make more profitable and efficient adjustments in corn production;

(4) to suggest some of the potential effects of increased corn yields on certain related crops and the Colombian livestock industry.

Methodology:

The study began by collecting available data on corn yields and corn production in Colombia from 1950-1965. Estimates of experimental yields for the same period were obtained from an examination of data made available by experiment stations. However, because the average farm yields and experimental yields were not measured under the same conditions, several modifications of the experimental results had to be made before sound comparisons were possible.

Several factors affecting corn yields were studied, using the experimental data. Some of these data were used to estimate a production function for corn from which economic optima were computed for various combinations of the prices of inputs and corn.

Reliable data on actual farm corn production practices were not available. Hence two farm surveys were made to find out what farm yields were being achieved in the Cauca Valley and to determine what methods of corn production were being used.

Recommendations were made for several farm sizes and various farming conditions. These recommendations were based on the farming conditions found to exist in the Cauca Valley and the results of the analysis of the factors affecting corn yields.

The final section of the study reported here concerned the effect that increased corn yields could have on other selected crops and livestock production.

Location of the Study

The study focused upon the Cauca Valley although other corn producing areas of Colombia were considered frequently. When studying the agriculture of Colombia it was necessary to be aware of the geography and climate of the country as both geography and climate affected the productivity of Colombian soils. Colombia, most northern of South American countries, is divided by three ranges of the Andes mountains beginning at the southern border and extending nearly to the Atlantic coast. To the east of the eastern range lies the Eastern Plains, drained by the Orinoco and Amazon watersheds.

The Cauca Valley lies between the western and central cordillera of the Andes mountains in southwestern Colombia. This valley is drained by the Cauca River which flows north to meet the Magdalena River just before the Magdalena River empties into the Caribbean Sea. The Cauca Valley is about 220 kilometers long and ranges in width from 15 to 40 kilometers, and is about 1000 meters above sea level. There are two distinct dry seasons and two distinct rainy seasons each year, with 900 to 1400 millimeters of rain per year. The soils of the Cauca Valley can be very wet or very dry depending upon the time of year, are subject to occasional flooding and in some areas they are poorly drained. The valley soils seem to respond well to good management practices and commercial fertilizers.

Almost all tropical and temperate crops can be grown in Colombia because of the wide range of altitudes and climatic conditions. The land ranges from sea level high rainfall areas on the Pacific Coast to snow capped mountains, high intermountain valleys, and back to sea level areas with very little rainfall on the Atlantic Coast.

CHAPTER II

THE COLOMBIAN CORN DILEMMA

The purpose of this chapter is to substantiate the view that corn yields on Colombian farms have remained low for the past several years, and at the same time, potential yields of corn have been five to seven times greater than average farm yields of corn.

Corn Production on Colombian Farms

1950 to 1965

The description of Colombian corn production presented here is based on many sources of information, some of which are in direct conflict with one another, hence inferences must be made with care.

One source, the "Caja de Credito Agrario,"[1] provided the data on total production, area harvested, and yields which are presented in Table II. These data indicate that production of corn remained between 620,000 and 928,000 tons[2] and that it slowly increased to over one million metric tons in the early sixties. Production appears to have declined according to this source in 1965 to less than one

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[1] Government Agricultural Credit Bank.

[2] Metric ton equal to 1000 kilograms. The word ton will always mean metric ton in this thesis.

TABLE II. COLOMBIA: PRODUCTION, HARVESTED AREA AND YIELD OF CORN, 1950-1965

Year	Production	Harvested Area	Yield of Corn
	metric ton	hectares	kilograms per hectares
1950	620,000	652,000	950
1951	845,000	768,000	1,100
1952	928,000	844,000	1,100
1953	770,000	700,000	1,100
1954	750,000	680,000	1,200
1955	769,999	660,000	1,200
1956	790,000	670,000	1,450
1957	746,450	613,000	1,210
1958	852,407	704,197	1,220
1959	891,202	729,850	1,220
1960	938,482	805,984	1,164
1961	1,060,016	808,200	1,311
1962	1,116,495	849,990	1,313
1963	1,019,217	823,850	1,237
1964	1,105,027	849,215	1,301
1965	965,971	890,489	1,084

Source: Caja de Credito Agrario, "Calculos de Produccion Agricola Nacional," Carta Agraria, Anexos 80, Febrero de 1962, 165, Julio de 1965; 193, Octubre de 1966. (Government Agricultural Credit Bank, "Estimates of National Agricultural Production," Carta Agraria, issues 80 February 1962; 1965 July, 1965; and 193, October 1966.)

million tons. Harvested area has increased slowly from 600,000 hectares in 1957 to nearly 900,000 hectares in 1965. Prior to 1957, the area harvested was between 650,000 hectares and 850,000 hectares. Since 1950 yields seem to have remained between 1.1 and 1.3 tons per hectare.[3]

Table III presents the same items as Table II but from a different source, INA,[4] for the years 1948 to 1965. Until 1960, estimates of corn production are much the same in both sources although the estimates of the "Caja Agraria" are consistently higher than the estimates of INA. The estimates from INA (Table III) show a decline in total production during the early 1960's in contrast with the rise in production shown in the estimates of the "Caja Agraria" in Table II. Yields of corn are much the same in both sources, with no trend apparent, although the "Caja Agraria" estimates of corn yields are somewhat higher than the yields of corn estimated by INA.

National averages, such as those presented above, obscure yield differences among departments.[5] Estimates by INA of production of corn, area harvested and yields are presented for all departments in Tables IV, V and VI for the years 1955 to 1965. Valle del Cauca is the only department showing a definite increase in production in this period with nearly all of the increase occurring between 1960 and 1965. Harvested area in Valle del Cauca increased at nearly the same rate as production during

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[3] One ton (metric) per hectare is equivalent to about 16 bushels of corn per acre.

[4] INA - Instituto Nacional de Abastecimientos, National Institute of Supply.

[5] Department is a political unit corresponding to a state or province.

TABLE III. COLOMBIA: PRODUCTION, HARVESTED AREA AND YIELD OF CORN, 1948-1966

Year	Production	Harvested Area	Yield of Corn
	metric ton	hectares	kilograms per hectare
1948	635,000	684,000	927
1949	737,620	707,180	1,043
1950	620,000	652,000	950
1951	845,000	768,000	1,100
1952	928,000	844,000	1,099
1953	890,000	700,000	1,271
1954	850,000	680,000	1,250
1955	736,000	830,000	880
1956	748,000	828,000	910
1957	697,500	604,000	1,150
1958	823,200	693,000	1,200
1959	857,500	721,000	1,220
1960	865,690	730,000	1,200
1961	757,521	711,000	1,060
1962	753,913	697,000	1,080
1963	781,593	689,000	1,135
1964	968,060	772,000	1,255
1965	870,755	869,000	1,000
1966	895,000	890,000	1,000

Source: Instituto Nacional de Abestecimientos, INA, Area, Produccion, Rendimiento de Maiz, Bogotá, Julio de 1966. (National Institute of Supply, INA, Area, Production and Yields of Corn, Bogotá, July, 1966.

TABLE IV. COLOMBIA: PRODUCTION OF CORN BY DEPARTMENTS, 1955 TO 1965

Department	Years										
	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
	thousands of metric tons										
Antioquia	90	100	99	107	116	118	95	93	110	104	88
Atlantico	12	8	7	12	11	10	11	12	12	17	6
Bolívar	47	56	49	53	59	59	67	73	67	56	16
Boyacá	65	84	75	70	90	88	34	40	27	48	25
Caldas	34	19	21	24	27	22	20	20	38	28	5
Cauca	22	26	18	24	19	19	31	32	32	27	21
Cordobá	58	66	69	75	87	91	84	69	78	71	38
Cundinamarca	60	78	75	90	80	92	55	55	52	113	43
Chocó	6	8	7	9	9	9	—	10	7	17	—
Huila	10	12	11	15	15	16	15	15	12	15	8
Magdalena	60	51	17	58	65	61	46	47	36	57	34
Nariño	35	40	38	54	46	53	53	52	41	31	12
N. Santander	20	28	30	25	37	37	29	28	25	30	11
Santander	47	43	46	63	58	64	66	48	63	47	24
Tolima	68	35	33	35	30	17	10	29	10	26	10
Valle	72	54	47	62	54	45	75	66	116	166	203
Meta	30	41	26	49	58	64	67	66	55	63	24
Others	—	—	—	—	—	—	—	—	—	56	7

Source: Instituto Nacional de Abastecimientos, INA, Seccion de Investigaciones Economicas, Area, Produccion, Rendimiento de Maiz, Bogotá, Julio de 1965. (National Institute of Supply, INA, Section of Agricultural Research, Area, Production and Yields of Corn, Bogotá, July 1965, mimeograph.

TABLE V. COLOMBIA: HARVESTED AREA OF CORN BY DEPARTMENTS, 1955 TO 1965

Department	Years										
	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
	thousands of hectares										
Antioquia	129	125	81	82	89	91	86	82	88	80	78
Atlantico	19	12	6	10	8	8	7	7	11	14	9
Bolívar	57	60	45	48	53	53	71	73	61	47	27
Boyacá	82	101	71	72	84	85	55	45	21	33	34
Caldas	45	22	21	24	26	21	17	17	48	31	6
Cauca	24	27	13	19	15	15	30	32	32	25	18
Cordobá	59	62	60	60	70	70	79	65	62	59	34
Cundinamarca	65	87	66	67	57	66	55	55	39	80	49
Chocó	8	9	7	9	8	9	—	12	9	20	—
Huila	11	12	11	14	14	16	13	14	11	13	5
Magdalena	65	57	42	53	59	57	44	44	30	43	34
Nariño	40	50	29	43	35	41	60	60	48	31	12
N. Santander	26	37	31	25	37	37	43	39	24	27	12
Santander	57	54	38	53	48	53	66	48	63	42	24
Tolima	62	29	27	29	24	14	8	23	9	20	8
Valle	48	39	31	41	36	30	30	33	83	104	87
Meta	33	46	25	47	57	64	48	48	49	53	21
Others	—	—	—	—	—	—	—	—	—	50	—

Source: Instituto Nacional de Abastecimientos, INA, Seccion de Investigaciones Economicas, Area, Produccion, Rendimiento de Maiz, Bogotá, Julio de 1965.
(National Institute of Supply, INA, Section of Agricultural Research, Area, Production and Yields of Corn, Bogotá, July 1965, mimeograph.

TABLE VI. COLOMBIA: YIELDS OF CORN BY DEPARTMENTS, 1955 TO 1965

	Years										
Department	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965
						kilograms per hectare					
Antioquia	700	800	1220	1300	1300	1300	1100	1130	1250	1300	1125
Atlantico	630	660	1110	1250	1250	1250	1620	1650	1100	1200	750
Bolívar	820	930	1100	1100	1100	1100	940	1000	1100	1200	600
Boyacá	790	830	1050	970	1080	1030	620	890	1300	1400	750
Caldas	750	950	980	1010	1020	1030	1220	1200	785	900	895
Cauca	920	950	1400	1250	1250	1260	1020	1000	1000	1100	1125
Cordobá	980	1070	1150	1250	1250	1300	1070	1050	1250	1200	1125
Cundinamarca	920	900	1140	1350	1400	1400	1000	1000	1350	1400	875
Chocó	740	800	970	1010	1010	1050	—	810	800	850	—
Huila	900	1030	1040	1050	1050	1020	1130	1070	1100	1150	1625
Magdalena	920	900	1120	1100	1100	1080	1050	1070	1200	1300	1000
Nariño	880	800	1300	1270	1300	1300	880	890	850	1000	1000
N. Santander	780	750	960	1020	1000	1010	670	720	1020	1100	875
Santander	820	800	1200	1200	1200	1200	1000	1000	1000	1100	1000
Tolima	1100	1200	1240	1230	1250	1250	1250	1250	1100	1300	1250
Valle	1500	1400	1500	1500	1500	1500	2480	2000	1400	1600	2325
Meta	900	900	1050	1030	1010	1010	1400	1380	1125	1200	1125
Others	—	—	—	—	—	—	—	—	—	1125	—

Source: Instituto Nacional de Abastecimientos, INA, Seccion de Investigaciones Economicas, Area, Produccion, Rendimiento de Maiz, Bogotá, Julio de 1965.
(National Institute of Supply, INA, Section of Agricultural Research, Area, Production and Yields of Corn, Bogotá, July 1965, mimeograph.)

1960 to 1965. Yields of corn in the department of Valle del Cauca of one and one-half to two and one-half tons per hectare put it ahead of other departments in this respect. Antioquia had been the largest corn producing department until 1963 when Valle del Cauca became the largest with 116,000 tons and increased its production to 203,000 tons of corn in 1965. Other departments have shown little or no change in their total production, area harvested, or yields during this time.

Tables VII, VIII and IX present estimates by the "Caja Agraria" of total corn production, harvested area, and yields for the years 1962 to 1965. They may be compared to previous data. This alternate source, the "Caja Agraria," indicates that Valle del Cauca was the largest producing department, in 1965, although prior to this year, Antioquia and Cundinamarca were the two largest corn producing departments. However production estimates for 1965 from the INA data for Valle del Cauca are 203,000 tons while in the "Caja Agraria" estimates, estimated corn production is 139,000 tons. Harvested areas for the departments are generally shown to be lower in the INA estimates than in the "Caja Agraria" estimates. The INA estimates of corn yields for the departments were different in almost every department from the "Caja Agraria" estimates of corn yields for the departments although neither source gave estimates consistently higher than the other. The estimates from the "Caja Agraria" of corn yields in Valle del Cauca remain well below two tons per hectare. Ranking of the five largest producing departments in 1965 was the same for both the INA estimates and the "Caja Agraria" estimates.

TABLE VII. COLOMBIA: PRODUCTION OF CORN BY DEPARTMENTS FOR THE YEARS 1962 TO 1965

Department	Years 1962	 1963	 1964	 1965
	metric tons			
Antioquia	134	129	134	102
Atlantico	17	12	13	8
Bolívar	65	62	69	66
Boyacá	86	79	106	72
Caldas	27	27	29	30
Cauca	46	39	39	39
Cordobá	103	95	101	73
Cundinamarca	123	98	103	84
Chocó	7	7	8	6
Huila	14	13	17	15
Magdalena	69	64	70	69
Meta	35	33	37	33
Nariño	79	70	71	53
N. Santander	37	34	37	25
Santander	79	72	73	59
Tolima	73	68	76	57
Valle del Cauca	89	82	83	139
Guajira	3	3	3	4
Amazonas	—	—	—	—
Arauca	1	1	1	—
Caquetá	25	26	30	27
Putumayo	4	4	4	4
Vaupés	—	—	—	—
Vichada	1	1	1	1

Source: Caja de Credito Agrario

TABLE VIII. COLOMBIA: HARVESTED HECTARES OF CORN BY DEPARTMENTS FOR THE YEARS 1962 TO 1965

Department	Years			
	1962	1963	1964	1965
	1000 hectares			
Antioquia	103	101	103	109
Atlantico	14	11	12	7
Bolívar	58	56	58	59
Boyacá	78	75	76	77
Caldas	27	26	27	27
Cauca	31	28	28	29
Cordobá	71	69	71	76
Cundinamarca	78	75	76	77
Chocó	7	7	8	8
Huila	15	13	15	16
Magdalena	56	57	59	63
Meta	31	29	32	34
Nariño	53	52	53	53
N. Santander	35	33	33	29
Santander	61	60	62	63
Tolima	54	55	56	54
Valle del Cauca	49	47	47	74
Guajira	3	3	3	4
Amazonas	—	—	—	—
Arauca	1	1	11	1
Caquetá	23	23	24	25
Putumayo	4	4	4	4
Vaupés	—	—	—	—
Vichada	1	1	1	1

Source: Caja de Credito Agrario

TABLE IX. COLOMBIA: COMPUTED YIELDS OF CORN BY DEPARTMENT FOR THE YEARS 1962 TO 1965

Department	Years			
	1962	1963	1964	1965
	kilograms per hectare			
Antioquia	1300	1280	1300	940
Atlantico	1210	1090	1080	1140
Bolívar	1120	1110	1190	1120
Boyacá	1100	1050	1390	940
Caldas	1000	1040	1070	1110
Cauca	1480	1390	1390	1340
Cordobá	1450	1380	1420	960
Cundinamarca	1580	1310	1360	1090
Chocó	1000	1000	1000	750
Huila	930	1000	1130	940
Magdalena	1230	1120	1190	1100
Meta	1130	1140	1160	970
Nariño	1490	1350	1340	1000
N. Santander	1050	1030	1120	860
Santander	1300	1200	1180	940
Tolima	1350	1240	1360	1060
Valle del Cauca	1810	1740	1770	1880
Guajira	1000	1000	1000	1000
Amazonas	—	—	—	—
Arauca	1000	1000	1000	1080
Caquetá	1080	1130	—	—
Putumayo	1000	1000	1000	1000
Vaupés	—	—	—	—
Vichada	1000	1000	1000	1000

Source: Computed yields from Tables VII and VIII, rounded to the nearest 10 kilograms.

On the basis of available data neither production of corn nor harvested area of corn appear to have changed significantly since 1950. Colombian corn yields have remained static at about one ton per hectare. Valle del Cauca seems to be an exception to the above, as production and area harvested seem to have increased in the most recent years. Corn yields in Valle del Cauca, although higher than all other departments, are quite static at about two tons per hectare.

Review of Corn Research in Colombia

Some of the accomplishments of the organizations involved in corn research in Colombia are presented here. The corn seed improvement program, the corn yield trials conducted by the experimental stations in Colombia, and the work of the Facultad de Agronomia[6] in Palmira in conjunction with Michigan State University during the 1950's, were the investigations of particular relevance to this study.

The Corn Seed Improvement Program[7]

The first corn seed improvement research in Colombia began about 1943 at the Estacion Agropecuaria Tulio Ospina[8] near Medellín. By 1950, four synthetic varieties[9] and several inbred lines had been

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[6] College of Agronomy

[7] Many points in this section were taken from Stakman, E.C., Bradfield R., and Mangelsdorf, P.C., Campaigns Against Hunger, the Belknap Press of Harvard University Press, Cambridge Massachusetts, 1967, Chapter 13 "Extending the Mexican Patterns," pages 216-234.

[8] Tulio Ospina Experiment Station, near Medellín, Antioquia.

[9] A synthetic variety is a variety produced by crossing among themselves several genotypes specifically selected for their good combining ability in all combinations, and maintained by open pollination.

developed. The three synthetic varieties of importance were Colombia 1, Colombia 2, and ETO; the fourth synthetic variety was an unnamed sweet corn. These varieties were developed primarily for altitudes between 800 and 1700 meters. Some work had begun also on corn adapted to colder and warmer climates than the climate at Medellin.[10]

In 1950, the Oficina de Investigaciones Especiales,[11] under the Colombian Ministry of Agriculture and aided by the Colombian Agricultural Program of the Rockefeller Foundation, was set up. This program took over many of the lines developed at the Tulio Ospina Experiment Station, and also brought several lines of corn from Mexico. The purpose of this corn breeding program was to develop and produce improved varieties[12] and hybrids[13] adapted to Colombian

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[10] The early work in corn breeding in Colombia is discussed in Chavarriaga M., Eduardo, "Maiz ETO, Una Variedad Producida en Colombia," Revista ICA, Organo Oficial del Instituto Colombiano Agropecuario, Publicacion del Centro de Communicaciones, Vol. 1, No. 1, Bogotá, Junio 1966, pages 5-30.

[11] Office of Special Studies. In 1952 the Departamento de Investigaciones Agropecuario, DIA, (Department of Agricultural Research) was established under the Ministry of Agriculture, which took over the work on the experiment stations, and the corn breeding program. In 1964, DIA was reorganized and renamed ICA, Instituto Colombiano Agropecuario, (Colombian Agricultural Institute).

[12] The improved varieties eventually made available to farmers were synethetic varieties.

[13] The hybrids made available to farmers were hybrid varieties. A hybrid variety is the product of a cross between two selected genetically dissimilar parents. It cannot be maintained by open pollination since the various genotypes begin to separate in successive generations. The hybrid varieties multiplied for distribution to farmers have been double cross hybrids, up to the present time, 1967.

conditions in expectation of increased yields and production of corn on commerical farms in Colombia. As might be expected on the basis of Colombia's geography, the corn breeding program had to adapt varieties to the diversity of climates encountered in the different regions in which corn is grown in Colombia.

As early as 1951, several improved lines of corn had been selected and multiplied for distribution to Colombian farmers. Since that time a number of both white and yellow corn varieties have been developed for each of the five climatic zones and made available to Colombian farmers. Some of these improved varieties and hybrids, and their characteristics are listed in Table X. Other improved varieties and hybrids have been developed by the corn breeding program but not all of them have been multiplied for general distribution. An improved seed must demonstrate that its yields and characteristics are superior to those already available to farmers within a given climatic region, before it is multiplied for distribution. However, a wide range of varieties are available in small quantities upon request to ICA.

Breeding of improved seed for possible distribution to farmers in the Cauca Valley is restricted to hybrids at the present time. It was thought that the potential yields of hybrids which could be developed were greater than that of improved varieties.

The cost of providing hybrid seed for distribution is about seventy-five percent greater than that of improved varieties. The reason for this is that all hybrid seed must be generated directly from the individual inbred lines or genotypes while varieties are self

TABLE X. IMPROVED VARIETIES AND HYBRIDS OF CORN DEVELOPED BY CORN SEED IMPROVEMENT PROGRAMS IN COLOMBIA

Varieties and Hybrids	Adaptation		Grain		Days to Maturity
	Altitude above Sea Level	Climate	Color	Hardness	
	meters				
Diacol V-1[1,2]	0- 600	hot	white	floury	
Colombia 1[1,3]	800-1700	moderate	yellow	hard	
Colombia 2[1,3]	800-1700	moderate	white	hard	170
Diacol V-ETO[1,3]	800-1700	moderate	yellow	hard	165
Diacol V-101[1,4]	600-1200	moderate hot	yellow	floury	150
Diacol V-103	0- 600	hot	yellow	hard	120
Diacol V-153	0- 600	hot	white	floury	135
Diacol H-104	0- 600	hot	yellow	hard	120
Diacol H-151	0- 800	hot	white	floury	140
Diacol V-206	600-1200	moderate hot	yellow	hard	120
Diacol V-254	600-1200	moderate hot	white	floury	135
Diacol H-201[5]	800-1700	moderate	yellow	hard	160
Diacol H-202	800-1700	moderate	yellow	hard	160
Diacol H-203	800-1700	moderate	yellow	hard	160
Diacol H-205	600-1200	moderate hot	yellow	hard	150
ICA H-207	600-1200	moderate hot	yellow	hard	145
Diacol H-251	800-1700	moderate	white	hard	165
Diacol H-253	600-1200	moderate hot	white	hard	135
Diacol V-351	800-1700	moderate	white	hard	145
Diacol H-301	1200-1700	moderate	yellow	hard	160
Diacol H-352	1200-1700	moderate	white	hard	160
Diacol H-401	1700-2200	moderate cold	yellow	hard	230
Diacol H-451	1700-2200	moderate cold	white	hard	230
Diacol H-501	2200-1700	cold	yellow	floury	300
Diacol V-502	2200-1700	cold	yellow	floury	300
Diacol V-551	2200-1700	cold	white	hard	300

TABLE X. (Continued)

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[1] These improved seeds were named before the standard nomenclature for the seeds developed by this program was established. The rest of the seeds listed follow the pattern:

a) H - hybrid and V - variety
b) The first number gives the number assigned to the climate and altitude to which it is adapted
c) The second number is 0 for yellow grain and 5 for white grain
d) The last number is a reference number for that particular hybrid or variety
e) The name Diacol means Departamento de Investigaciones Agropecuarias - Colombia. Prior to use of the word Diacol, Rocol was used. At the present time, the letters ICA are used, e.g. ICA H-207. Thus Diacol H-205 is a hybrid (H) developed under the Departamento de Investigaciones Agropecuarias, which is adapted to the altitudes between 600 and 1200 meters. It has yellow grain and is the fifth hybrid developed for distribution to farmers with the foregoing characteristics.

[2] Originally known as Rocol V-1.

[3] These were developed prior to 1950 at the Tulio Ospina Experiment Station.

[4] Originally known as Rocol V-101.

[5] Originally known as Rocol H-201.

Note:

1) Not all of the improved seeds that have been multiplied for distribution are listed. There were thrity-six by 1967.

2) Not all of the improved seeds listed are available to farmers at this time (1967). As superior seeds with specific characteristics are developed, others, with the same characteristics but lower yield potential may no longer be multiplied for general distribution since demand for them falls off.

Sources: Grant, U.J., Ramirez, Ricardo, Astralaga, Roberto, Casselett, Climaco and Torregroza, Manuel, Como Aumentar la Produccion de Maiz en Colombia, Bolentin de Divulgacion No. 1, Departamento de Investigaciones Agropecuarias, Abril, 1957, Tabla 1, page 14.

Taken from a Table entitled "Hibridos y Variedades Mejoradas de Maiz" (Improved Varieties and Hybrids of Corn), from mimeograph, anonymous.

propagating. However, the Colombian government subsidizes the price of hybrid corn seed so that the cost of hybrid seed to the farmer is the same or slightly less than the cost of improved varieties of corn.

The National Corn Program[14] is also studying the possibilities of use of high lysine corn. This characteristic of high lysine level is a genetic trait that considerably raises the protein quality of the corn.

There are several private seed companies in Colombia. Few of these private companies develop their own improved varieties and hybrids; typically they multiply the hybrids and improved varieties developed by ICA and the National Corn Program. Proacol Ltda., is one of the seed companies that has developed hybrids of its own, although it multiplies some of the ICA hybrids also. Most notable of the hybrids of Proacol Ltda. adapted to the Cauca Valley, is "Doble 6," a hybrid corn with characteristics and yield potential very similar to ICA H-207.

The private seed companies were selling one half or more of all the improved seed sold in Colombia[15] in 1967.

The Caja de Credito Agrario serves as an outlet to farmers for the hybrid seeds but not improved varieties.

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[14] The National Corn Program is the name given to the program of the Rockefeller Foundation working in research in corn in Colombia. The efforts of this program are integrated with the efforts of ICA. The National Corn Program - Colombia, is part of a larger project of the Rockefeller Foundation - the International Corn Program - for the countries Colombia, Venezuela, Ecuador, Peru and Bolivia. Because of the similarity in climatic conditions and the problems encountered in corn research in these countries, cooperative efforts under one international program are proving useful and efficient.

[15] Stakman, E. C., et al, op. cit., page 221

Corn Yield Experiments

The purpose of the discussion here on yield testing of corn is to provide evidence of the corn yields which have been obtained using the improved corn seeds, so that a comparison can be made between experimental yields and typical farm yields of corn in Colombia. The factors affecting corn yields which have been studied are mentioned briefly.

Yield testing of improved corn seeds has been carried out by the experiment stations in Colombia under the direction of ICA for several years. These experiments have been made both on the experiment stations and in regional trials on nearby farms. The experimental yields of corn obtained in the Cauca Valley[16] are of particular relevance to this study, although some data are presented from the experiment stations at Medellín[17] and Montería.[18]

Table XI relates the yields of some of the hybrids and improved varieties, adapted to regions below 1700 meters above sea level, to the year in which they first became available to farmers, and the number of trails upon which the yield estimates are based.

The yields for the first six improved corn seeds of Table XI were obtained on an experiment conducted at the Tulio Ospina experiment station, between 1952 and 1954. The yield estimated for Diacol H—104 was calculated from yields on regional trials in the Sinú Valley in 1966. The yield estimates of the last three hybrids in Table XI

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[16] Granja Agricola, Palmira, Valle del Cauca.

[17] The Tulio Ospina Experiment Station, Medellín, Antioquia, Colombia.

[18] Turipaná Experiment Station, near Montería, Cordobá, Colombia.

TABLE XI. EXPERIMENTAL YIELDS OF SOME OF THE IMPROVED CORN SEEDS ADAPTED TO REGIONS BELOW 1700 METERS

Variety or Hybrid	Yield	Number of Yield Trials	Year Seed Became Available
	kilograms per hectare	number	
Diacol V - ETO	4,601[1]	296	1943 - 1946
Colombia 2	4,397[1]	188	1943 - 1950
Diacol H - 201	4,959[1]	188	1951
Diacol H - 202	4,643[1]	104	1952
Diacol H - 203	5,299[1]	108	1954
Diacol H - 251	5,521[1]	108	1954
Diacol H - 104	4,576[2]	144	1957 - 1960
Diacol H - 205	4,889[3]	436	1959
Diacol H - 253	8,081[3]	72	1962
ICA H - 207	7,780[3]	247	1966

Sources:

[1] Grant, U.J., Ramirez, R., Astralaga, R., Casselett, C., and Torregroza, M., Como Aumentar la Produccion de Maiz en Colombia, Boletin de Divulgacion No. 1, Departamento de Investigaciones Agropecuarias, Abril 1957, Table 1, page 14.

[2] Turipaná Experiment Station, Seccion de Suelos, Records of Regional Trials 1966

[3] Granja Agricola, Palmira, Seccion de Suelos, Records of Regional Trials of Corn, 1965 and 1966.

Note: Yields from many of the lines of corn and some of varieties and hybrids developed in Colombia are available in Chavarriaga M., Eduardo, "Maiz ETO, Una Variedad Producida en Colombia" Revista ICA, Organo Oficial del Instituto Colombiano Agropecuario, Publicacion del Centro de Communicaciones, Vol. 1, No. 1, Bogotá, Junio 1966, pages 5-30.

were calculated from all the regional trials in the Cauca Valley during 1965 and 1966. The regional trials at Turipaná include eight combinations of nitrogen and phosphorus (P_2O_5) while the regional trials of corn in the Cauca Valley include nine combinations of nitrogen, phosphorus (P_2O_5) and potassium (K_2O).

A native variety, "Amagaceño," was included in the experiment from which yields for the first six improved seeds were obtained. "Amagaceño" produced an average of 3,507 kilograms per hectare[19] over a six semester period 1952 to 1954, on 298 observations. This unimproved corn did not demonstrate the yield capability of the improved seeds.

The hybrid, "Doble 6" developed by Proacol Ltda., is not shown in Table XI. Its yield potential is very similar to that of ICA H-207 and has been available in the Cauca Valley since 1965.

Many factors influencing corn yields have been studied in the "Granja Agricola" in Palmira. These factors include nitrogen, phosphorus, and potassium fertilizers, irrigation, planting date, plant densities, legume-corn rotations and time of nitrogen applications. From the data it was possible to study some other variables for which the experiments were not specifically designed, e.g. semester effect, herbicide, insecticide, and carbon to nitrogen ratios in the soils. The analysis of these factors will be considered in a later section of this report.

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[19] Grant, U. J., et al, op. cit., Table 2, page 16.

The Research of the Facultad de Agronomia and Michigan State University

A number of corn studies in the Cauca Valley were completed under the joint program between the Facultad de Agronomia in Palmira and Michigan State University during the 1950's. The results of three studies are presented briefly to ascertain the economically optimal level of corn production.

Delgado found the economic level of output to range from 5,894 to 6,111 kilograms per hectare[20] when irrigation was used. For non-irrigated land, economically optimum output fell to between 4,723 and 4,960 kilograms of corn per hectare.[21] These results were obtained in an irrigation-fertilizer-corn experiment made in 1958 using the hybrid Diacol H-203.

Bertolotto found the economically optimum level of corn output to be 5,590 kilograms per hectare[22] in a corn experiment in 1957. The corn seed used was not stated.

Trant[23] found yields of corn to be 4,050 kilograms per hectare with an application of 100 kilograms per hectare of nitrogen in 1957, despite a severe dry period just before tasseling of the corn. The corn seed used was not stated.

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[20] Delgado, Enrique, "Economic Optima from an Experimental Corn-Fertilizer Production Function, Cauca Valley, Colombia, S. A. 1958", Unpublished Master's Thesis, Department of Agricultural Economics, Michigan State University, 1962, pages 75, 76.

[21] Delgado, Enrique, ibid., pages 75, 76.

[22] Bertolotto, Hernan, "Economic Analysis of Fertilizer Input-Output Data from the Cauca Valley, Colombia," Unpublished Master's Thesis, Department of Agricultural Economics, Michigan State University, 1959, page 53.

[23] Trant, G. I., "Implications of Calculated Economic Optima in the Cauca Valley, Colombia, S.A.," J.F.E., 40:129-133, 1958, page 128.

Summary

It is apparent that improved corn seeds adapted to all corn growing regions have been available for many years to Colombian farmers. As well, the yields obtained by these improved seeds are significantly greater than yields obtained from the native corn varieties. During the first few years of the Corn Improvement Program attainable yields of the improved seeds were four to five times greater than average farm yields in Colombia. By 1966 improved corn seed had the potential of producing as much as eight times more than the average farm yields in Colombia. Although average farm yields in Valle del Cauca are higher than for the other departments, they are still only one-quarter of the yields attainable from the improved seeds adapted to the region.

The following chapter presents some of the possible reasons for this wide difference between experimental and average farm yields of corn.

CHAPTER III

REASONS FOR THE DIFFERENCE BETWEEN EXPERIMENTAL AND FARM YIELDS OF CORN IN COLOMBIA

The previous chapter served to demonstrate the wide difference between farm yields and experimental yields of corn in Colombia which has existed for many years. The intent of this chapter is to raise some considerations which may be useful in explaining this difference between attainable and obtained yields of corn in Colombia.

The considerations suggested in this chapter pertain to both agronomic and economic factors. The agronomic factors can generally be thought of as the purely physical relationships between corn yield and the environment in which corn is grown. The economic factors deal largely with the profitability of controlling the environment and with the efficiency of institutions involved in transforming a specific set of inputs or resources into a corn product for the consumer. While this chapter is organized around these two groups of considerations — agronomic and economic -- the distinction is not clear cut and a great deal of overlap is encountered.

Agronomic Considerations

In this section, several differences between the physical production process on experiment stations and on farms are discussed.

These differences provide some reasons for the difference in corn yields on experiment stations and on farms.

The experimentally obtained yields of corn are generally achieved on quite small plots, usually about 20-30 square meters. Farm corn yields, however, are obtained on a wide range of field sizes varying from tiny plots on the minifundia[1] to extremely large fields on the huge commercial farms. This difference leads to many implications. First of all, the environment within each experimental plot in the same study is generally very rigidly controlled. In designing the experiment, the uncontrolled factors in the environment generally remain constant within and among plots. The researcher's ability to do this stems in large part from the smallness of the plots with which he works, and his choice of the location for the experiment. Farmers, however, do not have this measure of freedom in producing corn. Many factors in the environment are uncontrollable and do not remain constant within the field; soil type and soil drainage are examples. The result is less uniform corn yields on farms.

Another implication arising from this difference between plot size and field size was noted by Davidson and Martin in their study of Australian farm and experimental yields.[2]

> "...in unfavourable years the average yield of commercial crops is approximately equal to yields obtained under experimental conditions. In years favourable to the crop, both farm and experimental yields increase but experimental yields increase at a greater rate than commercial yields.

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[1] A very small farm generally less than five hectares.

[2] Davidson, B. R., op. cit., page 132.

> This suggests that because the scientist is working on a small area he can carry out all cultural operations at the optimum time and take maximum advantage of the environment when it is favourable. The farmer, on the other hand, works on a larger acreage and must carry out some operations at an unsuitable time. In favourable years, the timing of cultural operations is the most limiting factor to high yields, and the farmer's inability to perform these operations at the optimum time reduces the relative yield."

This insight provides another argument for an expected difference between farm and experimental yields.

A third agronomic consideration, not unrelated to the previous one, is that the controlled factors in the environment are much more rigorously controlled on the experiment station than on farms. Furthermore, the controlled factors are generally set at a variety of levels on experimental plots whereas farms in general use only one combination of controllable and variable resources within a field. Coupled with suboptimal timing of operations on farms, farm corn yields are reduced.

Finally, researchers conducting corn yield experiments need not consider the many institutions through which the resources to produce corn and the corn itself must pass. Allied with this is that researchers do not attempt to use only the economically optimal combination of resources for corn production but also a wide variety of combinations to give both higher and lower corn yields than optimal output. By judicious choice of data, researchers can easily overestimate corn yields attainable with a particular variety of corn or particular production process. The choice of an economically optimal combination of resources under experimental conditions relative to farm corn yields is discussed in the following section. However, the use of experimental data to find this optimum combination of controllable resources is delayed until Chapters VI - IX.

Economic Considerations

The agronomic considerations discussed above indicate that experimentally obtained corn yields can not usually be compared directly with on-farm yields. However, production functions relating output to resource use can be fitted to experimental data from which economically optimal yields may be found to compare to on-farm corn yields. The intent of this section is to briefly indicate the conditions for optimal yield and to suggest some of the reasons why optimal experimental corn yields may exceed farm corn yields.

Under conditions of perfect knowledge and with variable resources, profit maximization occurs when marginal value product of each of the n resources, X_i, used in the production of the product Y, equals its marginal factor cost, i.e.,

$$MVP_{X_{i(y)}} = MFC_{X_i}$$

given that this occurs in Stage II of production, i.e.,

$$0 \leq MVP_{X_{i(y)}} \leq AVP_{X_{i(y)}} \quad \text{for } i = 1, 2, \ldots, n.$$

In this case, marginal factor cost is defined as the opportunity cost of that resource. Since this use of the definition of factor cost implies that:

$$MVP_{X_{i(yj)}} = MVP_{X_{i(yk)}} = MFC_{X_i}$$

for $i = 1, 2, \ldots., n$, and $j, k = 1, 2, \ldots, m$,

profit maximization for a single crop does not become different when all crops on the farm are considered.

The marginal factor cost of a resource is not necessarily the same on all farms. This can occur because of the difference in transportation cost of a resource to two different farms, or the cost of borrowing money to purchase the resource. In Colombia, for example, the minifundia may have to pay very high interest rates to obtain the funds to acquire a non-farm produced resource, so high in fact, that the use of the resource becomes unprofitable. Fertilizer and pesticides are two resources which require the outlay of considerable amounts of money, and the very high marginal cost of these factors to the small farmers may make their use unprofitable, even though use of them could greatly increase their yields of corn. This is of considerable importance since it has been estimated that eighty-three percent of the corn in Colombia is produced on farms of less than twenty hectares.[3]

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[3] Guerra, Guillermo A., Economic Aspects for Corn and Milo, (A Final Technical Report to the Agricultural Research Service of the U.S.D.A., Financed by Public Law 480, Sec. 104-K, under contract No. FC-Co-110), Seccion de Economia Agricola y Extension Rural, Facaltad de Agronomia e Instituto Forestal, Universidad Nacional de Colombia, Medellin, Colombia., July 1966.

The marginal factor cost is dependent on the other resources with which it is combined. As well, in many cases, it is just not feasible to use some modern inputs. For example, it is nearly impossible to use machinery on the mountain slopes where much of the corn in Colombia is grown. Hence, many methods of production, which are dependent on machinery use, cannot be employed. This could explain part of the low average national yields of corn.

In other words, the high cost and the infeasibility of use of many of the resources lead to very little use of these inputs on small farms, and results in lower corn yields.

Discounting

The assumption of perfect knowledge made earlier is now dropped. Under conditions of imperfect knowledge, or rather, risk and uncertainty, farmers usually discount expected yields. Hence in many cases the most profitable level of use of a resource is underestimated. It has been pointed out that "in discounting, safety is acquired and opportunities are foregone. Here, the economic principle is not to sacrifice more in terms of foregone opportunities when acquiring additional safety through discounting than the individual safety is worth."[4] Much of the corn in Colombia is produced on small farms, for which safety from a poor crop is of great importance. Hence, discounting of returns to the use of a resource[5] is very great, so great in fact that it may become

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[4] Bradford, L.A. and Johnson, G.L., Farm Management Analysis, John Wiley and Sons, Inc., New York, 1953, page 35. This is similar to the ideas expressed by L.V. Manderscheid, "Significant Levels, 0.05, 0.01 or ?", JFE, Vol. 47, No. 5, December 1965, pages 1381-1385.

[5] Reference here is to variable resources, purchased for use in production of the crop.

unprofitable to use any of the resource. The second hypothesis, then, is that the yields of corn on many of the small farms are low because the possible losses which could occur when using a resource are so great that they outweigh the possible gains accrued to the resource.

Variability in weather, crop plagues, and prices give rise to uncertainty and risk for which farmers discount expected returns to increase safety.

Marketing

The marketing system for corn in Colombia has in the past been somewhat inefficient. Corn is usually sold from the farm to brokers or wholesalers who store or sell the grain. The marketing margin between the farm price and the retail price for corn is quite large. Guerra[6] has estimated the difference in price between retail and farm prices of corn to be as high as 49 percent of the retail price of milled corn.

Some sales of corn are made directly to such companies as Quaker, S.A., or Maizena. Some companies engage in contract growing of corn and provide technical assistance in corn production. This, to some degree, averts the very high market margins.

Transportation to the market centers is difficult for many of the small farmers, and when they reach the market, they have difficulty finding a buyer willing to buy small quantities of corn except possibly at very low prices. This problem of transportation and finding a

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[6] Guerra, op. cit., page 48, Table III-6.

market for small quantities of corn results in many of the small farms growing only enough corn for their own use, even though they could grow some for sale to supplement their incomes. This considerably lowers the value productivity of resources, resulting in less of the resources used, and lower corn yields.

Harvesting Practices

Nearly all of the corn in Colombia is harvested by hand, even in areas well adapted to machinery use. Once a field has been harvested, gleaners may go over the field to pick up any corn left by the harvesters. Since gleaners are frequently the same persons who originally harvested the field, incomplete harvesting is quite common. Gleaning losses have been estimated to range from ten to twenty percent of corn yields depending upon the level of supervision of the field harvesters.

Corn yield losses by theft are quite common also since a man can pick and carry away up to three days wages worth of corn quickly and easily. Although watchmen are usually employed during the two months when the crop is ripening and drying, theft losses can still be quite serious. Estimates of losses by theft are unavailable.

The losses by gleaning and theft also must be taken into account when a farmer is considering use of resource. The yield of corn must be discounted for these losses, further lowering the value of the product accruing to the additional use of fertilizer or pesticides.

Management

Management of commercial farms is usually the work of a salaried "mayordomo" or administrator. Although they may be well qualified for such positions, they often lack incentive and initiative. The small farms are usually owner-operated with much of the labor supplied by the family. Although the small farmers may have the incentive to improve their farming practices, they are hampered by the high cost of resources and relatively low prospective returns to these resources. Because of this, they continue to use traditional production practices. Another reason for the use of production methods passed on to them from their forefathers is that alternative methods are unknown, or if known, are sometimes treated with skepticism and distrust. This is partly a result of the uncertainty of their knowledge concerning the returns to be had from alternative production methods.

One of the functions of management--timing of cultural operations and marketing--is of great importance in agricultural production. Although it was noted earlier that suboptimal timing of field operations can be expected on farms, a great many opportunities appear to be lost either from a lack of understanding of the importance of timing or a lack of incentive or initiative to take advantage of these opportunities.

Summary

Reasons for the difference between farm and experimental corn yields are divided in this chapter into two groups -- agronomic and economic. The agronomic considerations deal primarily with comparisons of the physical relationships between product and resources on farms and in experiments. The economic considerations begin with a suggested method for comparing farm corn yields and economically optimal yields calculated from experimental data. Following this is a discussion of several economic considerations which prevent farmers from attaining the optimal yield.

CHAPTER IV

RESULTS OF TWO FARM SURVEYS

During the summer of 1967, two farm surveys were made, one to determine on-farm yields of corn in the flat part of the Cauca Valley, the other to find out in detail the methods of corn production being used in this area.

Both surveys were made during the July-August harvest season of 1967 between the municipalities of Florida and La Union. Sampling of farms was difficult since land holdings were not well defined on maps, nor was there a complete list of farmers from which to choose. However the farmers chosen were considered to be sufficiently representative with respect to corn production methods and corn yields of the farms in the Cauca Valley.

The interviewers often found farmers hesitant to give information on their production methods, corn yields, and costs, and more hesitant still, to allow the interviewers to enter their corn field to see the crop or to take yield samples of it.[1] There were several apparent reasons for this. Farmers feared that the information would be used against them for taxation or land expropriation. Also, farmers feared loss of corn by theft, which in some cases, have been serious. Another reason was that they had been surveyed many times before and had heard

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[1] Guerra encountered this in his research in the Medellín area. Guerra, Guillermo, op. cit., page 31

nothing of the results of the surveys. However, once the farmers were convinced that the interviewers were from the Universidad del Valle, and not representing a government agency, they seemed quite willing to help.

The Corn Yield Survey

One field in each of twenty different farms were chosen in the Cauca Valley for this survey in the area described above. For each corn field, plots measuring ten meters long and two rows wide were harvested. The number of plots taken in each field ranged from one to five, depending upon uniformity of the corn crop, size of field, and owner permission. The grain yields of corn at 15.5 percent moisture content and the plant population density were determined. The results are presented in Table XII.

The ear corn from each plot was weighed and the moisture content determined from a grain sample. The weights of grain corn at 15.5 percent moisture content were calculated using a table of values relating ear corn weights at various moisture contents to shell corn weights.[2] The plot yields within each field were averaged for a grain corn yield representative of the field.

The grain corn yields at 15.5 percent moisture and the plant population densities for each corn field are related to field size

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[2] Aldrich, Samuel R., and Leng, Earl R., Modern Corn Production, Fand W. Publishing Corp., Cincinnati, Ohio, 1965, Reference Table 4, page 301.

TABLE XII. CORN YIELDS AND PLANT POPULATION DENSITIES ON TWENTY FARMS IN THE CAUCA VALLEY

Field Number	Field Size	Grain Yield (at 15.5% moisture)	Plant Density
	in plazas[1]	kilograms/hectare	plants/hectare
1	1/4	3,272	40,833
2	1/2	1,893	31,364
3	1/2	2,270	49,000
4	3/4	3,060[2]	37,500
5	1	3,073[2]	33,750
6	1	2,153[2]	32,467
7	2	3,644	50,543
8	2	1,988	28,182
9	2	3,720[2]	11,944
10	2	1,857[2]	30,000
11	3	3,333	42,000
12	3	4,306	35,625
13	6	3,197	26,136
14	7	4,729	54,079
15	8	3,134	39,000
16	15	3,952	43,290
17	22	3,798	27,625
18	30	4,503	28,925
19	70	5,644	55,361
20	80	4,947	38,850

[1] One plaza equals 0.64 hectares.

[2] These yields were produced from unimproved corn. All others used improved varieties or hybrids.

in Table XII. Since the yields of corn appeared to be related to field size, the average yields were calculated for various field sizes using two different methods — the one was a simple average of the corn yields from fields in a certain size group, the other was an average weighted by field size. These average yields are presented in Table XIII.

Table XIII indicates that corn yields apparently increased with farm size. This may be explained by the fact that as a farm size increased, farmers were more capable of commanding resources required for good corn yields, while the *minifundia* did not have such resources available.

The average yields of corn obtained in this survey in the Cauca Valley were considerably higher than the corn yields estimated for the department of Valle del Cauca, and presented in Tables VI and IX. Several reasons can be suggested for this. The corn yield estimates obtained from the survey were taken from the floor of the Cauca Valley only, while estimates of corn yields for Valle del Cauca include both the valley floor and the hill side fields. In addition, yields obtained in this survey were measured without harvesting or theft losses. Another possible reason was that by actually harvesting the corn, any tendency on the part of the owner to give a downward bias to yield estimates was avoided.

The average corn yield of the farms surveyed depends on the method of calculation used. Average yield calculated from an average of farm yields weighted by farm size was considerably higher than an average of farm corn yields with each farm given equal weight. The higher

TABLE XIII. AVERAGE CORN YIELDS FOR VARIOUS FIELD SIZES IN THE CAUCA VALLEY[1]

Field Size	Average Yields (simple average	Average Yields (av. weighted by field size)
plazas[2]	kilograms per hectare	
less than 1	2,624	2,598
1 to 5	3,009	3,160
6 to 10	3,686	3,684
greater than 10	4,569	4,925
all farms	3,424	4,695

[1] Calculated from the data presented in Table XII.

[2] One plaza equals 0.64 hectares.

estimate of average corn yields (4,695 kilograms per hectare) was calculated in the same way as the corn yield estimates by INA and the "Caja Agraria" given in Tables VI and IX. However, since the distribution of field sizes in the Cauca Valley was not necessarily the same as the distribution of field sizes in the survey, this average weighted by field size was subject to bias. No check on either estimate of average corn yields could be made since recent estimates of the distribution of field sizes were not available.

It must be pointed out that the corn yield survey was based on a judgement sample and hence was subject to sampling bias. Thus there were at least two potential sources of bias in the calculation of an average corn yield from the survey results to be representative of the Cauca Valley. Although these potential biases prevent use of these calculated average corn yields as a representative yield of the Cauca Valley, the results are important in understanding the level and pattern of corn yields by farm size in the Cauca Valley.

Plant populations per hectare were not closely related to the farm yields.

Survey of Corn Production Methods

During July and August of 1967, a survey of corn producing farms in the floor of the Cauca Valley was made between Florida and La Union. One hundred thirty-eight usable surveys were obtained although not all of them were necessarily complete in every respect.

The purpose of the survey was to find out how corn was produced, the methods used, the inputs used, and finally the use made of the corn produced. The survey was divided into nine parts.

1) General
2) Land Preparation
3) Planting Practices
4) Fertilizer Use
5) Irrigation Use
6) Insecticide Use
7) Herbicide Use
8) Machinery Use
9) Harvest and Distribution of the Corn Produced.

The questions in the schedule are presented in Appendix I. The results of many of the questions are presented in Appendix I also.

For presentation of the results of the survey, the respondents were divided into five groups according to the area of corn grown in the first semester (March - August) of 1967. The groups and the number of respondents in each group are as follows:

1)	50 plazas[3] or more of corn	17 respondents
2)	20-49 plazas	19 respondents
3)	10-19 plazas	13 respondents
4)	5-9 plazas	14 respondents
5)	less than 5 plazas	75 respondents

All of the questions relating to methods of production refer to the corn grown in the first crop semester (March - August) of 1967. The questions relating to yields, harvesting and distribution of the corn following harvest, refer to the previous crop, that is, the second semester of 1966. All of the 138 farms visited grew corn in the first semester of 1967.

General

Since farm size was closely related to the amount of corn grown on the farm, the results would have been very much the same had the farms been grouped according to farm size rather than amount of corn grown. Only two or three exceptions were noted.

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[3] One plaza equals 0.64 hectares. This unit of land is used since it is the most commonly used terminology of farmers (one plaza equals 1.57 acres).

The farmers with five to nineteen plazas of corn reported the highest yields of corn (3,634 to 3,897 kgms. per ha.), while the farmers with 20 or more plazas of corn reported yields of about one ton per hectare lower than this. The farms with less than five plazas of corn had the lowest yields, just over two tons per hectare. Lower yields on larger farms were contradictory to the results of the corn yield survey, reported previously. It could be that the larger farmers with more to fear from taxation deliberately understated their yields when replying to the interviewers. As well, the larger corn fields may be more difficult to supervise and hence robbery and harvesting losses might have been greater.

With regard to the kind of seed used all respondents with greater than ten plazas of corn who replied to the question, reported the use of an improved seed, purchased from either the Caja Agraria or Proacol Ltda. One farmer in the five to nine plaza category used unimproved seed. For the group of farmers with less than five plazas of corn who replied, 21 percent used unimproved seed, 27 percent used seed taken from a previous crop, and 51 percent used an improved seed.

The larger farms generally have used improved seed longer than the smaller farms. The use of improved seed has increased however on all farm sizes a great deal since 1966.

Neighbors and friends were apparently the most important source of information about improved production methods. Fifty-five percent of the farmers found out about improved seed from this source. Producers' organizations and the Caja Agraria and other governmental agencies were mentioned nineteen percent of the time. Newspapers and extension agents were seldom mentioned as providing information on improved seed. The commercial farmers tended to rely more upon extension agents, producers' organizations and governmental agencies than the smaller farmers.

Twenty-two percent of the farmers reported use of the product of a hybrid crop as seed. However this is much more common on the small farms as forty-one percent of the farmers with less than five plazas of corn indicated that they had grown second generation hybrid corn. Since this group has just recently become aware of the availability of hybrid corn seed, their use of second generation hybrid corn seed could increase considerably in the next few years. Instructions printed on the bag label may help to avoid this.

Farmers were asked if they planted corn continuously on the same field. This question must be treated with caution because the small farms often interplant corn, beans, platano, yuca, and other crops on the same field year after year. More than three-quarters of the farmers with less than five plazas of corn claimed that they planted corn on the same field year after year. Less than half of the farmers with more than five plazas of corn reported continuous planting of corn on the same field.

A legume, usually beans or soybeans, was often cited as a part of the crop rotation on the farms with more than five plazas of corn. Tomatoes, tobacco and beans or soybeans were more common as a part of the crop rotation on the small farms.

Land Preparation

The fields greater than five plazas in size were plowed once or twice, and worked with a disc or harrow at least three times in almost all cases. The fields with less than five plazas in size were plowed once or twice, and worked with a disc or harrow at least three times in almost all cases. The farmers with less than five plazas of corn who own or rent machinery, plow less often, usually once, and disc less often, seldom more than twice. Little or no hand preparation of the land occurred in fields of five plazas or more. About one-third of the fields of less than five plazas were prepared by hand.

The condition of the land was given almost unanimously as the way in which farmers determined the land was ready for planting. The land in the Cauca Valley is generally quite mellow and it is doubtful if the amount of work reported in this survey was necesssry in land preparation. The land was usually left barren as long as possible between crops and worked occasionally to stop weed growth. This occurred in the dry season and hence the top layer of soil is usually very dry by planting time. This leads to slow seed germination, forcing farmers to wait for planting until the rainy season has begun, or to irrigate. The effects of this late planting date and low soil moisture are discussed more fully in a later chapter.

Almost every farmer cultivated his corn after planting at least once either by hand or tractor cultivator.

Planting Practices

Nearly all fields of five plazas or more were planted by machine, while eighty-five percent of the fields of less than five plazas were planted by hand. Machinery can be used virtually everywhere on the valley floor. But, the smaller farms lack the resources to own or rent machinery and are more likely to hand plant corn.

The plant population per hectare and weight of seed corn used per hectare were much the same for all farm sizes. The weight of seed corn used per hectare was somewhat above the recommended rate of 18 kilograms per hectare. This could be explained by the fact that farmers recognized that a great many plants are lost by insect damage. As well, if the seed corn has been stored any length of time, the vigor of the plants during the first few days after germination was seriously impaired although the percent of the seed which germinates was within the tolerances specified on the label.

Fertilizer Use

The use of fertilizer is not a well established practice in the Cauca Valley. About one-half of the farmers with five plazas or more used fertilizer, while only one-fifth of the farmers with less than five plazas used fertilizer. The smaller the field of corn, the less likely was the farm to use fertilizer. The analyses of the fertilizers most commonly used were 45-0-0 (urea), 14-14-14, 10-20-20, and 10-20-10. There was not a wide variety of analyses of fertilizers available to farmers in the Cauca Valley.

Fertilizer was sometimes difficult to obtain at planting time but not necessarily at other times of the year. The fertilizer is sold in fifty kilo plastic bags, inside a burlap covered bag. Even with the plastic bag, however, the fertilizer draws water and cakes quite badly since it is not coated to prevent this. In discussions with farmers, they find this aspect of fertilizer use both time consuming and discouraging.

Of the forty-four farmers who used fertilizer, forty-eight percent used a soil sample to determine the analysis and the amount of fertilizer to use. Forty-one percent reported that they always bought the same analysis and amount per plaza each semester.

About one-half of the farmers using fertilizer applied the fertilizer by hand, and one-third of these farmers applied fertilizer by a mechanical spreader. Almost none of the farmers applied fertilizer with a fertilizer attachment on the corn planter.

The ninety-four farmers who did not use fertilizer were asked why they did not. Twenty percent of these farmers claimed fertilizer was too expensive, and twenty percent claimed that the land did not need fertilizer. Some of the farmers with small fields of corn claimed that it was not effective. In general, the larger farmers felt that the land did not need fertilizer, while the smaller farmers claimed that it was too expensive. Twenty percent of all these farmers could give no reason for not using fertilizer — they had not considered using it.

Irrigation Use

Forty-one percent of the farmers interviewed reported use of irrigation on corn. Of this forty-one percent, one-third used spray irrigation and two-thirds used flood irrigation. However, the larger farms were more likely to use irrigation than the smaller farms, and as well, the larger farms were more likely to have spray irrigation than flood irrigation.

Of the eighty-two farms which did not use irrigation on their corn, two-thirds claimed that they did not have a source of irrigation water, or that they did not have the equipment to apply irrigation. The remainder of them reported that irrigation was not needed because the rainfall was sufficient to grow corn, that irrigation was too expensive, or that irrigation was not effective in growing corn.

Insecticide Use

Ninety percent of the farmers growing five plazas or more of corn reported use of insecticide on their corn crop, while sixty-four percent of the farmers with less than five plazas of corn reported use of insecticide.

Insecticide was seldom applied more than three times to a crop of corn, more commonly only once or twice. It is doubtful if this was sufficient to check insect damage, but, on the other hand, no studies appear to have been done to determine how much insect damage the corn can withstand without significant losses in yield.

Insecticide was usually applied by hand as a powder, or by hand sprayer. Application by tractor mounted sprayers, light planes, or helicopters was infrequent.

One-third of the farmers who did not use insecticide claimed that it was not needed in corn production, and one-fifth claimed it was too expensive to apply to corn. Two-fifths did not reply. There were a variety of insects which could nearly always be found in a corn field. Root worms (tierrero) cut the stalk below the ground or damage the root system thus cutting off its water supply. Another common worm which seriously damages the foliage and stalk of the plant is "cogollero." The stalk damage by this worm contributed considerably to lodging of the corn, making harvest more difficult.

The corn grown in the Cauca Valley has very heavy husks on the ears which reduce the damage done by corn borer, although these husks considerably lengthen the time required for field drying of the corn.

Herbicide

Only nine of the one hundred thirty-eigth farmers interviewed reported use of herbicide. All of these nine farmers had ten plazas or more of corn. Hand methods of application were by far the most common. Gesaprim,[4] as a post-emergent, was the most commonly used herbicide.

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[4] Gesaprim is a commercial name of a herbicide similar to the herbicide commercially known as Atrazine in the United States.

A great number of reasons were given for not using herbicide. High cost, harmful to other crops in following semester, not effective in controlling weeds, harmful to the soil, not convenient and not necessary, were the most common responses.

Cultivation of corn fields, the only alternative to control weed growth, was nearly a universal practice as noted earlier. However the tropical climate and the heavy rains during the rainy season were very conducive to weed growth. Since machinery often could not be used during the rainy season in the fields, hand labor was the only other practicable method of controlling weeds if herbicides were not used.

Machinery Use

Machinery use in corn production was largely restricted to land preparation, planting, and cultivation. The large farms generally owned their machinery while the smaller farms contracted the plowing and discing when machinery was used. About one-third of the farmers with less than five plazas of corn used no machinery in corn production.

Harvesting and Crop Use

Very little use is made of mechanical corn harvesters in the Cauca Valley. Threats of violence are not uncommon by the farm laborers when mechanical corn harvesters are used. The initial cost of corn harvesting machines is very high, relative to the cost of hand picking.

Machinery harvesting of corn was largely confined to farms with at least twenty plazas of corn although less than half of these used machines for harvesting. Most of the corn was picked by hand. Two-thirds of the corn harvesting equipment was rented, usually from nearby farms.

On the farms with five plazas or more of corn, gangs of laborers, both men and women, were contracted by the farm for harvesting, assisted in part by the permanent farm workers in almost every case. However over half of the farmers with less than five plazas of corn reported the farm family harvested all or part of the corn and one-third used contracted groups only, for corn harvesting.

Harvesters were usually paid by the bulto,[5] rather than by area harvested, or by day. The harvesting cost per bulto may or may not include shelling. When shelling is included, the cost of harvesting is about eight pesos per bulto of shelled corn. Harvesting costs are about two to four pesos per bulto[6] of ear corn.

The farms with five plazas or more of corn sold virtually all of it. The farms with less than five plazas of corn sold about eighty-five percent, kept eleven percent for food and four percent for animal feed. Although asked, none of the farmers estimated losses by theft or spoilage.

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[5] A bulto is, literally, a bag. However, it is also a volume measure with specific weights assigned to various grains. One bulto of shelled corn is 75 kilograms.

[6] In this case, bulto means bag, not necessarily 75 kilograms.

The larger farms generally had storage space in sheds for all or nearly all of their crop. The small farms with less than five plazas of corn usually stored the amount they kept in a room in the house, and sold the remainder.

Farmers generally sold their corn soon after harvest; only about one-fifth of the farmers stated that they waited after harvest for a more favorable price.

Summary

The results of two farm surveys were reported in this chapter. The corn yield survey was undertaken to estimate corn yields on farms in the Cauca Valley. The purpose of the survey of corn production methods was to document the cultural and marketing practices of farmers in the Cauca Valley to better understand corn production problems and to enable useful recommendations to be made from the research reported later in this thesis. Neither survey can be purported to be free of sampling bias, since it was impossible to choose farms completely randomly.

The corn yield survey results indicated that corn yields on farms may very well be higher than reported yields. The corn production practices survey results, in general, indicated that there was a wide difference between the very large and very small farms in terms of inputs used, production methods, and use of the corn. One of the implications drawn from these surveys was that as recommendations were made to corn producers later in this report, account would have to be taken of the wide range of farm sizes.

CHAPTER V

SOME FACTORS AFFECTING CORN PRODUCTION

Several inputs in corn production and factors affecting productivity of corn are discussed in this chapter. Hypotheses are suggested which may be useful in explaining the effect of these factors used in corn production.

Planting Date

Farmers generally plant corn just prior to the rainy season in the Cauca Valley. The rainy season in the first crop semester[1] begins usually in late March and gradually ends in late June. The rains during the second crop semester begins in late September and last until late December or early January. If the crop is planted just prior to the season, subsequent rains provide moisture for crop growth.

It has been recognized that there was usually a difference in the corn yields which can be obtained in the two semesters, higher yields usually being obtained in the second semester. Tables III and IV of Appendix II provide a comparison of average corn yields and variances in the two crop semesters over a four year period. The

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[1] The first crop semester refers to March through August, and the second crop semester to September through February.

corn yields in the second semester were nearly always greater than corn yields in the first semester, and it was found that there was a statistically significant difference (0.05 level) in yields between semesters. Table I of Appendix IV also presents corn yields from a planting date experiment during 1963 and 1964 which indicate that the yields of corn from crops planted in September were considerably higher than those planted in March.

Two factors which could affect the productivity of corn during the semesters are rainfall and light energy. Since measurements of light energy in the Cauca Valley were not available, it was decided to use hours of sunshine per day as an estimate of energy available. Average hours of sunshine per day for thirty-six periods during the year,[2] and their variances are presented in Table I, Appendix V. These data for sunshine and rainfall are based on the years 1954-1964.

There was not a significant difference in amount of rainfall between the two semesters although the rainfall in the first semester seemed to be more intermittent than the rainfall in the second semester. (See Figure I, Appendix V). Based on the years 1930-1964, there was no difference in rainfall in the two semesters, however, the first semester averaged four ten-day periods without

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[2] Each month was divided into three parts, first to tenth day, eleventh to twentieth day, and twenty-first to the last day. The variance of this last period in the month was adjusted where necessary to represent a ten day interval.

rainfall, while the second semester averaged only 2.9 ten-day periods without rain during that 35 year period.[3]

The second semester tended to have more sunshine than the first crop semester although it seemed more irregular or intermittent than in the first semester (See Figure II, Appendix V).

To determine if rainfall was the only cause of the difference between yields obtained in each semester, a test was made on the Agricultural Experiment Station in Palmira in which corn was planted at various times over the two year period 1963-1964. Half of the plots were irrigated when the water available in the soil had fallen to fifty percent of the water holding capacity of the soil. Since this was well above the level at which wilting occurred, there should have been no lack of water for the corn on the irrigated plots. The other plots received enough irrigation to allow germination. The average yield of corn obtained in each of the twelve plantings is given in Table II, Appendix IV. The yields of corn were considerably lower when the corn was not planted during March-April, or September for both the irrigated and nonirrigated plots. As well, irrigation of the corn improved yields even when the corn was planted at the beginning of the crop semester. Finally, the corn grown in the second semester produced higher yields than the corn grown in the first semester. The conclusion reached was that available water was not the only factor causing a difference in yields in the two semesters.

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[3] Gomez, Jairo A., and McClung, A. Colin, "Influjo de la Irrigacion de la Poblacion, y la Fertilizacion con Nitrógeno en la Produccion y Otras Caracteristicas del Maiz," unpublished paper, Soil Section of the Agricultural Experiment Station in Palmira, 1965.

Some other factors were considered to explain the difference between semesters and the yields from corn planted at times other than the first of the semester. Since temperatures remained fairly constant during the year, well above the 55°F. required for corn growth, temperature was eliminated as a possible influence on corn yields in the Cauca Valley. The evaporation rate was not considered to significantly affect yields of corn grown under irrigation since the water available in the soil remained above 50 percent of the water holding capacity of the soil under irrigated conditions. The high evapotranspiration rates in the Cauca Valley could however contribute to the shortage of water on the nonirrigated plots. Although day lengths were long believed to influence both height and yield of corn, the day length in the Cauca Valley does not change by more than twenty to thirty minutes throughout the year. The days become progressively longer throughout the growing period of the first semester and progressively shorter during the growing period in the second semester. However since plant height increases and yields decline when the corn crop is planted late in both semesters, day length did not appear to explain the difference between yields of corn planted in each of the semesters, or between yields of corn planted earlier or later in the semester.

Rainfall and sunshine were the only factors for which data existed which could be used to explain the difference in corn yields obtained from corn planted at different times in the year. Both were used as explanatory variables in some production functions presented later in this report.

Irrigation

Irrigation of corn in the Cauca Valley has been recognized as a means of increasing yields of corn. Experience indicated that sufficient water for germination should be applied as soon as possible after planting. This should overcome the low viability of the seed resulting when the seed is left too long in the ground before germination, and allow the seedling to establish an initial root system before insects can damage the seed. Farmers seemed to be aware that long periods without rain or supplemental water after planting can result in poor corn crops. Generally, farmers who did not use irrigation in the Cauca Valley, often began to plant early in March or September and then systematically replanted the corn when rains had not come a certain number of days after planting.

Studies indicate that the most critical period for water use is the time between tasseling and filling of the ear, after which time water use drops sharply.[4] These results were confirmed by Gomez and McClung in experiments in the Cauca Valley.[5]

Table I, Appendix IV presents a comparison between yields of corn obtained under irrigated and nonirrigated conditions.[6] The corn plots receiving irrigation produced yields considerably above the yields produced by the nonirrigated plots. As well, nitrogen fertilization resulted in increased yields regardless of planting date only when supple-

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[4] Holt, R. F. and Van Doren, C. A., "Water Utilization by a Corn Field in Western Minnesota," Agronomy Journal 53:43-45, 1961.

[5] Gomez, Jairo A., and McClung, A. Colin, op. cit., pages 14-15.

[6] This experiment was referred to earlier under Planting Date, in this chapter.

mental water was added. This indicates that water may have been the limiting factor in corn production in this experiment. Irrigation will be used as an explanatory variable in two production functions presented later in this report.

Plant Density

Several factors influence the optimum plant density of corn. Water and nutrient requirements increase as plant populations increase. Higher plant densities usually increase the possibility of lodging and hence varieties resistant to lodging would probably have higher optimum plant densities, than those which were not resistant to lodging.[7]

Since insect damage of the stalk of the corn plant could lead to lodging, insecticide use may increase the optimum plant density. Weed control may raise optimum plant densities since weeds, if not removed, compete with the corn for water and nutrients.

Studies indicate that yields decline rapidly after a certain plant density has been reached. What this plant density is, depends on the many factors noted above.[8]

Much of the corn in Colombia is planted in hills, particularly the corn on small farms, and the corn in mountainous areas. On the commercial farms, where the terrain is adapted to machinery use, corn is usually planted in rows by machine. No studies have been done to compare the optimum plant densities for these two systems of planting nor have comparisons been made

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[7] Termunde, D.E., Shank, D.B. and Dirks, V.A., "Effects of Population Levels on Yield and Maturity of Maize Hybrids Grown on the Northern Great Plains," Agronomy Journal 55:551-555, 1963.

[8] Ibid, page 553.

between yields of corn obtained under each of these systems of planting. It would be expected that optimum plant densities under the two planting methods may depend on the variety of corn, since some may do well under competitive conditions while others may not.

It is interesting to note that the corn grown for breeding stock and the yield tests of the improved corn varieties and hybrids have been planted in hills. The objectives of this Corn Program in Colombia have been to help increase yields of corn on commercial farms which ordinarily plant corn in rows by machine. Although hill planting of corn may be the most accurate method of testing the difference in yield between two corn lines, no testing of the improved corn lines is made in rows before the variety is multiplied for general distribution.

Plant density is used as an explanatory variable in a production function presented later.

Nitrogen

Nitrogen is one of the soil nutrients most lacking in the Cauca Valley. However nitrogen fertilizer is still not widely used anywhere in Colombia. The effect of nitrogen on corn yields has been studied for several years in the Cauca Valley. In general the results indicate that the effect of nitrogen applications depends on many other factors with which it is combined.

Adequate soil moisture is necessary for nitrogen to be taken up by the plant. The corn yield data presented in Table I, Appendix IV

indicate that unless moisture was added, nitrogen applications as high as 200 kilograms per hectare did not increase corn yields.

It was pointed out earlier that the optimum plant density is probably related to the available nutrients in the soil. Studies also indicate that root development in corn and the efficiency of the use of soil water increase under higher applications of nitrogen.[9]

If the carbon to nitrogen ratio[10] in the soil is low, nitrogen applications do not seem to affect corn yields. The yields of Diacol H-205 corn in regional trials on land with a carbon to nitrogen ratio of approximately 12.4 showed no reaction to any of the nine levels of fertilizer use. The greatest increases in yields occurred with nitrogen applications to land with the highest carbon to nitrogen ratios. The yields of corn obtained on land with carbon to nitrogen ratio of 12.5 were approximately the same as the yields of corn grown on land with a carbon to nitrogen ratio of 22.5 when 200 kilograms of nitrogen per hectare were added. This indicated that nitrogen may not have been the limiting resource on lands with a low carbon to nitrogen ratio, while it may have been on lands with a high carbon to nitrogen ratio. (See Appendix III, Tables III and VI).

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[9] Linscott, D.L., Fox, R.L. and Lipps, R.C., "Corn Root Distribution and Mositure Extraction in Relation to Nitrogen Fertilization and Soil Properties," Agronomy Journal 54:185-189, 1962.

[10] For a discussion of the carbon to nitrogen ratio in soils, see Buckman, H.O., and Brady, N.C., The Nature and Properties of Soils, The Macmillan Company, New York, 1960, pages 146-155, and also, Thompson, L.M., Soils and Soil Fertility, McGraw-Hill Book Company, Inc., New York, 1962, pages 134-139.

The relationship between cation exchange capacity and corn yield has not been well established when the exchange capcity is of a reasonable level. Exchange capacity of soils is "the capacity of a soil to hold exchangeable ions."[11] The exchange capacity is expressed in milligrams of hydrogen or its equivalent in 100 grams of soil. The exchange capacity of a soil depends on the kind of clay material present in the soil, the percentage of clay in the soil and the percent of humus in the soil.

From the data of the regional trials in the Cauca Valley, it was noted that applications of nitrogen resulted in increased yields only when the exchange capacity was low, but still of reasonable level.[12] However, it is thought that since exchange capacity is related to the organic matter in the soil, the effect on yield of nitrogen fertilization attributed to the carbon to nitrogen ratio and the exchange capacity are one and the same.

Heavy application of nitrogen usually resulted in a higher protein content in the grain. Grain corn samples taken from a legume-corn rotation experiment indicated that plots receiving high applications of nitrogen both in the form of fertilizer and nitrogen fixed by legumes produced grain with a protein content significantly higher than corn grown without nitrogen applications in the second crop after the legume. Table V, Appendix II presents a comparison between the nitrogen content of the grain corn grown under various conditions in the corn-legume rotation.

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[11] Thompson, L.M., <u>op. cit.</u>, page 100.

[12] See Tables IV, V, VIII and IX of Appendix III.

The timing of nitrogen applications to the corn crop seem to have some effect on yields. Table VII, Appendix III presents yield data from two experiments in the Cauca Valley comparing three times for the application of nitrogen. In general, the conclusion suggested by these data was that the more nitrogen was applied to the crop, the earlier it should be put on. However, for moderate amounts of nitrogen, the recommendation by the Agricultural Experiment Station in Palmira of 1/3 of the nitrogen at planting time and 2/3 of the nitrogen when the corn is 70 centimeters high, appeared to be well taken.

Legumes included in a crop rotation were found to effectively increase corn yields and lower the amount of nitrogen which need be applied to the corn crop. Corn yield estimates from various corn-legume rotations are presented in Tables I, II of Appendix II. The inclusion of soybeans or alfalfa significantly increased yields of corn in the first crop of corn following the legume, whether or not additional nitrogen fertilizer was applied. The effect of the legume was diminished on the second corn crop after the legume, although the yields obtained from the second crop of corn after alfalfa were slightly higher than the yields of corn obtained from the second crop after soybeans. However, the alfalfa had been grown for two years consecutively prior to the corn whereas the soybeans had been grown for only one semester. As alfalfa is difficult to establish in the Cauca Valley, and since there is very little market for it, soybeans seemed to be the better legume to include in the rotation.

Yields of corn in the corn-legume rotations were increased significantly with added nitrogen. The yields of corn obtained with nitrogen added in the legume rotations were higher than yields of corn grown continuously with the same nitrogen fertilizer applications.

The optimum amount of nitrogen fertilizer to use when legumes are included in this crop rotation could not be determined since only two levels of nitrogen fertilizer were used, 0 and 200 kilograms per hectare. However, it would appear to be profitable to apply some nitrogen to corn grown in the first semester, immediately following a legume, since the average value product of each kilogram of nitrogen added was higher than the cost of the nitrogen. It would also seem profitable to have used nitrogen fertilizer on the second crop of corn following the legume.

A study completed using United States' data indicated that soybeans were expected to leave the equivalent of 84 pounds of nitrogen per acre[13] in the soil for a following crop.[14] However, since the amount of nitrogen fixed in the soil by legumes depends upon the initial soil fertility,[15] it would be difficult to apply these results directly to the Cauca Valley.

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[13] Ninety-five kilograms per hectare.

[14] Shrader, W.D., Fuller, W.A., and Cady, F.B., "Estimation of a Common Nitrogen Response Function for Corn (Zea mays) in Different Crop Rotations," Agronomy Journal, pages 397-401.

[15] Buckman, H.O., and Brady, N.C., op. cit., pages 425-426.

Phosphorus

There has been no consistent response of corn yields to phosphorus applications in the Cauca Valley. Some individual regional trials of corn, however, have shown a statistically significant response to phosphate fertilizer. The soil pH did not seem to restrict the availability of phosphorus since most soils in the Cauca Valley have a pH in the range of 5.7 to 7.0.

Potassium

Few, if any, signs of potassium deficiency have been observed in the Cauca Valley, and hence there has been no indication that potassium is seriously deficient.

Minor Elements and Micronutrients

There has been no indication of widespread deficiency of the minor and micronutrients in the Cauca Valley soils. However, it is possible that some shortage may occur as the soils are more intensively cropped.

Land Preparation

It was suggested earlier that farmers may be overpreparing their soils for the corn crop. This can lead to different effects. The upper part of the soil may become very dry, leading to very slow germination, particularly if irrigation is not used. It can also result in compaction of the soil, particularly in the lower strata, if the soil was tilled while it was quite wet. The tractors and machinery used in the Cauca Valley are generally quite large and heavy, and can easily cause soil compaction.

A study made in the United States indicates that soil compaction was found to be the physical property most highly correlated with reduction in growth and yield of corn, although no differences were found in soil moisture content, soil temperature, or percent of content of oxygen in the soil air.[16]

Insecticide and Herbicide Use

There were insufficient data to determine the increase in yields of corn expected from insecticide use. Although insects can devastate a corn field in the Cauca Valley very quickly, there are a great many insecticides available in Colombia which can provide adequate control of them. Some of these are: Aldrin (liquid or powder), Aldrex, Dipterex, and Parathion.

The cost of application is 17 pesos per hectare by helicopter or light plane, and 8 to 25 pesos per hectare by tractor sprayer depending on the amount of water used. Much of the insecticide, particularly Aldrin, in powder form, is applied by hand at a cost of 12 to 16 pesos per hectare.

There is no close substitute for insecticides in insect control. This has been recognized by farmers in the Cauca Valley as nearly all of them use insecticide in corn production. Although hand application seems less costly, this method is somewhat inefficient because of the amount

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[16] Kirkham, C., and Phillips, R.E., "Soil Compaction in the Field and Corn Growth," <u>Agronomy Journal</u>, Vol. 54, 1962, pages 29-33.

of powder wasted. However, application by tractor sprayers is limited because of the heavy rains making it nearly impossible to use machinery in a field during some periods in the growing season.

Two herbicides most commonly used are 2-4D Amine and Gesaprim.[17] Costs of application are approximately 32 pesos per hectare by light plane, or 25 pesos per hectare by tractor sprayer.

Hand labor or tractor cultivators are the only substitutes for herbicide. On the small farms, hand cultivation was used almost exclusively. Since the opportunity cost of farm labor is generally quite low, hand cultivation was used almost exclusively. Since the opportunity cost of farm labor is generally quite low, hand cultivation is probably the most profitable method of weed control on these small farms. On the other hand, adequate weed control on large farms can likely be accomplished most profitably by mechanical cultivation or by herbicide use depending on whether the land is dry enough to permit tractor use.

Meager data existed concerning the effect on corn yields by herbicides. Although the kind of herbicide was unknown, data are presented in Table X of Appendix III to compare corn yields grown with and without herbicide. While there was a marked increase in corn yields when herbicide was applied, it is unknown if it was economical to maintain this increase with herbicide.

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[17] A trade name, equivalent to Atrazine in the United States.

Summary

Several factors affecting corn yields were discussed in this chapter. The intent was to document as many factors as possible which may be useful in explaining corn yields. Some data were available which permitted empirical examination of the magnitude and direction of the influence of some of these factors. For other factors, however, where Colombian data did not exist, United States research results were used to document the influence of the factors on corn yields.

Some of the factors influencing corn yield suggested in this chapter are used in the subsequent chapter in designing a production model for corn. While the importance of many factors was recognized in this chapter, data did not exist to incorporate all of these into the production model.

CHAPTER VI

AN ESTIMATED PRODUCTION MODEL FOR CORN

The purpose of this chapter is to present a production model for corn grown in the Cauca Valley. An attempt is made to combine agronomic and economic information into the analysis. Data from an experiment at the Agricultural Experiment Station in Palmira were used to estimate production relationships between corn yields and nitrogen fertilizer applications, corn plant densities, and several weather variables.

The purpose of deriving this model was to develop economic optima for nitrogen, plant density, water use, and planting times. These optima, their derivations, and implications, are presented in the following four chapters of this report.

The Production Model

In constructing a production model, agronomic and economic information should be combined to provide a representation of the physical production process as it is employed by the economic units in the farming sector. In the case of corn in the Cauca Valley, this task was difficult since the farming units vary from a few hectares to many hundred hectares. The resources used to produce corn vary widely among these different sizes of farming units. Therefore the production model should be applicable to the wide range of farming situations in the Cauca Valley.

Variables Used in the Model

The previous chapter indicated the importance of many variables in the corn growing process. The selection of variables for the production function analysis was largely dictated by whether or not information was available on the variables. Many variables mentioned earlier had to be excluded on this basis, e.g., herbicide use, insecticide use, and land preparation practices. As well, some of the variables did not appear to be of significant value in explaining corn yields to pursue in a more rigorous analysis, e.g., phosphorus and potassium fertilizers, and day length. Hence, the variables selected for use had to meet two criteria; first, the variables had to be relevant to the explanation of corn yields, and secondly, data had to be available on the variable which, in turn, could be incorporated into the model.

The variables meeting these specifications were nitrogen fertilizer, planting date, planting density, rainfall, irrigation, and sunlight. Although no corn yield experiments conducted in the Cauca Valley specifically included all of these variables, daily observations on sunlight, rainfall, and the amount of irrigation were available which could be matched with a corn yield experiment involving planting date, plant density, nitrogen fertilizer, and irrigation.

Initially, attempts were made to include planting date specifically as a variable in the analysis. However, few useful relationships could be found. Since planting date was a proxy variable for the characteristics of weather and seasonal growing conditions, it was decided to replace the planting date variable with the weather variables, sunlight and rainfall. Corn yields specific to any planting date could then be predicted for any planting date by using the mean values of the weather variables characterizing that planting date. Thus, planting date is not represented in the model as a variable, but it is included implicitly into the model by use of its characteristics.

The problem faced when characterizing planting dates with weather variables was how many variables are needed, and what characteristics should be embodied in this description. For example, should one variable for rainfall be used during the entire growing period? Furthermore, the water requirements of corn change considerably over the growing season. On the other hand, if all of rainfall, sunlight, temperature, humidity, and evapotranspiration rates were used, statistical problems, such as multicollinearity, could make both estimation and interpretation difficult.

The variables, humidity and evapotranspiration rate could not be controlled by either the researcher or the corn producers in the Cauca Valley. Furthermore, the effects of humidity and evapotranspiration rates can largely be overcome by providing supplementary water to corn plants through irrigation. The temperature variable also could not be controlled, but it was pointed out earlier that as long as temperature was above 55°F., there was little indication of a direct effect of temperature; however, it does influence both humidity and evapotranspiration rates, which in turn can influence corn yields significantly when soil water is inadequate. Hence, these variables were excluded from the descriptive weather variables even though it is recognized that they are not controlled, and can influence corn yields.

Although sunlight cannot be controlled, it was considered necessary to include some measure of the sunlight energy available in the Cauca Valley. This energy can affect temperature, and evapotranspiration rates. Since data were not available on the energy level from sunlight, the proxy variable, hours of direct sunshine per day was used. Although this is only a crude measure of the sunlight energy, it was the only measure available. As a result, the variables used to portray growing conditions were sunlight and rainfall.

The final problem of how to use variables for sunlight and rainfall to characterize a planting date was solved in the following manner. The first hundred days after planting of each corn crop were divided into ten 10-day periods. The average daily hours of sunshine and the total amount of rainfall during each of the periods was calculated from records at the Experiment Station. Then one sunlight variable and one rainfall variable were designated for each of the ten 10-day periods. The choice of 10-day intervals was a compromise between two alternatives. For periods longer than ten days, effects of extreme dryness or wetness could be observed since the effects of rainfall usually dissipate in less than ten days. For periods shorter than ten days, the carryover effects of rainfall could influence one or more following periods. Hence ten day intervals seemed the relevant time periods. The possibility of aggregating these variables across the ten periods for each planting was briefly considered. It was rejected because there was no a priori procedure whereby the rainfall or sunlight could be aggregated according to some measure of their importance in the growth and yield of corn.

The inclusion of both rainfall and irrigation as variables in the production model presented some serious theoretical problems. To include both suggests that a marginal product of both rainfall and irrigation existed. Although water from rainfall cannot be controlled, it can be supplemented with water from irrigation, hence the marginal product of water could be calculated in two ways if both variables are included. To circumvent this problem of interpretation of two marginal products of water, water from rainfall was added to water from irrigation, for each of the ten 10-day periods. The implicit assumption made was that one millimeter of rainfall was equivalent to one millimeter of irrigation water. Thus, only one water variable was used for each 10-day period.

In summary, twenty-two variables were chosen. They were: kilograms of nitrogen fertilizer, plant density, average daily hours of sunshine for each of the ten 10-day periods, and total millimeters of water applied in each of the ten 10-day periods.

The Data

The basic data were drawn from an experiment carried out by the Soils Section on the Experiment Station at Palmira during 1963-1964. Four levels of nitrogen fertilizer, three levels of seeding density, two levels of water use, replicated twice was the design of the experiment. The four levels of nitrogen fertilizer were: 0, 50, 100, and 200 kilograms per hectare. The two levels of water use were: (1) natural rainfall, no irrigation, and (2) natural rainfall plus irrigation when the soil water fell to 50 percent of the water holding capacity of the soil. This design was repeated twelve times at about two month intervals over a two year period.[1] There were 48 observations for each planting date and 576 observations in all.

The records kept by the Experiment Station on the experiment included data on the plant density at harvest and the date and quantity of irrigation water added. From the meteorological records at the Experiment Station in Palmira, daily records of rainfall and hours of direct sunshine were available. As a result, these data could be incorporated into the model along with the basic data from the experiment.

For one of the variables there was a choice between either of two definitions with data available for either specification. Seeding density—the number of seeds planted per hectare—was one of the variables originally used in the experiment. Only three levels of seeding density were included in the experiment. In addition, records

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[1] For the twelve planting dates, see Appendix IV, Table II.

of the plant density at harvest were available. The plant density at harvest did not seem to be a three-valued variable but rather a continuous variable ranging from far below the lowest seeding density up to the highest seeding density. The choice of which data series to use for plant density was based partially on the interpretation preferred for the variable and partially on which of the two series would be expected to explain more variation in corn yields.

To interpret a seeding density variable, the marginal product of seeding density would be the change in corn yield for a given change in seeding density. However, this relationship does not take into account the knowledge that the level of rainfall and irrigation, and nitrogen fertilizer applications can significantly alter the plant density at harvest from the initial seeding density and result in vastly different corn yields for the same seeding density. Thus, the marginal product of seeding density would be conditional upon the level of use of other resources required for corn growth.

The interpretation of a plant density at harvest variable is more tenable. The marginal product of plant density at harvest would be the change in corn yields for a given change in plant density at harvest. This marginal product would be free of the conditions placed on the seeding density variable. When using the model to make recommendations to farmers concerning seeding density, these interrelationships can be taken into account by recommending a seeding density conditional upon the level of use of other resources. This method implies the use of some knowledge of the relationship between seeding density and plant density at harvest, and their effect on yield.

It was felt that plant density at harvest would be more useful in explaining variation in corn yields than would seeding density. When low levels of nitrogen and available water were used, corn yields were expected to be quite insensitive to seeding density, while at higher levels of nitrogen and available water corn yields may be quite sensitive to seeding density. On the other hand, it was felt that corn yield could be equally sensitive to plant density at harvest for all levels of use of the other resources. By this argument, then plant density at harvest was expected to explain a greater percentage of the variation in corn yields. Plant density at harvest was finally chosen as the more useful of the two measures of plant density.

The Model

Inspection of the data indicated that observations were taken from at least stages II and III of production. Little evidence could be found to conclude that observations were taken from the left of the inflection point[2] in stage I. Thus, the functional form had to be able to incorporate both stages II and III and that part of stage I to the right of the inflection point on the production surface. The polynominal production function was chosen because of its ease of estimation and interpretation. A second degree polynominal was sufficient to include

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[2] The inflection point is defined as that point at which the second derivative changes sign while the first derivative maintains the same sign. For the production function, the inflection point occurs at the same level of input as the maximum marginal product.

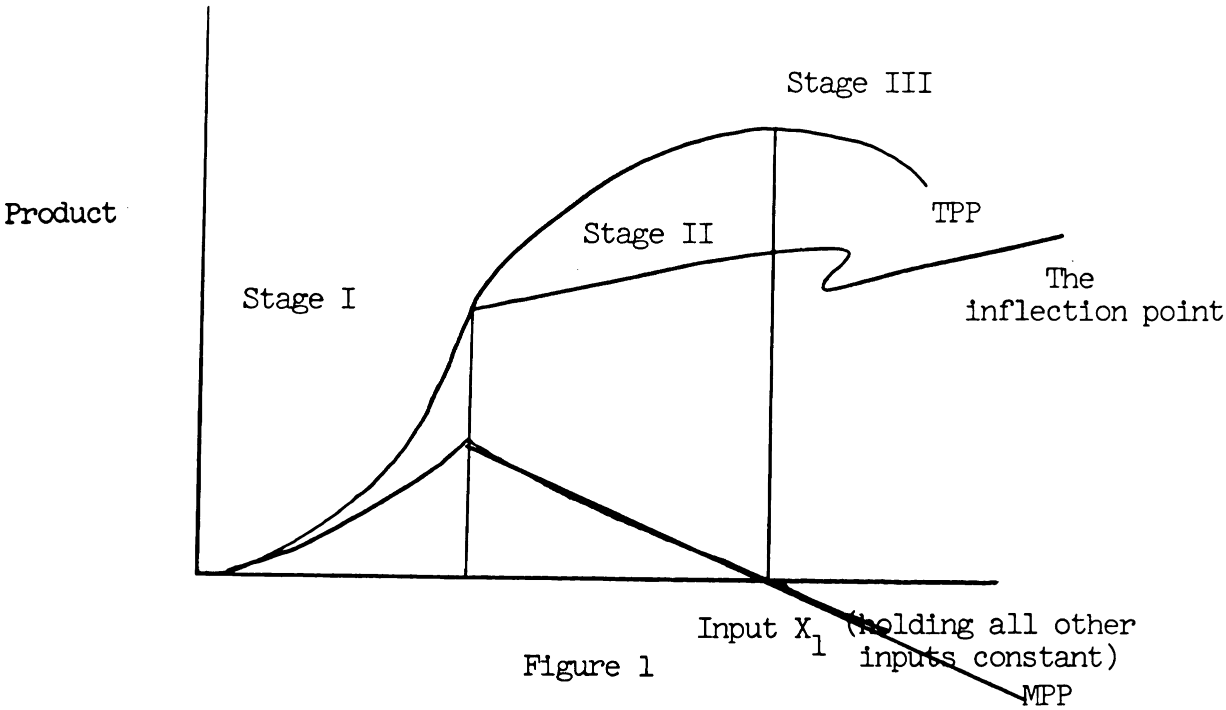

Figure 1

stages II and III, and that part of stage I to the right of the inflection point in the production surface. Although the polynominal production function can more quickly reduce the number of degrees of freedom in estimation than other structural forms, this problem was not serious in this analysis because of the large number of observations available.

The general form of the second degree polynominal production function with k variable inputs is:

$$Y_t = \delta + \alpha_1 X_{t1} + \alpha_2 X_{t2} + \dots + \alpha_k X_{tk} + \beta_1 X_{t2}^2 + \dots$$

$$+ \beta_k X_{tk}^2 + \omega_1 X_{t1} X_{t2} + \omega_2 X_{t1} X_{t3} \dots + \omega_s X_{tk-1} X_{tk} + \varepsilon_t$$

where: $s = 1/2\ k\ (k-1)$

k = number of explanatory inputs

$t = 1, 2, \dots, T$

T = number of observations

X_{ti} = t^{th} observation on the i^{th} input ($i = 1, 2, \ldots, k$)

Y_t = t^{th} observation on the output (endogenous) variable

ε_t = the random disturbance

In developing a polynominal form applicable to the data from the corn experiment, it was felt that some modifications of the general second degree polynominal form were necessary. First of all, not all cross-product terms were considered to be of importance. The economic justification for a cross-product term is to include the interaction between two inputs to influence total product. In this context there was no basis for assuming that an interaction term composed of sunlight during the first ten days after planting and sunlight or rainfall during any of the other ten-day periods was relevant. It was possible, however, to hypothesize some interaction between sunlight and rainfall during the same ten-day period after planting. Secondly, because of the possibility of interaction between more than two of the inputs, interaction terms between three and four inputs were included. Again two or more sunlight variables were not allowed in the same interaction term and two or more rainfall variables were not allowed in the same interaction term. When both sunlight and rainfall variables were combined with either nitrogen and/or plant density variables in the same interaction term, the sunlight and rainfall variables had to represent conditions in the same ten-day period following planting. In this manner, instead of 231 possible two-variable interaction terms, there were 51; instead of 1540 three-variable interaction terms, there were 40; and instead of 7425 four-variable interaction terms, there were 10. In total there were 146 explanatory variables specified; 23 linear terms, 22 squared terms, 51 two-variable interaction terms, 40 three-variable interaction terms, and 10 four-variable interaction terms. They are:

X_o = constant

X_1 = kilograms of grain corn per hectare

X_2 = kilograms of nitrogen applied per hectare

X_9 = thousands of plants at harvest per hectare

X_{16+i} = average hours of direct sunshine per day in the i^{th} ten-day period after planting ($i = 1, 2, \ldots, 10$)

X_{46+i} = total millimeters of water added by rainfall and irrigation in the i^{th} ten-day period after planting ($i = 1,2,\ldots,10$)

$X_{57} = X_2^{\,2}$

$X_{58} = X_9^{\,2}$

$X_{58+i} = (X_{16+i})^2$ for $i = 1, 2, \ldots, 10$

$X_{68+i} = (X_{46+i})^2$ for $i = 1, 2, \ldots, 10$

$X_{78+i} = (X_{16+i}) \cdot (X_{46+i})$ for $i = 1, 2, \ldots, 10$

$X_{88+i} = X_2 \cdot (X_{16+i}) \cdot (X_{46+i})$, for $i = 1, 2, \ldots., 10$

$X_{98+i} = X_9 \cdot (X_{16+i}) \cdot (X_{46+i})$, for $i = 1, 2, \ldots, 10$

$X_{108+i} = X_2 \cdot X_9 \cdot (X_{16+i}) \cdot (X_{46+i})$, for $i = 1, 2, \ldots., 10$

$X_{118+i} = X_2 \cdot (X_{16+i})$, for $i = 1, 2, \ldots, 10$

$X_{128+i} = X_2 \cdot (X_{46+i})$, for $i = 1, 2, \ldots, 10$

$X_{138+i} = X_9 \cdot (X_{16+i})$, for $i = 1, 2, \ldots, 10$

$X_{148+i} = X_9 \cdot (X_{46+i})$, for i = 1, 2, ..., 10

$X_{158+i} = X_2 \cdot X_9 \cdot X_{16+i}$, for i = 1, 2, ..., 10

$X_{168+i} = X_2 \cdot X_9 \cdot X_{46+i}$, for i = 1, 2, ..., 10

$X_{179} = X_2 \cdot X_9$

With the 146 explanatory variables in the production model, the function becomes very unwieldy and cumbersome. Although there was no a priori information by which the number of variables could be reduced, some reduction in the number of variables was needed before the model was estimated. The statistical problem of dealing with this many variables is immense and estimation may in fact be impossible. This problem is dealt with in the following chapter.

Summary

This chapter has presented the economic and agronomic background for the choice of the variables included in the model, the data used to estimate the model, and the structural form of the production model. There were twenty-three variables chosen originally—a constant, nitrogen, plant density, ten sunlight and ten water use variables. The data were drawn from an experiment conducted during 1963 and 1964 at Palmira in the Cauca Valley. A second degree polynomial with selected cross product terms was presented as the structural form. Although there were twenty-three original variables, there were 123 additional variables in the function. Estimation of this function is discussed in the following chapter.

CHAPTER VII

ESTIMATION OF THE PRODUCTION MODEL

This chapter deals with the procedure followed to estimate the production model derived in the previous chapter. The estimation procedure involved two purposes: one was to aid in the selection of relevant variables from the 146 possible variables, the second was to obtain the estimated regression coefficients for these relevant variables. A description of the statistical procedure is followed by a presentation of the estimated production model. Several statistical tests are performed to assess the appropriateness of the model and its applications.

Estimation - Problems and Procedure

In the previous chapter it was pointed out that the production model was very unwieldy and cumbersome because of the large number of explanatory variables. Furthermore, estimation may be impossible. However, there was no a priori economic or agronomic information by which the relevant explanatory variables could be selected from the 146 variables. For this reason it seemed appropriate to chose a statistical estimation procedure by which both selection of relevant variables and estimation of the resulting function could proceed simultaneously.

To present the estimation problem in more detail, the model developed in the preceding section can be written in general as:

$$X_1 = f\ (X_0, X_2, X_9, X_{17}, X_{18}, \ldots., X_{26}, X_{47}, X_{48}, \ldots., X_{179}) - - - - (1)$$

where (1) indicates that X_1 is some linear combination of the 146 variables. Estimation of this equation using ordinary least squares, or maximum likelihood procedures was subject to two shortcomings. First, both the ordinary least squares and maximum likelihood methods require that the 146 observations vectors be linearly independent. Since twenty-two original variables were used to make up all others, the possibility of near exact linear dependence was very high, making estimation impossible. The second problem was that while estimation may be possible with the entire 146 explanatory variables, the standard errors of the estimated regression coefficients could be very large with the result that the estimated coefficients can not be distinguished from zero at a reasonable level of Type 1 error. This problem, in general, is known as multicollinearity.[1]

To overcome these problems, a step-wise regression estimation procedure was used. Several step-wise estimation procedures are available. Most of these procedures can be described as a method by which variables are selected to enter the function one at a time in a particular sequence according to some specified criteria. The alternative methods of step-wise regression differ by the criteria used to determine which variable should enter the function at any step. The method used in this

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[1] For more complete discussions of this problem see Johnston, J., Econometric Methods, McGraw-Hill Book Co., Inc., New York, 1963, pages 201-207, or Goldberger, A.S., Econometric Theory, John Wiley and Sons, Inc. New York, 1964, pages 192-194.

analysis was to have that variable enter the function, which, upon addition to the function, would increase the coefficient of determination (R^2) more than any other variable remaining outside the function. No specifications were placed upon the level of significance of the deviation of the estimated regression coefficient from zero. In theory with 146 explanatory variables, the result of this step-wise procedure should be 145 different[2] estimated equations in an order such that each equation has one more explanatory variable than the preceding estimated equation. In practice, however, it may be impossible to complete all of the 145 regressions because of the near linear dependence between the 145 observation vectors.

As more and more variables are included in the estimated regression model, the coefficient of determination (R^2) will continue to rise monotonically, although it will increase at a progressively slower rate. The relationships

$$R^2 = \frac{SSR}{SST} = \frac{\text{Regression Sum of Squares}}{\text{Total Sum of Squares}} \quad \text{-----------} \quad (2)$$

and $$SST = SSR + SSE \quad \text{-----------} \quad (3)$$

where $SSE = \text{Error Sum of Squares}$

indicate that error sum of squares must decline monotonically as more explanatory variables are added to the function because the total sum of squares is constant, regardless of the number of explanatory variables in the function.

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[2] The constant, X_o, is included in all equations and X_1 is not regressed on X_o individually, thus there are only 145 different equations possible.

The standard error of estimate (S),

$$S = \frac{1}{T-k} \cdot SSE$$

where T = number of observations

k = number of explanatory variables

is expected to first decline and eventually rise again as more and more variables are included in the estimated model. The standard error of estimate initially declines because the decrease in SSE more than offsets the decrease in T-k. Eventually the incremental change in SSE, as another variable enters the function, becomes so small that the incremental change in T-k will raise the standard error of estimate.

Another phenomenon which appears as variables added to the function is that both the value and statistical significance of estimated regression coefficients of variables already included in the function can change. The statistical significance of the deviation of a regression coefficient from zero can decrease because of an increase in the sample variances of the regression coefficients. This increase in sample variances of the regression coefficients can be caused by the multicollinearity problem referred to earlier.

In the discussion of the production model, reference was made to the fact that because of the inability to delete from the 145 variables, those variables which were not of importance in explaining corn yield, using only <u>a priori</u> information, use would be made of the estimation procedure to assist in the selection of relevant variables. The stepwise regression procedure can assist in this selection of relevant variables because each variable is selected to enter the function on the basis of explaining more of the remaining variation in corn yield than any other variable outside the function. To some degree, then the variables were selected in an order according to their importance in explaining corn yields within this experiment. The problem remaining was when to stop including variables, i.e., where was the dividing line to be drawn between relevant and irrelevant variables?

The function finally chosen contained thirty-eight explanatory variables including the constant term. There were several reasons for this. The last variable to enter the function was the "nitrogen squared" variable thus making it possible to calculate an economically optimal level of nitrogen fertilizer use for a given rainfall and sunlight pattern. The standard error of estimate was approaching its minimum; it was within 2.5 percent of its minimum. The estimated values of the regression coefficients of the first few variables to enter the function initially had fluctuated widely, as more variables entered the function. By the addition of the thirty-eighth explanatory variable, these estimated regression coefficients had become quite stable as new variables entered the function. Finally, the levels of significance of the deviations of the estimated regression coefficients from zero began to fall sharply after the addition of about the thirty-eighth to fortieth variable. The estimated regression coefficients, their standard errors, their levels of significance when tested different from zero with a t-test and the R^2 deletes are given for the thirty-eighth variable function in Table XIV. The variables are listed in order of entry into the function.

TABLE XIV. THE ESTIMATED REGRESSION COEFFICIENTS, THEIR STANDARD ERRORS, SIGNIFICANT LEVELS, AND R^2 DELETES FROM THE THIRTY-EIGHT VARIABLE PRODUCTION MODEL

Variable	Description[3]	Estimated Regression Coefficient	Standard Error of Coefficient	Significance[1] Level	R^2 Delete[2/]
X_0	Constant	24556.6305	3773.9302	<0.0005	
X_{51}	5th Water	-163.7094	40.6380	<0.0005	0.814
X_{73}	${X_{51}}^2$	0.4488	0.1811	0.013	0.818
X_{108}	$X_9 \cdot X_{25} \cdot X_{55}$	0.5832	0.1104	<0.0005	0.810
X_{83}	$X_{21} \cdot X_{51}$	31.2951	5.5236	<0.0005	0.809
X_{158}	$X_9 \cdot X_{56}$	-3.3951	0.6674	<0.0005	0.811
X_{20}	4th Sunlight	-340.4203	225.5839	0.128	0.819
X_{172}	$X_2 \cdot X_9 \cdot X_{50}$	0.0008	0.0003	0.013	0.818
X_{23}	7th Sunlight	-6364.1357	544.6960	<0.0005	0.774
X_{80}	${X_{18}}^2 \cdot X_{48}$	5.7833	2.4331	0.017	0.818
X_{76}	${X_{54}}^2$	1.2320	0.1719	<0.0005	0.803
X_{49}	3rd Water	97.2011	26.5813	<0.0005	0.815
X_{107}	$X_9 \cdot X_{24} \cdot X_{54}$	-0.0005	0.0823	0.946	0.820

TABLE XIV. (Continued).

Variable	Description[3]	Estimated Regression Coefficient	Standard Error of Coefficient	Significance[1] Level	R^2 Delete[2/]
X_{157}	$X_9 \cdot X_{55}$	0.2597	0.4488	0.570	0.820
X_{65}	$X_{23}{}^2$	519.1344	47.7077	<0.0005	0.780
X_{17}	1st Sunlight	384.8508	154.5873	0.013	0.818
X_{54}	8th Water	-137.6608	15.6598	<0.0005	0.794
X_{71}	$X_{49}{}^2$	-0.4989	0.1145	<0.0005	0.813
X_{81}	$X_{19} \cdot X_{49}$	-4.5099	2.6086	0.080	0.819
X_{53}	7th Water	-49.6334	10.8152	<0.0005	0.813
X_{50}	4th Water	22.6045	5.3874	<0.0005	0.814
X_{98}	$X_2 \cdot X_{26} \cdot X_{56}$	-0.0091	0.0022	<0.0005	0.814
X_{95}	$X_2 \cdot X_{23} \cdot X_{53}$	-0.0028	0.0040	0.484	0.820
X_{87}	$X_{25} \cdot X_{55}$	-8.1036	1.6112	<0.0005	0.811
X_{58}	$X_9{}^2$	-1.0807	0.2188	0.0005	0.811
X_9	Plant Density	142.3529	50.5148	0.005	0.818
X_{78}	$X_{56}{}^2$	0.2777	0.1016	0.006	0.817
X_{169}	$X_2 \cdot X_9 \cdot X_{47}$	-0.0016	0.0005	0.001	0.816

TABLE XIV. (Continued)

Variable	Description[3]	Estimated Regression Coefficient	Standard Error of Coefficient	Significance[1] Level	R^2 Delete[2/]
X_{175}	$X_2 \cdot X_9 \cdot X_{53}$	0.0020	0.0005	<0.0005	0.815
X_{141}	$X_9 \cdot X_{19}$	-10.3092	3.8764	0.008	0.817
X_{125}	$X_2 \cdot X_{23}$	0.8660	0.2904	0.003	0.817
X_{21}	5th Sunlight	-823.9487	251.9980	0.001	0.816
X_{56}	10th Water	-17.6515	11.5681	0.123	0.819
X_{143}	$X_9 \cdot X_{21}$	14.1562	5.6263	0.012	0.818
X_{140}	$X_9 \cdot X_{18}$	-9.1718	3.6721	0.012	0.818
X_{145}	$X_9 \cdot X_{23}$	-4.8821	2.4052	0.040	0.818
X_{26}	10th Sunlight	-339.2539	198.2605	0.084	0.819
X_{57}	$X_2{}^2$	-0.0108	0.0068	0.106	0.819

$R^2 = 0.82$ $\bar{R}^2 = 0.81$ Standard Error of Estimate = 833.3890

[1] The level of significance indicates the probability that the estimated regression coefficient differs from zero.

[2] The R^2 delete is the R^2 which would have occurred if that variable had been excluded from the estimated equation.

[3] Each of the composite variables is given in terms of the original twenty-two variables.

The usual assumptions of classical least squares estimation procedure were assumed to hold. They were:

(i) $E(\varepsilon i) = 0 \quad i = 1, 2, \ldots, 576$

(ii) $E(\varepsilon\varepsilon') = \sigma^2 1$

where ε is the 576 x 1 vector of random disturbances and 1 is a 576 identity matrix.

(iii) The X_j, ($j = 0, 2, 9, 17, 18, \ldots, 26, 47, 48, \ldots, 179$) are assumed to be non-stochastic and fixed in repeated samples.

(iv) The X matrix (matrix of 576 observations on 38 variables) is of rank

$m < T$ where m = number of explanatory variables

T = number of observations.

To justify the use of Student's t-distribution in determining the significance level of the estimated regression coefficients, one further assumption was required. This assumption is that the disturbance terms (ε_i, $i = 1, 2, \ldots, 576$) are normally distributed.

In summary, the two-fold problem of estimation and selection of relevant explanatory variables was met with a step-wise regression procedure. The estimated production model chosen contained 38 explanatory variables including the constant term. The following section presents the results from several statistical tests of the model designed to determine the accuracy and appropriateness of the estimated model.

Testing the Estimated Model

The estimated model presented in the previous section containing 38 explanatory variables was chosen somewhat arbitrarily. For this reason, several statistical tests were performed to judge the appropriateness and usefulness of the estimated model. The first set of tests were designed to determine whether or not more or less variables should have been included in the model. The second test deals with the importance of the individual variables in explaining the variation in corn yield. The third statistical measure concerns the adequacy of the model as a whole in explaining corn yield variation. The final test is an inspection of predictive ability of the estimated model.

Before proceeding to the first set of tests to determine if more or less variables should have been included in the model, the consequences of the inclusion or exclusion of relevant and irrevelant variables should be noted. It can be shown that exclusion of relevant variables can lead to biased and inconsistent estimates of the regression coefficients corresponding to the included variables. Thus the cost of including relevant or important variables may be measured in terms of the bias or inconsistency of the estimates. Furthermore, the extent of the bias and inconsistency varies directly with the correlation between the included and relevant excluded variables. Because of the way in which many of the 146 variables were formed, these correlations could be quite high, causing significant bias and inconsistency in the estimated regression coefficients.

On the other hand, the inclusion of irrelevant or unimportant variables leaves the estimated regression coefficients corresponding to all of the included variables unbiased and consistent although possibly less efficient than if all irrelevant variables had been excluded. This loss of efficiency is related directly to the correlation between the relevant and irrelevant variables included in the estimated model. Thus, the cost of including irrelevant variables is a loss of relative efficiency but not a loss of the unbiasedness and consistency of the estimated regression coefficients. Since the significance levels of the estimated regression coefficients in the 38 variable model seemed acceptable, the exclusion of relevant variables would appear to be a more serious error than inclusion of irrelevant variables. Thus the model was tested only for exclusion of relevant variables from the model.

One assumption upon which the above discussion rested was that if a variable as it entered the function using the step-wise procedure could be determined to be irrelevant in explaining corn yield variation, then all variables individually remaining outside the function were considered to be irrelevant as well. However, this assumption did not imply that a group of individually irrelevant variables remaining outside the function could not be jointly important in explaining the variation in corn yield.

On this basis, tests of significance were performed to determine if the excluded variables did in fact significantly increase the regression sum of squares. The null and alternate hypothesis may be stated in general form as:

$H_o : \beta_{k+1} = \ldots. = \beta_H = 0$

$H_A : H_o$ not true

where:

k = the number of variables included originally in the function;

H = the number of variables included originally in the function, augmented with H-k variables whose relevancy in explaining variation in the dependent variable is being questioned.

Goldberger[3] derives a test statistic for this test:

$$F = \frac{\Delta SSR/(H-k)}{SSE/(T-H)}^4$$

where:

ΔSSR = the change in regression sum of squares due to the inclusion of the additional H-k variables;

SSE = the error sum of squares resulting when the dependent variable is regressed upon H variables;

T = number of observations.

The test statistic is distributed as an F-distribution with H-k and T-H degrees of freedom; high values of the test statistic lead to rejection of the null hypothesis that the endogenous variables does not depend upon X_{k+1}, X_{k+2}, ..., K_H.

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[3] Goldberger, A.S., Econometric Theory, John Wiley and Sons, Inc., New York, 1964, pages 196-177.

[4] This test statistic differs only in notation from the one given by Goldberger.

When one more variable was included in the model (H-k = 1, or H = 39), the calculated value of the test statistic was 0.074. Using a Type 1 error level of 5 percent, the value of F with 1 and 537 degrees of freedom is approximately 254.3. Thus, the null hypothesis was accepted that the dependent variable—corn yield—does not depend upon the thirty-ninth variable. When 13 more variables were included in the function, the calculated value of the test statistic was 1.98. The value of F with 13 and 525 degrees of freedom using a Type 1 error level of 5 percent, is 2.21. Again the null hypothesis that corn yields did not depend upon the 13 variables must be accepted. Furthermore, by the entry of the fifty-first variable, the significance levels of the estimated regression coefficients were falling quickly. This probably indicated that relative efficiency was being lost by the inclusion of variables correlated with the original 38 variables, i.e., the multicollinearity problem. It was concluded that although more variables could have been included in the function, additional variables did not appear to explain a significantly larger part of the variation in corn yields.

By studying the variables which entered the function, and their estimated regression coefficients, several points could be noted. By regrouping the variables, it can be seen that there were twelve linear terms, seven squared terms, eleven two-variable interaction terms, and seven three-variable interaction terms. Only two of the original 22 variables did not appear in the estimated function in any form. They were the sunlight and water variables for the sixth interval after planting, i.e., the 51st to 60th days after planting. No particular significance could be attached to or found for this omission from the function.

The rainfall and sunlight variables appeared to dominate the function. Only four of the 38 explanatory variables did not contain either a sunlight or a rainfall variable—the plant density variable, the squared nitrogen and squared plant density variable, and the constant term. Twenty-three variables contained some rainfall variable, and 19 variables contained some sunlight variable. Nine variables contained both sunlight and rainfall variables.

The magnitudes of the estimated regression coefficients can be misleading if interpreted as a measure of importance of their corresponding explanatory variable on the dependent variable-corn yields. Goldberger suggests use of the "beta coefficient" for this.[5] Although the two largest beta coefficients correspond to sunlight variables, there are several large beta coefficients corresponding to rainfall variables.

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[5] Goldberger, A.S., Econometric Theory, John Wiley & Sons, Inc., New York, 1964, pages 197-200. The "beta coefficient" is defined as:

$$\beta_j = b_j \frac{S_{jj}}{S_{yy}}$$

where β_j = the beta coefficient

$$S_{jj} = \{ \sum_{t=1}^{T} (X_{tj} - \overline{X}_j)^2 \}^{\frac{1}{2}} = \text{T. Std. Dev. of } X_j$$

$$S_{yy} \quad \{ \sum_{t=1}^{T} (Y_t - \overline{Y}) \}^{\frac{1}{2}} = \text{T. Std. Dev. of } Y$$

β_j gives the effect on Y of a typical of "equally likely" change in the j^{th} variable.

Some of the signs of the estimated regression coefficients were difficult to interpret. For example, the estimated regression coefficient of the seventh sunlight interval, X_{23}, had a negative sign and the estimated regression coefficient of X_{23}^2 had a positive sign. If the variable X_{23} had not occurred anywhere else in the function, one could conclude that corn production was in stage I for the relevant range of this variable. However, X_{23} occurs three other places in the function. Hence, the above conclusion does not necessarily follow. Because of this difficulty in interpretation, a sensitivity analysis is made later to indicate the magnitude and direction of change in corn yield for a given change in each of the original 22 explanatory variables.

Of the 38 estimated regression coefficients, three were not significantly different from zero at the 0.13 level of significance, 29 were significantly different from zero at the 0.05 level, and 23 were significantly different from zero at the 0.01 level. Attempts were made to trace the cause of the very low levels of significance of the three estimated regression coefficients—those corresponding to the variables X_{95}, X_{107}, and X_{157}. The significant level of the estimated regression coefficient of X_{95} fell sharply as the variables X_{169} and X_{125} entered the function in the step-wise procedure. The simple correlation between X_{95} and X_{169} was 0.48, and between X_{95} and X_{125}, 0.59. It appeared that multicollinearity was the reason for this very low level of significance. The significance levels of the coefficients of X_{107} and X_{157} fell sharply when X_{26} entered the function. The simple correlation between X_{26} and X_{107} was -0.31 and between X_{26} and X_{157}, -0.48. Although these correlations did not appear excessive, multicollinearity was again expected to be the reason for these two low levels of significance. It was suspected that the causes of these low levels of significance were not isolated to high correlations between two variables, but rather, due to more complex interdependence among the explanatory variables.

Draper and Smith[6] give one possible method of determining the adequacy of the model by relating the mean square due to lack of fit to the "pure error" in the variation of the dependent variable. Since the experiment from which the data were drawn was designed with two replications observations could be paired which had identical levels of each of the independent variables—with one exception. The plant density at harvest was used instead of the seeding plant density, hence, all observations could not be paired. Forty-nine pairs of observations were found where the plant densities at harvest were identical or the plant densities at harvest deviated by one plant per plot,[7] and values of all other independent variables were identical within each pair. "If .... repeat measurements (i.e., two or more measurements) have been made at the same value of X, we can use these repeats to obtain an estimate of σ^2. Such an estimate is said to represent "pure error" because, if the setting of X is identical for two observations, only the random variation can influence the results and provide differences between them. Such differences will usually then provide an estimate of σ^2 which is much more reliable

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[6] Draper, N.R., and Smith, H., Applied Regression Analysis, John Wiley and Sons, Inc., New York, 1966, pages 26-29.

[7] Each plot was two meters by 12 meters. This is a deviation in plant density of about one percent or less.

than we can obtain from any other source". The mean square for pure error is

$$S_e^2 = \frac{\sum_{i=1}^{K} \sum_{u=1}^{n_i} (Y_{iu} - \overline{Y}_i)^2}{\sum_{i=1}^{K} n_i - K}$$

where:

Y_{iu} = the uth observation on the dependent variable at the ith set of repeat observations on the dependent variables.

$\overline{Y}_i$ = the mean of the dependent variable values at the ith set of repeat observations.

n_i = the number of repeat observations in the ith set.

K = the number of sets of repeat observations.

Calculation of the mean square for pure error gives $S_e^2 = 613530.10$ where:

$n_i = 2$

$i = 1, 2, \ldots., 49$

$K = 49$[8/]

The residual sum of squares can then be decomposed into pure error and error from lack of fit by subtraction, i.e.,

$SSE = S_e^2 + MS_L$ where:

SSE = residual sum of squares

MS_L = mean square of lack of fit.

[8/] These refer to values in the formula for S_e^2 given previously in this chapter. This k is different from the k used earlier to denote the number of independent variables.

By using the test statistic

$$F = \frac{MS_L}{S_e^2}$$

with T - K - k and K degrees of freedom, the null hypothesis that the residual sum of squares is due only to pure error in the observations on the dependent variable—corn yield, may be tested. The alternate hypothesis is that the residual sum of squares is due not only to pure error but also due to lack of fit because of some incorrect specification of the structural form. The null hypothesis is rejected for high values of the test statistic. The observed value of $\frac{MS_L}{S_e^2}$ = 0.132 while the tabled value of the F-distribution with 489 and 49 degrees of freedom at the 0.10 level of significance is approximately 1.19.[9] Thus, the model appeared adequate for use with the data.

The estimated model was intended for use in the prediction of corn yields for given rates of use of the variable inputs, thus some confirmation of its predictive ability should be made. Draper and Smith claim that "work by J. M. Wetz (in a 1964 Ph.D. thesis, "Criteria for Judging Adequacy of Estimation by an Approximately Response Function," written at the University of Wisconsin) suggests that in order that an equation should be regarded as a satisfactory predictor (in the sense that the range of response values predicted by the equation is substantial compared with the standard error of

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[9] This value of F is taken from ∞ and 60 degrees of freedom at the 0.10 level of significance.

the response), the observed F-ratio of (regression mean square)/(residual mean square) should exceed not merely the selected percentage point of F-distribution, but about four times the selected percentage point."[10] The observed F-ratio was 66.11, easily in excess of four times the tabled value of the F-distribution[11] at the 0.99 level of significance with ∞ and 40 degrees of freedom. Thus, there seemed to be some assurance that the model was adequate for predictive purposes.

Summary

The step-wise regression estimation procedure used for the model appeared to accomplish its dual role—that of selection of relevant variables and that of estimation. The estimated model met the statistical tests employed and hence the structure of the model, the variables included in the model, and the predictive ability of the model were deemed acceptable.

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[10] Draper, N.R., and Smith, H., op. cit., page 64.

[11] The tabled value of the F-distribution with ∞ and 40 degrees of freedom at the 0.99 level of significance is 1.60.

CHAPTER VIII

CALCULATED ECONOMIC OPTIMA FOR NITROGEN, CORN YIELD AND PLANT DENSITY

The estimated corn production model presented earlier in this report was developed for the purpose of calculating optimal levels of use of inputs and product in corn production. The intent of this chapter is to present the methodology for computation and to discuss the implications arising from these calculated economic optima.

Calculation of Economic Optima

One of the uses of the estimated production function was to provide information on the most economically efficient combination of resources to produce corn. This economically efficient combination of resources, of course, occurs at that input use yielding maximum profit. Because the function chosen to represent the corn production process was so unwieldy, the methodology of calculating economic optima is derived initially. Following this, modifications are discussed which were necessary to use the general methodology for this function.

Suppose total product (Y) can be expressed as some function of n variable inputs (X_i) in the following manner:

$$Y = f\ (X_1,\ X_2,\ \ldots.\ X_n) \quad \text{- - - - - - - - - - - - -} \quad (4)$$

In an attempt to find the combination of the n variable inputs which maximizes profit (π), a second function is needed — the profit function. This can be given as:

$$\pi = P_y \cdot Y - \sum_{i=1}^{n} P_{x_i}\ X_i \quad \text{- - - - - - - - - - - - -} \quad (5)$$

The equation (5) indicates that profit is defined as the difference between the value of the product (Y) and the cost of the resources. To maximize profit, the first derivatives of (5) with respect to each of the variable inputs are set equal to zero, subject to the condition that the second derives of (5) with respect to the variable resources are negative. Then, for constant prices,

$$\frac{\partial \pi}{\partial X_i} = P_y \cdot \frac{\partial Y}{\partial X_i} - P_{x_i} = 0 \text{ for } i = 1,\ 2,\ \ldots.,\ n \quad \text{- - - - - - - -} \quad (6)$$

subject to

$$\frac{\partial^2 \pi}{\partial {X_i}^2} = P_y \cdot \frac{\partial \left(\frac{\partial Y}{\partial X_i}\right)}{\partial X_i} < 0 \text{ for } i = 1,\ 2,\ \ldots.,\ n \quad \text{- - - - - - - -} \quad (7)$$

The expression $\frac{\partial Y}{\partial X_i}$ can be calculated from the production function in equation (4). Recall, however, that $\frac{\partial Y}{\partial X_i}$ can be expressed as the marginal physical product of X_i in the production of Y, i.e., $MPP_{x_{i(y)}}$. The set of n equations in (6) can be given as:

$$P_y \cdot MPP_{x_{i(y)}} = P_{x_i} \quad \text{- - - - - - - -} \quad (6a)$$

and the conditions in (7) can be given as:

$$\frac{\partial MPP_{x_{i(y)}}}{\partial X_i} < 0 \text{ for } i = 1,\ 2,\ \ldots.,\ n \quad \text{- - - - - - - -} \quad (7a)$$

By solving the set of n equations in (6a) the profit maximizing rates of use may be found for each resource, subject to the n conditions in (7a), which state that the marginal physical product must be declining at that rate of use of the variable resource.

An Aside

The above method provides a procedure to obtain the most efficient combination of resources i.e., that combination of resources which yields maximum profit. However, it is implicit in this procedure that both output and levels of resource use are attainable at the high profit point. If the firm faces a budget constraint which will not permit it to attain the level of output and the level of resource use which yield highest profit, a somewhat different method is appropriate. Using the Lagrange function for maximization of output, for a given level of cost:

$$h_1 \equiv P_y \cdot Y + \lambda(C_o - \sum_{i=1}^{n} P_{x_i} \cdot X_i)$$

where n = the number of variable resources,

C_o = some fixed level of input costs i.e., the budget constraint,

differentiation with respect to each of the variable inputs result in

$$\frac{MVP_{x_i}}{P_{x_i}} = \lambda \quad \text{for } i = 1, 2, \ldots, n.$$

λ will equal one at the point of profit maximization with no constraint on costs. Furthermore, it can be seen that the marginal rate of technical substitution of X_i for X_j equals λ.

If, instead of a budget constraint, there is an output quota which will not permit profit maximization, a slightly different procedure is applicable. Using the Lagrange function for minimization of cost for a given level of production

$$h_2 \equiv \sum_{i=1}^{n} P_{x_i} X_i + \lambda \, [Y_o - f(X_1, X_2, \ldots., X_n)] \, P_y$$

where Y_o = some fixed level of output,

$f(X_1, X_2, \ldots., X_n)$ = the expression relating input use to output differentiation with respect to each of the variable inputs result in

$$\frac{MVP_{x_i}}{P_{x_i}} = \lambda \quad \text{for } i = 1, 2, \ldots., n.$$

Again the marginal rate of technical substitution equals λ. In both of these procedures, the results indicate that the ratio between the MVP and the price of a given variable resource must equal that ratio for any other variable resource. In effect these two procedures indicate that when highest profit is unattainable, the point on the "line of least cost combinations" of resources nearest the high profit point is optimal.

Conceptual Problems

Application of this methodology directly resulted in some serious conceptual problems. Although sunlight varies throughout the year, it is not a controllable resource. The cost of increasing or decreasing the amount of sunlight is virtually infinite after the planting date has been selected. Farmers are forced to accept what is provided after the decision is made to plant corn. Thus, the methodology presented above is not applicable to the sunlight variables.

Another problem, related to the above problem was that rainfall is also not a controllable resource. However, the cost of increasing rainfall is not virtually infinite as in the case of sunlight. The cost of supplementary rainfall is the cost of irrigation. The effects of rainfall may also be decreased to some extent at a finite cost through the use of drainage ditches, tiling, subsoiling, or in the extreme case, a greenhouse. By considering this as a production problem, some light can be shed on the effective price of water use. In Figure II, the variable resource -- water use with all other inputs constant, is related to total product. Suppose rainfall provides OW_1 of water for crop use. Since total product is still increasing for increases in water use, it would not be profitable to use less than OW_1 of water, i.e., it would not pay to avert any rainfall. The effective price of OW_1 water use provided by rainfall is zero. To decrease

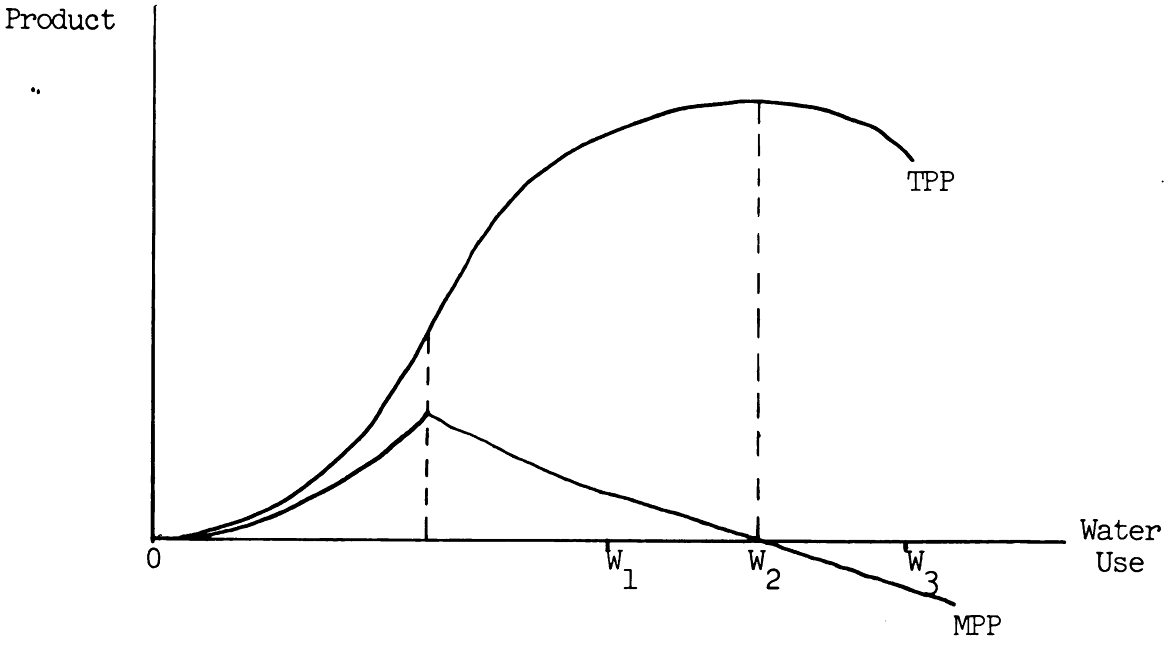

Figure II.

water use below W_1 through drainage, tiling, etc., costs would be increased and total product would be lower. Thus at least OW_1 of water will be used. In fact, irrigation may be profitable if the marginal value product of water is greater than the marginal factor cost of irrigation. Optimum water use is found by equating the marginal factor cost of irrigation and the marginal value product of total water use (rainfall plus irrigation).

Suppose now that OW_2 of water is provided by rainfall in Figure II. It is not profitable to either increase or decrease water use in this case. A decrease in water use below W_2 would increase costs (drainage, tiling, etc.) and lower total product. An increase in water use above W_2 would increase costs (irrigation) and again lower total product. Thus, the effective cost of water use, OW_2, is zero, and is equated to the marginal value product at that level of water use.

Now, suppose that water provided by rainfall is OW_3 in Figure II. In this case, it certainly would be unprofitable to increase water use even at zero cost since total physical product is in stage III of production with respect to water use. By the use of drainage, tiling etc., at some positive cost, the effects of rainfall may be decreased, and total product can be increased. Thus, it may be profitable in this case to avert the effects of rainfall to some extent. In fact, profit would be maximized where the marginal factor cost of averting rainfall through drainage, tiling, etc., is equated to the negative of the marginal value product of water use.

From this discussion it is apparent that it would be incorrect to maximize profit with respect to water use simultaneously with other variable resources. For that matter, sunlight should not be treated as a controllable resource and, hence, it would also be incorrect to maximize profit with respect to sunlight simultaneously with other resources.

In calculating economic optima for the estimated function, optimal rates of use of nitrogen fertilizer were found for given levels of rainfall plus irrigation, sunlight and plant density. Although economic optima could have been calculated for both nitrogen and plant density for given patterns of rainfall and sunlight, optimal plant density was too sensitive to variations in rainfall, sunlight, and prices to achieve useful results. Thus, three levels of plant density were used: 45,000, 55,000 and 65,000 plants per hectare.

Earlier in this report, the importance of planting date was pointed out. Although planting date was not included in the function, it was indicated that weather variables could be used to characterize particular planting dates. For a given planting date the expected rainfall and sunlight patterns could be used to calculate economic optima for nitrogen and expected corn yield. To find "expected" rainfall and sunlight patterns, each month of the year was divided into three approximately equal time periods, i.e., the first through the tenth day, eleventh through the twentieth day, and twenty-first through the last day of each month. This gives 36 approximately equal intervals of time during the year. To obtain expected rainfall and sunlight patterns for each of the 36 intervals, average rainfall in millimeters and average sunlight in hours per day were calculated from daily records of the years 1954-1964.[1] Using these expected or average characteristics of each interval, economically optimal rates of use of nitrogen fertilizer could be calculated for each interval.[2] Irrigation water to supplement rainfall could also be included in the characteristics and optimal rates of use of nitrogen fertilizer could be found for each interval again. Finally, corn yields could be predicted based on the expected patterns of sunlight and water (rainfall plus irrigation if applicable) and optimal rates of use of nitrogen for each of the 36 intervals.[3] Thus, yields for 36 planting dates could be compared.

In the choice of the optimal planting date, further computations were necessary because a comparison of yields between alternative planting dates obscured the difference in cost of resources required to produce each yield. For this reason, a profit function was set up to indicate the level of profit at a given planting time for a particular combination of resources. In this manner, comparisons between alternative planting periods were made possible.[4]

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[1] See Appendix V, Tables I and II for these 11-year averages.

[2] See Appendix VI, Table I for optimal rates of use of nitrogen for the 36 planting dates.

[3] See Appendix VI, Tables II to VI for predicted yields of corn for given rates of use of the resources for 36 planting periods.

[4] See Appendix VI, Tables VII to XI for profits expected from various rates of use of the variable resources for 36 planting periods.

Economic Optima for Nitrogen

The procedure for the calculation of economically optimal rates of use of nitrogen was presented in the previous section of this report. The calculated optima for nitrogen are presented in Appendix VI, Table I. Before proceeding with a discussion of these results, several points should be noted.

The optimal rate of use of nitrogen is given by:[5]

$$X_2 = 46.39640\,(0.00075\,X_9\,X_{50} - 0.00914\,X_{26}\,X_{56} - 0.00283\,X_{23}\,X_{53} - 0.00164\,X_9\,X_{47} + 0.00196\,X_9\,X_{53} + 0.86604\,X_{23} - P_{x_2}/P_{x_1}) \quad (8)$$

For this equation it can be seen that optimal nitrogen use depends on plant density, on sunlight in only two periods (61 - 70 days and 91 - 100 days after planting). Because of this, the optimal rate of use of nitrogen for a specific rate of water use in the first, fourth, seventh, and tenth 10-day periods after planting, remains the same regardless of the level of rainfall or irrigation during the other 10-day periods. This implication is very dubious if it is interpreted in a biological sense. However, it can probably be accepted in the sense that the optimal rate of use of nitrogen can be reasonably estimated with this function.

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[5] This equation is found by setting the first derivative of the estimated production function with respect to X_2, equal to the price ratio P_{x_2}/P_{x_1} where P_{x_2} = price of nitrogen per kilogram and P_{x_1} = price of corn per kilogram, and solving for X_2.

Only one value of the price ratio P_{X_2}/P_{X_1} was used to calculate optimal nitrogen use. This was due to the great many combinations of sunlight, rainfall, plant densities, and planting intervals already used in calculations of optima. However, the effect of price changes on optimal rate of use of nitrogen can readily be seen from the above function. The value of P_{X_2}/P_{X_1} used was 4.25. A ten percent increase from 4.25 would result in about a twenty kilogram per hectare decrease in optimal nitrogen use. Similarly, a decrease in the price ratio to 3.25 would result in an increase in optimal nitrogen use of 46.4 kilograms per hectare. These results hold for any combination of resources.

The variable X_{47} (water use 1-10 days after planting) enters the estimated production function only in an interaction term with nitrogen use and plant density. When nitrogen use is zero, then the value of the entire interaction variable becomes zero. The result was that if nitrogen use is zero, then the rate of water use, in the first 10-day period after planting, will not affect predicted yields in any way.

The economic optima for nitrogen were calculated on the assumption that if irrigation was used in any ten 10-day periods after planting, irrigation would also be used in all previous 10-day periods. For example, if water use during the fourth 10-day period was set at 80 millimeters,[6] water use during the previous three 10-day period is also 80 millimeters. For calculation of the first economic optima, only expected rainfall was used for all ten water use variables, then water

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[6] This implies that rainfall plus irrigation equals 80 millimeters. Since expected rainfall in any one of the 36 10-day intervals of the year did not exceed 72 millimeters, irrigation was always necessary to raise total water use to 80 millimeters.

use in the first period after planting was set at 80 millimeters, thereafter, only rainfall, then, in the first two periods after planting water use was set at 80 millimeters, thereafter only rainfall, and so on. Irrigation was not allowed after the 80th day following planting. This method kept the number of combinations of inputs within a reasonable level.

The economically optimal rates of nitrogen use for the 36 intervals of the year when expected sunlight and rainfall without irrigation for three levels of plant density are found in the first three columns of Table I of Appendix VI. One obvious conclusion is that if nitrogen is to be used without irrigation use, then it should be used only if corn is planted during February and March or August and September. Another obvious result is that the greater the plant density, the greater is the optimal rate of use of nitrogen. Both results conformed to expectations.

One aspect of these results is peculiar to the mathematical function chosen. The optimal rates of nitrogen use appear to fluctuate widely from one 10-day period to the next. It would seem difficult to justify the conclusion that optimal rates of nitrogen do in reality vary so widely in such brief time periods. However, these results can give an indication of when to apply nitrogen and the approximate amounts to be used by smoothing the calculated optima over several time intervals.

Two aspects of the above results were contrary to expectation. On the basis of the results in Table I, Appendix IV, there was no significant change in corn yields for levels of nitrogen use up to

200 kilograms per hectare when no irrigation was used to supplement rainfall, i.e., the returns to nitrogen appeared low or zero. Hence, no positive nitrogen use would be expected when no irrigation was used. In fact, of the four planting times in Table I, Appendix IV, corn yields decreased in three and rose in only one as nitrogen use increased from zero to 200 kilograms per hectare. Furthermore, these results are based on the data used to estimate the production model. On the other hand, the calculated optimal levels of nitrogen use were positive in several time intervals of the year when no irrigation was used. However, the results are not necessarily inconsistent with one another.

First of all, the results of Table I, Appendix IV are in highly aggregated form. The second reason is more complex. The "expected" or average rainfall for each 10-day period used to calculate optimal nitrogen use is not necessarily the most probably level of rainfall for that 10-day period. During the drier times of the year, the rainfall based on an 11-year average is most likely higher than the model rainfall level. This suggests that the probability distribution of rainfall during drier times of the year is skewed to the right (positive skewness).[7] Some justification can be found for this by noting that rainfall cannot be normally distributed since the values of rainfall are truncated at zero. Furthermore, the mean rainfall is often within less than one standard deviation from zero--its lower bound.[8]

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[7] Skewness is the third moment of a probability distribution. Positive skewness indicates that the mode (highest point on probability density function) lies to the left of the mean.

[8] See Appendix V, Table II for means and variances of rainfall in each of the 36 10-day periods.

Because of this possible skewness in the rainfall distributions, the characterization of rainfall with simple averages of observations, could over-estimate the "most likely" level of rainfall and, hence, could over-estimate nitrogen use for some planting dates.

The second result contrary to expectation was the high optimal rates of use of nitrogen given for planting times in February and August. Since the crop semester rains do not generally begin until late March and late September, adequate water for crop growth is generally not available during February and August. Partial explanation of this was again the possible influence of the skewed distribution for rainfall.

The optimal rate of nitrogen use is zero when irrigation is used to supplement rainfall to a total water use of 80 millimeters,[9] during the first and the first two and the first three 10-day periods after planting. These results held for any plant density in the range of 45,000 to 65,000 plants per hectare.[10]

When total water use is increased to 80 millimeters by means of irrigation in the first four, first five, and first six, 10-day periods after planting only two or three intervals of the year show any positive optimal rate of nitrogen use.[11] Again, the conclusion that the optimal rate of nitrogen use rises as plant density rises appeared justified.

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[9] Observations on X_{47}, X_{48} did not exceed 80 millimeters, and hence yield predictions for higher levels of water use did not appear justified.

[10] These data are not written out in Table I, Appendix VI.

[11] These data are presented in the fourth through the sixth columns of Table I, Appendix VI.

The ranges of observations on water use during the fourth through the sixth 10-day periods after planting (variables X_{50}, X_{51}, X_{52}) permitted higher rates of total water use in prediction, but no positive optimal rates of nitrogen use were found for total water use of 100 millimeters and 125 millimeters for any of the three plant densities.

By extending irrigation use into the seventh 10-day period after planting, optimal nitrogen use became positive for every planting interval.[11] Similar to the results when no irrigation was used, the optimal nitrogen rate increased for increases in plant density. Furthermore, the optimal nitrogen use increased as available water increased in the senenth 10-day period after planting. These results apply also when irrigation was added to corn for either the first eight or the first nine 10-day periods after planting.

One final aspect of these results is that the optimal nitrogen use is lower when corn is planted during March and September, than for other planting dates. The causes for this are not readily apparent.

Predicted Optimal Yields

The predicted optimal yields were calculated by evaluating the estimated production function at optimal rates of use of nitrogen, three different plant populations, various levels of water use and average

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[11] These results are presented in columns seven through nine of Table I, Appendix VI.

sunlight for each of the 36 10-day intervals of the year. These results are tabulated in Tables II through VI in Appendix VI.

When no irrigation is used to supplement rainfall, it is apparent that corn can be produced only when it is planted near the beginning of the crop semesters to fully utilize the seasonal rains.[13] This was, of course, fully in accord with expectations. Farmers, in general, recognize this aspect of corn production in the Cauca Valley.[14]

In interpreting the results from this table and the others which follow, it would be misleading to assert that the wide variations in predicted yields between consecutive planting dates do in reality exist. As in the case of the optimal rates of use of nitrogen, some smoothing of yields over two or more 10-day intervals is necessary.

One of the tentative conclusions made earlier in this study was that corn yields were generally higher in the second crop semester (September-February) than in the first crop semester (March-August).[15] From the results in Table II of Appendix VI, little support can be found for this conclusion, even though the conclusion stems in part from an analysis of the data used in estimation of the production function.

The effect of irrigation in the first 10-day period after planting to raise the total water use to 80 millimeters on corn yields was considered next. Table II of Appendix IV, columns 4, 5, and 6 reports

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[13] See Table II, Appendix VI, columns 1 through 3.

[14] See page 63 of this report for a discussion of the cropping characteristics in the Cauca Valley.

[15] See pages 74-75 for a discussion of the difference in corn yields between semesters.

predicted yields, at three levels of plant density. Their results did not differ a great deal from the predicted yields when no irrigation was employed. In fact, many of the predicted yields were identical. The reason for this was that when optimal nitrogen use was zero, then the rate of water use in the first ten days after planting in no way affected predicted yields. This peculiarity of the estimated function was discussed earlier.[16] The only perceptible difference between predicted yields without irrigation use and this case appeared to be that predicted yields, when irrigation was used in the first ten days after planting, fluctuated marginally less across consecutive time periods.

Table III of Appendix VI contains the predicted corn yields for three plant densities when total water use was 80 millimeters in the first two 10-day periods (columns 1-3) and in the first three 10-day periods (columns 4-6) after planting. It should be recalled that optimal nitrogen use was zero in both of these cases for all planting intervals.

Predicted corn yields appear to increase the farther that irrigation is extended into the growing period. Also the predicted corn yields seem to be marginally higher when irrigation to supplement rainfall was used for more 10-day periods after planting. Another feature of these predicted corn yields was that positive corn yields were obtained for planting intervals successively farther from the generally accepted planting times of the year (March and September) as irrigation use is extended farther into the growing period for corn.

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[16] See page 96 of this report.

One implication of this result was that when irrigation is used to supplement rainfall, the planting date for corn becomes less critical. In other words, corn yields tend to be less sensitive to planting date. For farmers, this suggests that the cost, in terms of yield, of missing the optimal planting date is considerably reduced when irrigation is employed in corn production.

When water use is 80 millimeters during the first four or first five 10-day periods after planting, corn yields are considerably higher than when irrigation is used to supplement rainfall in fewer 10-day periods after planting. The predicted corn yields for water use of 80 millimeters during the first four and first five 10-day periods after planting are presented in Table IV of Appendix VI. Optimum nitrogen use was positive only in two or three of the 10-day planting intervals of the year. Conclusions similar to those for irrigation during the first three 10-day intervals can be drawn from the table. Planting date appeared to be less critical than when less irrigation was used. Predicted corn yields appeared to be rising as irrigation was used farther into the growing period for corn.

Since X_{52} -- water use in the sixth 10-day period after planting -- did not enter the estimated function, neither optimal nitrogen use nor predicted corn yields were affected by irrigation use in this period. In effect, the optimal nitrogen use and predicted corn yields in this case were the same as optimal nitrogen use and predicted corn yields when irrigation was used to supplement rainfall in each of the first five 10-day periods after planting.

Predicted corn yields for three plant densities, water use of 80 millimeters in each of the first seven 10-day periods and water use of 80 millimeters in each of the first eight 10-day periods after planting are presented in Table V of Appendix VI. Optimal nitrogen use for these conditions was positive in all of the 36 planting dates of the year. However, predicted corn yields appeared lower in this case than when irrigation was used only in the first five or six 10-day periods after planting.

It would have been possible to calculate predicted corn yields for a given plant density using irrigation during the ninth or tenth 10-day period after planting. The ranges of observations on the ninth and tenth water use variables (X_{55} and X_{56}) were certainly large enough to permit such prediction. However, from a practical point of view, it would be difficult to irrigate corn this length of time after planting. The corn plants would be nearing their maximum height and growth making it extremely difficult to work with the irrigation equipment in the corn field. It would seem that to irrigate corn after the 70th or 80th day of growth either flood irrigation or overhead spray irrigation would be necessary. Flood irrigation is widely used on the larger corn farms in the Cauca Valley. Also, only one overhead spray irrigation system was sighted in the Cauca Valley by the author.

The range of observations and the water use variables in the third and fourth 10-day periods after planting (X_{49} and X_{50}) did permit levels of water use up to 125 millimeters for prediction of corn yields. The predicted corn yields for three plant densities and two levels of irrigation during the third and fourth 10-day periods after planting are presented in Table VI of Appendix VI. The first three columns of Table VI, Appendix VI provide predicted yields for three plant densities and one other level of irrigation use during the third and fourth 10-day periods after planting. The three levels of irrigation used were: 1) water use of 80 millimeters during the first four 10-day periods after planting, thereafter only rainfall, Table IV, Appendix VI; 2) water use to 80 millimeters during the first two, and water use to 100 millimeters during the third and fourth 10-day periods after planting; and 3) water use to 80 millimeters during the first two, and water use to 125 millimeters during the third and fourth 10-day periods after planting. Comparisons of these results indicated that predicted corn yields could be increased by using additional water in the third and fourth periods up to some point. However, predicted corn yields had begun to fall when water use of 125 millimeters was reached in the third and fourth periods. The conclusion was that stage III of production had been reached before water use of 125 millimeters was reached in the third and fourth 10-day periods after planting.

With the information presented so far, it was impossible to draw specific conclusions concerning optimal planting periods, or the particular combinations of resources which yield highest profits. Since the economically optimal rates of input change with different planting intervals of the year, it is impossible to make a comparison between two planting intervals. These comparisons await the discussion and development of the profit function presented later in this thesis. Before turning to the profit function some useful implications should be noted concerning the choice of a plant density.

Plant Density

Tables II through VI of Appendix VI were designed to show predicted corn yields for three levels of plant density for each combination of optimum nitrogen and water use. In this way, it was possible to obtain information concerning the estimated production surface with respect to plant density. By comparing yields obtained for the same planting dates across three levels of plant density, it can be determined within which stages of production the plant densities occur. For example, if predicted yields with 45,000 plants per hectare are 4,000 kilograms per hectare, with 55,000 plants per hectare are 4,500 kilograms per hectare, and with 65,000 plants per hectare are 4,100 kilograms per hectare, then the optimal plant density must be less than 65,000 plants per hectare. It is admitted that this is not a very precise way to obtain optimal plant density. However, the plant density used in this model is plant density at harvest which can differ greatly from seeding density due to water use, insecticide use, and herbicide use. In this sense, it is difficult for corn producers to reach optimal plant density at harvest with precision. Consequently, it was probably not necessary to obtain great precision in estimating optimal plant density.

By studying the predicted yields across the three plant densities for the planting intervals February through May, and August through November, a rough pattern seemed perceptible in Tables II through VI of Appendix VI. The optimal plant density began quite low in early February, rose quickly to a level possibly in excess of 65,000 plants per hectare and then as planting date progressed into April and May, the optimal plant density fell again to very low levels, possibly lower than 45,000 plants per hectare. This same cycle seemed to repeat itself during the second crop semester as well. While this cycle was not without exception by any means, the same general pattern seemed to emerge from the predicted yields in these results.

One implication of this phenomenon is that during the usual planting times for each of the crop semesters (March and September), the optimal plant density is higher than the 55,000 plants per hectare recommended by the agronomists at the experiment station in Palmira. This recommendation was discussed earlier in Chapter V of this report.

Summary

From the results presented in this chapter, several conclusions can be drawn. If nitrogen fertilizer is to be used at all, without irrigation, the corn should be planted just prior to the beginning of the seasonal rains in both semesters. When irrigation is used, corn yields did not appear to warrant supplementary water after about the 50th day following planting. Optimal plant densities appeared to vary considerably for different planting dates although a general pattern appeared to emerge. This pattern indicated that optimal plant densities are quite high early in the planting season but gradually declined as the planting time neared the beginning of the seasonal rains. Finally, no significant difference existed between the corn yields in the two semesters.

Since the levels of resource use varied with each planting date, no comparison could be made of alternative planting dates to determine an optimal planting time. This comparison awaits the development of the profit function in the succeeding chapter.

CHAPTER IX

COMPARISON OF ALTERNATIVE PLANTING DATES

It has been impossible in the analysis thus far to determine an optimal planting time. The reason for this was that there was no way to compare alternative planting dates in the year since the corn yields, optimal nitrogen use, water use, and plant density varied from one planting date to another. Higher corn yields were not necessarily preferred. In an attempt to compare alternative planting dates, a profit function was developed to indicate the relative profits obtainable from each planting date. By comparison of profits for each planting date, the optimal planting date can be found. The purpose of this chapter, then, is to present the development of the profit function, to use it to compare alternative planting dates, and finally to study the implications of the selected planting dates.

The Profit Function

The rationale for the development of the profit function was that there was no way to obtain an optimal planting date directly from the estimated production model by a maximization procedure such as in the case of nitrogen. Higher yields did not necessarily indicate a preferable planting time. To accomplish the comparison of alternative planting dates to find an optimal planting time, the difference between the value of the predicted corn yield and the total variable cost of the variable resources for each of the 36 planting times was examined. Fixed costs were not included in this analysis since the inclusion of fixed costs would affect only the absolute level of profit for each planting date but would not affect the relative level of profit in each case.

The difference between total value of product and total variable costs can be presented as

$$\pi = P_{x_1} \cdot X_1 - P_{x_2} \cdot X_2 - P_{x_9} \cdot X_9 - \sum_{i=1}^{10} X_{46+i} \cdot [f(P_{x_{46+i}})]$$

where π = profit,

$f(P_{x_{46+i}})$ = a price function for water use,

and the other variables are the same as those defined for the production function. The prices per unit of corn, nitrogen, plant density, and irrigation water were assumed constant.

The prices used in the profit function for corn and nitrogen were, of course, the same as those prices used to find economically optimal rates of use of nitrogen. The price of grain corn was one peso per kilogram and the price of nitrogen was 4.25 pesos per kilogram. This price of nitrogen was derived by using the price of 1,900 pesos per ton for urea and assuming that urea was 45 percent nitrogen.

The price associated with plant density was based on the assumption that 20 kilograms of seed were necessary to obtain a plant density of 45,000 plants per hectare. The cost of improved seed was 4.25 pesos per kilogram, resulting in 1.89 pesos per 1,000 plants as the cost associated with plant density.

The cost of water use was assumed to be zero for rainfall and a positive constant price for irrigation water. This was the reason for the function of price corresponding to the water use variable in the above profit function. The cost of irrigation water used was 1.20 pesos per millimeter of water added per hectare. This cost of water was approximately $9.00 (U.S.) per acre foot--very similar to the cost of irrigation water in the southwestern United States.

The profit for a given planting interval and combination of resources was calculated for only one set of constant input and product prices. Although these prices can and do vary over time, it was not expected that these variations would greatly affect the choice of the optimal planting date--the reason for the development of the profit function.

Implications

In presentations of the calculated profits for various combinations of resources in Tables VII through XI of Appendix VI, only the planting intervals 5 through 12 and 24 through 30 were shown. These intervals correspond to February 11-April 30, and August 21-October 30, respectively. The reason for this was that the possibility of planting at other times of the year was limited by the seasonal rains. Farmers cannot be certain of being able to use farm equipment in fields after the beginning of the seasonal rains. The intervals, for which profit was calculated, included at least one month before the usual beginning of the rainy seasons and at least three to four weeks after their beginning.

On studying the Tables VII through XI of Appendix VI, several important conclusions could be drawn. First of all, it appeared that irrigation could, in fact, be economically used well into the growing period for corn. Calculated profits seemed to reach their highest levels when irrigation was used to supplement rainfall during the first 50 days after planting. Irrigation after 60 days following planting appeared to lower profits. This was about the only generality one could draw which to hold for both crop semesters. For this reason the following discussion deals with each semester individually.

For the first crop semester, when little or no irrigation was applied, the optimal planting date was early April. More specifically, the calculated profits tended to slowly increase for progressively later planting dates until the first part of April. At that point profits fell off very suddenly for later planting dates.

As irrigation is extended farther into the growing period, profits seemed to be high in early March, and again in early April. However, the planting date in early and mid-April seemed to predominate.

For the second crop semester, when little or no irrigation was employed, calculated profits rose suddenly to their highest level during mid-September, then fell slowly for later planting dates. When irrigation is extended farther into the growing period of corn, profits seemed to be high first in mid-September and again in mid-October. However, profit in mid-September appeared to predominate.

For the choice of the optimal plant density at harvest for the first crop semester, 65,000 plants per hectare for early April plantings gave the highest calculated profits for all except one combination of irrigation and nitrogen.[1] For the second crop semester, 55,000 plants per hectare yielded the highest calculated profits for mid-September plantings. For the early March plantings, calculated profits were highest for 55,000 plants per hectare as long as irrigation was not used beyond the 50th day after planting. However, calculated profits were highest for 65,000 plants per hectare for mid-October plantings of corn.

Summary of Results

The estimated model, developed and presented in earlier chapters, permitted an examination of several variables to obtain recommendations concerning the allocation of resources for corn growth in the Cauca Valley. The resources examined were nitrogen fertilizer, irrigation use, plant density, and planting date. The results indicated that:

1) Corn yields and profits appeared highest for early April and mid-September plantings. However, early March and mid-October corn plantings resulted in reasonably high yields and profits when irrigation was used well in the growing period.

2) Optimal plant densities were 65,000 plants per hectare for early April and mid-October plantings, and 55,000 plants per hectare for early March and mid-September plantings. These results gave some support to the belief that higher plant densities were optimal for corn plantings later in the semester. These plant densities refer to plant densities at harvest.

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[1] When water use was 80 millimeters during the first 10-days after planting, thereafter only average rainfall.

3) When irrigation was available, higher yields and profits could be expected when irrigation was used to supplement rainfall during the first 50 days after planting.

4) Nitrogen fertilizer was necessary when no irrigation was used, probably to the extent of 60 to 100 kilograms per hectare. When irrigation was used during the first 50 days after planting, no positive nitrogen fertilizer use appeared for the recommended planting dates. However, these results are based on an experiment carried out on reasonably fertile land on the experiment station at Palmira. For this reason, for continuous cropping of corn on farms, nitrogen fertilizer would probably be necessary to the extent of 60-100 kilograms per hectare for each crop.

CHAPTER X

IMPLICATIONS AND RECOMMENDATIONS

A considerable amount of information has been presented in this research report concerning corn production and corn yields in the Cauca Valley. This information has been obtained from several sources, published aggregate statistics on corn production and yields, two farm surveys, and data from various studies conducted by the experiment station near Palmira in the Cauca Valley. In an attempt to pull together the information, this chapter was written to point out the implications of the results derived from the various sources, and to suggest recommendations which could be beneficial to the production of corn in the Cauca Valley.

Implications

Corn Yields

Early in the research work, it was noted that published statistics on corn yields in the Cauca Valley vary markedly from the results of the survey on corn yields on farms. Part of the discrepancy was attributed to the fact that reported statistics represented corn production and yields from the entire department, Valle del Cauca, whereas the survey results were taken only from the flat part of the Cauca Valley. Since surveys of corn yields were not undertaken in the mountaious part of the department, there was no way of determining the actual difference in corn yields between the two parts of the department. However, it was clear that it would be misleading to assume that corn yields in the flat part of the Cauca Valley were representative of the reported corn yields for the department.

It is possible to provide some check on the published corn yields noted in Tables VI and IX in Chapter II. The average yield of corn in the entire department is a weighted average of the corn yields in the Cauca Valley and the mountainous part of the department, i.e.

$$X_1 Y_1 + X_2 Y_2 = z$$

where X_1 = yields of corn in the Cauca Valley

X_2 = yields of corn in the mountainous part of the department

Y_1 = the proportion of the land area in corn in the entire department found in the Cauca Valley

Y_2 = the proportion of the land area in the entire department found in the mountains

z = average yield for the department.

Although, reliable estimates of Y_1 and Y_2 are not presently available, the use of some hypothetical values of Y_1 and Y_2 are useful. If the average corn yield in the Cauca Valley is four tons per hectare, and the average corn yield in the mountainous part of the department is one ton per hectare, then about one-third of the corn in the department is grown in the Cauca Valley if the published yields for the department of two tons per hectare are correct. Although the Cauca Valley makes up only 18 percent of the land area of the department, it is very possible that the Cauca Valley provides more than one-third of the corn grown in the department.[1] One reason for this is that virtually all of the corn in the mountains must produce without machinery and hence large commercial corn enterprises in the mountains are probably quite rare. Furthermore, a much higher proportion of the land area in the mountains is not suitable for tillage by either machine or hand than in the Cauca Valley. If the proportion of corn grown in the Cauca Valley relative to the mountainous area of the department is greater than one-third, then it would appear that the two tons per hectare published yield for the department is too low.

The yields found in the corn yield survey may have been higher than corn yields attained by farmers, since the surveyed yields were not adjusted for harvesting losses, theft losses, or insect losses. But it was again doubtful that all of the difference between surveyed and reported yields could be attributed to these losses.

There was a question raised by these surveys as to the accuracy and usefulness of the reported production and yield statistics for the department. Some serious thought could be given to appraising the usefulness of a census of agricultural production, particularly in the areas amendable to mechanized agriculture. Corn production entering commercial channels from the mountainous areas could be ascertained by cooperation with the military checkpoints (retenes) located on the main

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[1] Computed on the basis of information in Corporacion Autonomia Regional del Cauca (CVC), El Sector Agropecuario (Una Evaluacion Preliminar), Division de Planeacion Regional Proyecto de Investigacion No. 2, Preparado por Oscar Mazuera G., Septembre de 1965, page 2.

roads. This method would give valuable information concerning both the corn production entering commercial markets as well as the flows of corn in the marketing system.

The problems of obtaining a census of agricultural production even in the flat parts of Colombia would be immense, since adequate records of land holding and land holders did not appear to exist. However, aerial photography would seem to be one way of obtaining accurate estimates of the land area in a particular crop. Combining this information with sample corn yields and farms may provide adequate information for planning purposes.

Effects of Increasing Corn Yields on Other Crops

The corn research program conducted by ICA and The Rockefeller Foundation since 1951 has led to a great increase in potential corn yields for Colombia. From the results of the corn yield survey, it appeared evident that corn yields have increased in the Cauca Valley above the reported corn yields for the late 1940's and early 1950's. This increase in corn yields as well as improvements in other crops' productivity, has put heavy pressure on land holders in the Cauca Valley to use their land for cultivated crops instead of grazing land for animals and animal products. This has been a strong reason for the transference of a great deal of arable grazing land in the Cauca Valley in recent years to beans, corn, cotton, rice, and other crops.

One major crop of the Cauca Valley is--and has been for sometime--sugarcane. A great deal of the land in sugarcane is not owned by the sugar producing firms but rather the land is leased for five, ten, or twelve year periods. The leasing price of this land very commonly is tied to the domestic price of sugar and the domestic price of sugar is readjusted about each two year period. During 1967, the leasing price of land for sugarcane production ranged from 100,000 to 125,000 pesos per plaza (156 to 196 pesos per hectare) per month. This method of long term commitment of land has been of importance in slowing the shifts of land use into or out of sugarcane production. Furthermore, it is quite possible that the returns to land used in sugarcane production have been the real opportunity cost of land in the past. However, the use of the new corn hybrids in the Cauca Valley may be changing this to some degree. In effect, if the attainable corn yields on farms continue to rise with little or no change in the productivity of other crops, the returns to land used for corn production may become--or may be already--the real opportunity cost of land in the Cauca Valley.

The attainable yields of other crops are probably rising as well. For example, improved varieties of beans, rice, sorghum, and cotton are now available in Colombia. Federal laws have been enacted to allow cotton production in only one crop semester of the year to break the cycle of the insects which can so devastatingly reduce cotton yields. The use and availability of pesticides in the production of cotton, corn, and beans is well established. However, the yields of sugarcane have not appeared to keep pace with the attainable improvements in yields of the other crops. One reason for this is that the sugarcane producers have been slow to adopt the use of fertilizers to improve yields in the Cauca Valley. Even though improvements in sugarcane yields in the Cauca Valley may not be keeping up with yield increases in other crops, the long term land commitments to sugarcane result in very slow changes in land use patterns. As a result of these factors, it is unlikely that increased corn yields will, in the short run, significantly change the land use pattern in the Cauca Valley as long as yields of other crops grow proportionately. On the other hand, corn as well as other crops could draw land away from sugarcane production in the long run if sugarcane producers were unwilling to effectively compete for land.

In summary, it appears that increases in corn yields in the Cauca Valley could result in significant increases in corn acreage in the long run if the yield increases of other crops do not keep pace with corn yields. However, it is more likely that the yields of rice, beans, cotton, and other crops, will improve along with corn yields with the possible exception of sugarcane. But the long term land commitments to sugarcane indicate that sugarcane will remain as a major crop for many years to come in the Cauca Valley.

Corn as a Feed Grain in Beef and Milk Production

One final consideration is the possibility of using corn as a feed grain if corn yields and corn production were to increase significantly. At present a very small share of the corn produced in Colombia is used for animal feed with the exception of poultry. Almost no corn goes to dairy or beef cattle as feed grain. While the Colombian food consumption is deficient in protein available in meat and meat products, it is highly unlikely that corn will be used to any extent in beef or milk production. The reasons for this are largely economic.

First of all, the feed conversion ratio in the cattle typically found in Colombia is higher than in North American cattle breeds; that is, it takes more feed to produce one kilogram of live body weight in the Colombian cattle than in North American breeds. Furthermore, the price of corn relative to the price of beef is higher in Colombia than in the United States.

The beef in Colombia is generally raised on pasture unsuitable for tillage. There is about 30-40 million hectares of pasture land in Colombia, although not all of it is used for agricultural production and not all of it is unsuitable for tillage. Slaughter cattle generally are raised on pasture for three to six years. The reason for this very long growth period is inherent in the breeds of beef cattle typically found in Colombia. These Zebu cattle are well adapted to the tropical and semi-tropical climates because of their heat resistance although they do not appear to be as efficient in meat or milk production as North American breeds in more temperature climates.[2]

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[2] Morrison, F. B., Feeds and Feeding, The Morrison Publishing Company, Ithaca, New York, 1957, pages 153-155.

The pastures of Colombia are largely unimproved and their carrying capacity for beef production is typically quite low. However, a good deal of this pasture land is quite mountainous and not suited to mechanized agriculture or cultivated crops. This land has almost no alternative use in agriculture. Another large portion of the pasture lands in Colombia lie in the Eastern Plains. Again, the carrying capacity of this natural pasture in beef production is very low, although improved pasture forages are becoming available. Furthermore, not all of the natural pastures in the Eastern Plains appear fully utilized. It appears, then unlikely that corn will become a major feed grain and decline in use as a food grain in Colombia for several years.

Farm Production Practices

The survey of corn production practices on 138 farms attempted to give the major characteristics of farming methods in the Cauca Valley. It provides the background information necessary to make recommendations to farmers to improve corn yields.

The corn yields by farmers reported in the survey differed markedly from the corn yields found by actually harvesting plots within fields. While no account was taken in the corn yield survey of the losses by theft or during harvest, the larger farmers persistently tended to underestimate their yields when asked what were their corn yields. Although the farmers may have had good and sufficient reasons for this, it would seem that to ascertain corn yields on farms, actually harvesting plots within fields appeared to be the only way to obtain reasonably accurate estimates of corn yields on farms.

The use of hybrid and improved varieties appeared to be well established on larger farms while adoption on smaller farms was generally quite recent. The occurrence of second generation hybrid seed was not uncommon on smaller farms suggesting the need for some flow of information to these recent adopters of improved corn varieties. However, it did not appear to be necessary for agencies such as ICA, or INCORA to reach every farmer with this kind of information. The smaller farmers tended to obtain their information from neighbors, friends, and nearby larger farms. Because of this, extension programs may be most usefully applied to selected farmers which, in turn, actively pass information along to others less willing or able to accept assistance directly from the extension agencies.

Herbicides were seldom used on farms for a variety of reasons, both economic and noneconomic, while insecticide use appeared to be well established. In part the reason for this was that insecticide, most essential for corn growth, did not have a near substitute, while herbicides have several substitutes. The low opportunity cost of labor used for weed eradication may have made the use of herbicide uneconomic.

Fertilizers have been adopted by only a few farmers in the Cauca Valley even though nitrogen is generally deficient in heavily cropped soils. This low adoption level is, in part, due to the quality of fertilizers available and the quantities available during certain times of the year. Fertilizers are difficult to find at planting time but are available at other times. Furthermore, the fertilizer is not treated to prevent caking during prolonged storage. Thus, the lack of fertilizer adoption could be due, in part, to the inconvenience of procurement and use.

Irrigation use was restricted to those farms with an available water source. Also, farmers seemed to be aware that irrigation use was of importance in corn growth in the Cauca Valley. It would appear, then, that the irrigation programs such as the ICA project near Roldanillo would be generally accepted by farmers.

Corn was generally harvested by hand in the Cauca Valley although a few mechanical pickers and shellers were encountered. Initially, it would appear that the opportunity cost of labor was sufficiently low that it was uneconomic to use machines for harvesting. However, some recent events in the Cauca Valley have suggested that the use of mechanical harvesters has been restricted because of threats by laborers to sabotage machines which may displace them. For example, in 1967, the laborers employed by the experiment station in Palmira threatened to burn a small new mechanical corn and bean harvester. Their rationale was that the machine was taking away their positions as harvesters and hence reducing their incomes. Some solution to this problem must be found before mechanical harvesters can be used on a wide scale in the Cauca Valley.

The corn producers generally sold their corn shortly after harvest even though many had storage space on their farms and though many farmers recognized that corn prices usually rose later in the season. This action can put a great deal of stress on the capacity of marketing channels. Furthermore, farmers seemed to be losing some revenue by not holding their corn for more favorable prices. The reason for this behavior was not apparent. Studies of the marketing, storage, and distribution channels may reveal some causes of this behavior.

In conclusion, the corn producers in the Cauca Valley seemed to be aware of the necessary resources for corn production and the problems associated with their use with a few exceptions—herbicide and fertilizer, specifically. However, they did not appear to take advantage of the potentially higher prices by storing corn for two or three months. Finally, the extension agencies may be advised to work with a small number of selected farmers which in turn pass information on to the rest of the farming community.

The Production Model and Profit Function

The production model was derived and estimated in an attempt to analyze some of the resources used in corn production. The resources used in the model were restricted to those for which data were available; specifically, nitrogen, plant density, rainfall, irrigation, and sunlight. Since rainfall and sunlight were used to typify a particular planting date, the effects of planting date on corn yields were also studied. The profit function was necessary to compare these alternative planting dates.

There appeared to be some substitution effect between water use and nitrogen. When no irrigation was used, optimal nitrogen use appeared to range between 60 and 100 kilograms per hectare. When irrigation was used during the first 40 days after planting, optimal nitrogen use fell to zero. However, as irrigation use was extended farther into the growing period for corn, optimal nitrogen use rose again to about 60 to 100 kilograms per hectare. While this effect was found in the production model, it is doubtful if one could expect to replace nitrogen with some irrigation under continuous cropping of corn. The optimal nitrogen range under continuous cropping of corn with or without irrigation appeared to be 60 to 100 kilograms per hectare.

The plant density as used in the production model referred to the plant density harvest, not the seeding density. The reasons for this were given in Chapter VI of this report. The optimal plant density found from inspection of the estimated production cannot then be construed as the optimal seeding density for corn. Some adjustment upward must be made to obtain a seeding density. The extent of the upward adjustment depends upon the level of nitrogen and irrigation.

While in the Cauca Valley the author had an opportunity to work with a large farming enterprise and to study the production of corn on a 57 plaza field. Fertilizers were applied to the field prior to planting according to the recommendations derived from a soil test. The seeding density was approximately 75,000 plants per hectare. Immediately after planting during early September, spray irrigation was begun on one end of the field. However, due to mechanical difficulties with the pump, it took ten days to reach the other end of the corn field with irrigation.[3] The early irrigation on the one end of the corn field resulted in taller corn four weeks after planting and a considerably heavier and more uniform plant density—72,000 plants per hectare as opposed to 55,000-60,000 plants per hectare on the opposite end of the field. By the end of October, the plant density had fallen to 68,000 plants per hectare under early irrigation and 50,000-55,000 plants per hectare under the late irrigation. Although this timing of the irrigation was not intentional, it did point out the effect of irrigation on plant density quite remarkably.

In searching for reasons for this decline in plant density in corn without irrigation for ten days after planting, the agronomists with whom the author corresponded suggested that the vigor of the seedlings in the dry soil had been drained to the point that many were not viable by the time irrigation reached them.

The experience gained from this study highlighted the necessity of providing water immediately after planting and the relationships between seeding density and plant density at harvest. Seedling densities

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[3] Shortly after the irrigation was completed, the semester rains began making it unnecessary to continue with irrigation the second time.

of 70,000-75,000 plants per hectare are probably necessary to maintain a plant density at harvest of 60,000-65,000 plants per hectare when the corn is planted well before the seasonal rains and irrigation is used. Without irrigation, the plant density at harvest could fall below 50,000 plants per hectare. When corn is planted just prior to the seasonal rains or after the rains have begun, irrigation would probably not be necessary to maintain 55,000-60,000 plants per hectare at harvest from a seeding density of 70,000 to 75,000 seeds per hectare.

Relating these implications to the optimal plant densities found from the estimated production model, it would appear that irrigation would be imperative to obtain a plant density at harvest of 65,000 plants per hectare for early March and mid-September plantings. Early April and mid-October plantings of corn would not necessarily need irrigation to obtain a plant density at harvest of 55,000 plants per hectare. All of this, of course, is based on a seeding density of 70,000-75,000 seeds per hectare. The results would need modification for different seeding rates. Finally, if the plant density at harvest was far below the seeding density, one could expect a less uniform stand of corn than if the plant density at harvest was maintained as near as possible to the seeding density.

The optimal planting dates suggested by the analysis in the foregoing chapter were early March or early April in the first crop semester and mid-September or mid-October in the second crop semester. Early April and mid-October may not be feasible as planting dates since both of these periods ordinarily fall after the beginning of the seasonal rains. The result is that the only feasible and optimal planting dates are early March and mid-September.

One final implication of the model must be considered. The data used to estimate the production model were drawn from an experiment using the hybrid variety H-205, a yellow flint hybrid adapted to the Cauca Valley climate. The results of the estimated model indicated that this hybrid was sensitive to both water and sunlight changes. However, after the experiment was completed, a new hybrid variety H-207, was introduced and widely adopted in the Cauca Valley because of its superior yield potential. Then, unless the newly adopted hybrid H-207, has the same sunlight and water sensitivity, the implications and recommendations drawn from this production model must be restricted to the H-205 hybrid variety. Data were unavailable on the new hybrid H-207 to estimate the same production model, or to test in some way the hypothesis that the water and sunlight sensitivity of the H-207 corn hybrid differed from that of the H-205 corn hybrid.

Recommendations

The recommendations resulting from this study cover a wide latitude of aspects of corn production. First of all, suggestions are directed toward the corn producers on both large farms and small farms. Secondly, some recommendations are made to enable the agricultural and social scientists to study interdisciplinary problems relevant to corn production and marketing. Finally, attention is turned to the research needs which this study uncovered but could not pursue for want of time.

The recommendations to farmers arising from the study can to a great extent be drawn directly from the implications spelled out earlier in this chapter. The optimal rate of use of nitrogen appeared to be 60-100 kilograms per hectare under intense cropping practices. This level of use of nitrogen probably need not be as high under a corn-legume rotation. The intercropping of corn, beans, yuca, and others on the very small farms has not received attention in this study. It is possible that the intercropping of legumes and nonlegumes continuously may provide an adequate amount of nitrogen for normal corn growth and yield. However, this yield cannot be compared to corn yields where intercropping does not occur.

Irrigation use seemed to offer gains in profits when used during the early growing period of the corn—the first 50 days after planting. When water sources are unavailable, then planting date should be adjusted to correspond as closely as possible to the early April and mid-October planting dates. With water available for irrigation, optimal planting periods appeared to be either early March or early April and either mid-September or mid-October. Optimal plant densities at harvest were found to be about 65,000 plants per hectare for early plantings—early March and September—and about 55,000 plants per hectare for later plantings in each semester. The seeding densities required to maintain these plant densities at harvest appeared to vary with the water availability. Furthermore, to maintain uniformity of stand, the plant density at harvest should be kept as near as possible to the seeding density.

The premise on which these recommendations to farmers must be made was that the particular hybrid variety used in the experiment (H-205) has similar water and sunlight sensitivity as the presently more popular hybrid, H-207.

The second group of recommendations attempt to meet the problems of combining information from several sources generated by professionals in alternative disciplines. During the research effort described in this report, the author found much information generated in experiments which dealt with only one or two aspects of corn production. Also, the information on several experiments could not, in general, be combined to provide data on several variables simultaneously. Finally, the data needs of the agricultural economist differ in some respects to the needs of the agronomist or soil scientist. For example, while in Colombia, the author found experiments concerning the affects of herbicides on weed growth in corn providing data on the dry weight of weeds per hectare resulting from a particular level of use of a herbicide, but no record of the yield attained by the corn.

To overcome these problems, it is recommended that the research conducted on the experiment stations in Colombia be developed jointly by professionals from several disciplines. To accomplish this, the researchers must be willing to work with professionals from the other disciplines, and they must be willing to see their segment of research on corn integrated into an over-all program for corn research. It is hoped that this method would establish priorities in research in corn. Furthermore, this method would place emphasis on the total corn research program and the function or role of the individual experiment in the total research program.

Finally, it is recommended that some method be established to record and annotate the research works on corn in Colombia, and to make the data generated from these experiments generally available. The Centro Internacional para Agricultura Tropical (CIAT) would seem to hold a great deal of promise in putting these recommendations into effect.

The final set of recommendations deal with the research topics concerning the resources used in corn production, the corn production process itself, and the marketing and distribution of corn in Colombia. Several inputs and their interactions were examined in this study. However, the analysis of these variables and their interactions was, by necessity, crude. It is hoped that this study will prompt more refined analysis as well as assist in the ordering of priorities for research on the inputs in corn production. A more thorough understanding is needed of the inputs for corn production and interactions in their effect on corn grown and yield.

The marketing channels for corn were mentioned very briefly in this report. There was evidence to suggest that the marketing system is somewhat inefficient, manifested by high marketing margins, and poor transportation facilities. It is recommended that a study of the marketing system be undertaken to determine its effects and the supply and distribution of corn and how the marketing system might be made more dynamic and responsive to price. A study of corn marketing is presently underway by Latin American Market Planning of International Programs, Michigan State University.

The purpose of the research recommended above is of critical importance to Colombian development. The heavy dependence by the Colombian people on corn as a food grain must be recognized. As well, the malnutrition and undernourishment of segments of the Colombian people is extreme. It is toward the resolution of these problems that the research on corn production, marketing, and effective demand for food, in general, must be directed.

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APPENDICES

APPENDIX I

The Questionnaire and Results from the Farm Production Practices Survey

APPENDIX I

TRANSLATION OF SURVEY OF CORN PRODUCTION PRACTICES IN VALLE DEL CAUCA, COLOMBIA

Confidential

I - General

1. a) How many plazas do you have in your farm?

   b) How many plazas do you rent?

2. a) Did you grow corn in the second semester of 1966?

   If yes,

   b) How many plazas of corn did you grow?

   c) What yield of corn did you have?

3. a) Are you growing corn now on your farm?

   If yes,

   b) How many plazas of corn do you have now?

   c) What corn seed are you using?

   If the reply to 3. c) was one of the improved varieties or hybrids available in the Cauca Valley,

   d) When did you begin using improved seed?

   e) How did you find out about the availability of improved seeds?

      i) neighbors and friends

      ii) newspapers

      iii) producers' organizations

iv) extension agents

v) other (specify)

4. a) From whom are you buying your corn seed?

   b) Have you ever used the product of a hybrid crop for seed?

5. a) Do you plant corn semester after semester on the same field?

   If not,

   b) What crop rotations do you use?

II - Land Preparation

1. How do you prepare your land for corn?
   - a) Plow
   - b) Disc
   - c) By hand
2. How do you determine when the land is ready for planting?
3. Do you cultivate your corn after it has germinated?

III - Planting Practices

1. How do you plant your corn?
   - a) By hand
   - b) By machine
2. How many arrobas of seed do you use per plaza?
3. If corn is planted in hills:
   - a) How many plants are there in each hill?
   - b) How many centimeters are there between hills?
4. If corn is planted in rows:
   - a) What is the distance between the corn rows?
   - b) How many plants per meter are there?

IV - Fertilizer Use

1. Do you use fertilizer on your corn?
2. If yes,
    - a) What analysis of fertilizer do you use?
    - b) How many kilos of fertilizer do you apply?
    - c) When do you apply the fertilizer?
        - i) before planting
        - ii) at planting time
        - iii) after planting
    - d) How do you determine the analysis and the amount of fertilizer to use?
        - i) soil sample
        - ii) always buy the same
        - iii) don't know
        - iv) other (specify)
    - e) How do you apply the fertilizer?
        - i) by hand
        - ii) with the corn planter
        - iii) by fertilizer spreader
        - iv) other (specify)
3. If fertilizer is not used, why do you not use fertilizer?
    - a) The land does not need it
    - b) It is not effective
    - c) It is too expensive
    - d) Don't know
    - e) Other (specify)

V - Irrigation

1. Do you use irrigation on your farm?
2. Do you use irrigation for your corn?

   If yes,

   a) What kind of irrigation do you have?

      i) flood irrigation

      ii) spray irrigation

3. How do you decide when to irrigate?

   a) Moisture content of the soil

   b) A certain number of days without rain

   c) When time is available

   d) Don't know

   e) Other (specify)

4. On the average, how many times do you irrigate a corn crop?

   If irrigation is not used for corn,

5. Why do you not use irrigation?

   a) Too expensive

   b) No water source

   c) Rainfall is sufficient

   d) No irrigation facilities

   e) It is not effective

   f) Other (specify)

VI - Insecticide Use

1. Do you use insecticide on your corn?

   If yes,

2. What insecticides do you use?

3. How many times to you apply insecticide to a corn crop?

4. How do you apply insecticide?

   i) by hand (dry)

   ii) tractor-sprayer

   iii) hand sprayer

   iv) in the irrigation water (spray irrigation)

   v) by light plane or helicopter

5. When do you apply insecticide?

   i) after you see insect damage

   ii) when the corn is a certain height

   iii) at a certain age of the corn, regardless of whether or not you see insect damage

If insecticide was not used,

6. Why do you not apply insecticide?

   i) too expensive

   ii) insecticides are not effective

   iii) don't need insecticide

   iv) don't know

   v) other (specify)

VII - Herbicide Use

1. Do you use herbicides on your corn?

If yes,

2. What herbicides do you use?

3. How many times do you apply herbicides?

4. How do you apply herbicide?
    - i) by hand (dry)
    - ii) by hand sprayer
    - iii) by tractor sprayer
    - iv) by light plane or helicopter
    - v) other (specify)

5. Do you cultivate your corn if you use herbicide?

   If herbicide is not used,

6. Why do you not use herbicides?
    - i) too expensive
    - ii) they are not effective
    - iii) hurts the corn crop, and future crops
    - iv) damages the soil
    - v) prefer to use hand methods of weed control
    - vi) other (specify)

VIII - Machinery Use

1. Do you use machinery for corn production?

   If yes,

2. Whose machinery is it?
    - i) your own
    - ii) rented
    - iii) contracted

3. If machinery is rented or contracted, what is the cost of:
    - i) plowing and discing
    - ii) planting

        iii) cultivating
        iv) harvesting

IX - Harvesting and Distribution of Crop

1. How do you harvest your corn?
    - i) by hand
    - ii) machine

If harvesting is done by hand,

2. What labor is used to harvest corn?
    - i) only your family
    - ii) contracted labor
    - iii) permanent employees
    - iv) other (specify)

If harvesting is done by machine,

3. Do you own the machine or rent it?
4. What is the cost of harvesting corn?
    - i) by hand
        - a) ear corn
        - b) shelled corn
    - ii) by machine
5. What do you do with your corn?
    - i) human food on the farm
    - ii) animal feed on the farm
    - iii) sold
    - iv) corn lost, stolen, or damaged
    - v) corn for seed

If some corn is sold,

6. When do you sell your corn?
    - i) immediately after harvest
    - ii) depends on the price
    - iii) other (specify)

7. Do you have storage facilities on your farm for corn?

If yes,

8. How much of your corn can you store?

9. What kind of storage is it?
    - i) silo
    - ii) corn cribs or grain bin storage
    - iii) room in the house
    - iv) other (specify)

APPENDIX I TABLE I. MEAN YIELDS REPORTED FOR SECOND SEMESTER OF 1966, BY FIELD SIZE

Field Size	Yield of Corn	Number of Respondents
plazas	kilograms per hectare	number
50 or more	2,875	11
20 - 49	2,870	8
10 - 19	3,897	6
5 - 9	3,634	9
less than 5	2,269	57

APPENDIX I TABLE II. FREQUENCY OF RESPONSES TO NUMBER OF SEMESTERS FARMERS HAVE USED IMPROVED SEED

Field Size	Number of Semesters				
	1-2	3-5	more than 6	d.k.[1]	n.r.[2]
plazas					
50 or more	7	5	2	2	1
20 - 49	8	5	0	2	4
10 - 19	6	2	1	1	3
5 - 9	8	1	3	0	2[3]
less than 5	20	6	1	6	42[4]
Total	49	19	7	11	52

[1] Don't know

[2] No reply

[3] One of these two used criollo or improved seed

[4] Thirty-four of these used criollo seed or seed from the previous crop.

APPENDIX I TABLE III. FREQUENCY OF RESPONSE TO HOW FARMERS FOUND OUT ABOUT IMPROVED SEED PRODUCERS

Field Size	Friends Neighbors	News papers	Organizations Gov't agencies	Extension agencies	Other
plazas					
50 or more	6	1	5	5	1
20 - 49	9	1	6	2	0
10 - 19	7	1	3	1	0
5 - 9	8	2	3	0	1
less than 5	27	2	4	5	3
Total	57	7	21	13	5

APPENDIX I TABLE IV. FREQUENCY OF USE OF THE PRODUCT OF A HYBRID CROP FOR SEED

Field Size	Use of Second Generation Hybrid Seed			
	Yes	No	d.k.[1]	n.r.[2]
plazas				
50 or more	3	13	0	1
20 - 49	2	14	0	3
10 - 19	2	10	1	0
5 - 9	2	11	0	1
less than 5	24	34	2	15
Total	33	82	3	20

[1] Don't know

[2] No reply

APPENDIX I TABLE V. USE OF CROP ROTATIONS INVOLVING CORN

Field Size	Crop Rotation Used	Continuous Corn	d.k.[1]	n.r.[2]
plazas				
50 or more	8	8	1	0
20 - 49	10	7	1	1
10 - 19	8	5	0	0
5 - 9	11	2	0	1
less than 5	18	52	0	5
Total	55	74	2	7

[1] Don't know

[2] No reply

APPENDIX I TABLE VI. METHODS OF PLANTING, WEIGHT OF SEED PER HECTARE USED AND PLANT DENSITY OF CORN

Field Size	Method of Planting		Plant Population	Weight of Seed per Hectare
	by hand[2]	by planter[3]		
plazas	- - - frequency	- - -	plants/ha.	kilograms
50 or more	0	17	45,267	22.7
20 - 49	1	18	49,122	24.9
10 - 19	1	12	43,445	21.6
5 - 9	3	11	42,630	22.5
less than 5[1]	59	8	42,171	20.8

[1] Eight farmers did not reply to this question.

[2] Corn planted by hand was always in hills.

[3] Corn planted by corn planter was always in rows.

APPENDIX II

Data Taken from a Legume-Corn Rotation in Palmira at the Agricultural Experiment Station during the Years 1963 - 1966.

APPENDIX II TABLE I. AVERAGE CORN YIELDS BY SEMESTER FOR A CORN-LEGUME ROTATION EXPERIMENT[1]

Rotation[2]	Year and Semester							
	1966B	1966A	1965B	1965A	1964B	1964A	1963B	1963A
	kilograms per hectare							
MMMMMMMM	6,846	5,756	6,224	6,701	6,308	6,211	6,331	4,818
MSMSMSMS	7,747		7,486		7,855		7,359	
SMSMSMSM		6,353		7,158		6,886		5,109
SMMSMMSM		6,034	7,425		7,042	6,443		4,372
MMSMMSMM	7,184	6,266		7,055	7,348		5,581	5,655
MSMMSMMS	7,040		5,842	7,070		5,021	6,932	
AAAAMAAA					6,486			
AAMAAAAM			7,040					5,247
AAAAMMAA					7,128	6,701		
MAAAAMMA	6,885					6,699	5,410	
MMAAAAMM	7,830	6,792					6,438	5,855
AAMMAAAA			7,143	7,052				

[1] This experiment began in 1958 on the experiment station in Palmira. The plots were divided in 1961 and nitrogen was applied to one-half of them at the rate of 120 kilograms per hectare. Beginning in 1964A, 200 kilograms of nitrogen per hectare were applied.

[2] M = corn; S = soybeans; A = alfalfa.

APPENDIX II TABLE II. AVERAGE CORN YIELDS BY SEMESTER FOR A LEGUME-CORN ROTATION EXPERIMENT[1]

Rotation[2]	Year and Semester							
	1966B	1966A	1965B	1965A	1964B	1964A	1963B	1963A
	kilograms per hectare							
MMMMMMMM	3,272	2,385	1,903	2,783	3,204	3,621	3,509	2,439
MSMSMSMS	6,168		4,214		6,476		6,159	
SMSMSMSM		5,031		5,227		4,863		5,307
SMMSMMSM		3,324	5,143		3,401	4,013		2,304
MMSMMSMM	3,271	4,861		3,293	6,516		3,357	5,132
MSMMSMMS	6,214		1,593	5,037		3,801	6,628	
AAAAMAAA					5,893			
AAMAAAAM			6,355					2,767
AAAAMMAA					5,152	4,663		
MAAAAMMA	6,789				3,038	5,234		
MMAAAAMM	6,578	6,788					4,462	5,381
AAMMAAAA			4,149	5,226				

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[1] This experiment began in 1958 on the experiment station in Palmira. One-half of the plots did not receive any fertilizer. The other half received nitrogen applications after 1961. (See Table I, Appendix II).

[2] M = corn; S = soybeans; A = alfalfa.

APPENDIX II TABLE III. CORN YIELDS, STANDARD DEVIATIONS AND NUMBER OF OBSERVATIONS IN SOYBEAN-CORN ROTATIONS, 1963-1966[1]

Treatment	Fertilizer[2]	First Semester			Second Semester		
		Mean Yield	Standard Deviation	Number of Observations	Mean Yield	Standard Deviation	Number of Observations
		kgms/ha.		number	kgms/ha.		number
First crop after soybeans in SMM rotations	yes	6,359	707.86	16	7,191	608.33	16
	no	4,761	1,065.66	32	6,125	985.66	32
Second crop after soybeans in SMM rotations	yes	5,620	1,531.74	16	6,412	1,466.26	16
	no	3,181	1,159.58	32	2,906	964.71	32
S M rotations	yes	6,264	1,578.19	16	7,612	836.03	16
	no	5,107	660.87	32	5,754	1,262.76	32

[1] Calculated from the same data as used in Tables I and II, Appendix II.

[2] Fertilizer used, means 200 kilograms of nitrogen per hectare, for observations taken during and after 1964, first semester. Prior to this 120 kilograms were used.

APPENDIX II TABLE IV. CORN YIELDS, STANDARD DEVIATIONS AND NUMBER OF OBSERVATIONS IN ALFALFA-CORN ROTATIONS, 1963-1966[1]

Treatment	Fertilizer[2]	First Semester			Second Semester		
		Mean Yield	Standard Deviation	Number of Observations	Mean Yield	Standard Deviation	Number of Observations
		kgms/ha.		number	kgms/ha.		number
First crop after alfalfa in AAAAMM rotations	yes	6,625	850.62	16	6,147	1,737.64	8
	no	5,515	1,382.77	32	6,013	1,192.12	16
Second crop after alfalfa in AAAAMM rotations	yes	6,699	395.21	4	7,136	968.27	16
	no	3,036	691.31	8	5,085	1,202.61	32
AAAAM rotations	yes	5,247	1,131.80	4	6,763	211.53	8
	no	2,767	722.53	8	6,124	1,430.54	16

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[1] Calculated from Tables I and II, Appendix II.

[2] Fertilizer used means 200 kilograms of nitrogen per hectare, for observations taken during 1964, first semester and after. Prior to this, 120 kilograms per hectare were applied.

APPENDIX II TABLE V. COMPARISON OF NITROGEN CONTENT IN GRAIN CORN GROWN UNDER VARIOUS LEGUME-CORN ROTATIONS AND NITROGEN APPLICATIONS[1]

Rotation[2]	Nitrogen Fertilizer Added[3]		No Nitrogen Fertilizer Added[4]	
	Average Percent Nitrogen in Grain[5]	Variance	Average Percent Nitrogen in Grain	Variance
M-M-M *+	1.60	0.010725	1.40	0.10981
M-S-M-S +	1.70	0.012375	1.53	0.1549
S - $\underline{\text{M}}$ - M +	1.69	0.008275	1.53	0.13609
S - M - $\underline{\text{M}}$ *	1.61	0.01915	1.41	0.015045
AAAA $\underline{\text{M}}$ - M	1.67	0.013425	1.57	0.16818
AAAA M - $\underline{\text{M}}$ *	1.68	0.025737	1.46	0.019936

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[1] Legume-corn rotation experiment, 1958-1966.

[2] M = corn; S = soybeans; A = alfalfa. The letter underlined indicates the crop in the rotation for which the data are presented.
* indicates the means of percentage nitrogen differ significantly (0.05 level) in that particular rotation.
+ indicates that the variances of nitrogen content of the corn differ significantly (0.05 level) for that rotation.

[3] 200 kilograms per hectare of nitrogen were applied during 1963A-1965A. For years 1959B to 1962B, 120 kilograms of nitrogen were applied.
Each mean and variance in the columns under nitrogen added are based on nine observations.

[4] Each mean and variance in the columns under no nitrogen added are based on 12 observations.

[5] Nitrogen content is directly related to protein content. One percent by weight of nitrogen is equivalent to 6.25 percent by weight of protein.

Note: This data will also be presented by Gomez, Jairo A., in a forthcoming paper, Soils Section, Agricultural Experiment Station, Palmira.

APPENDIX III

Data Taken from Regional Trials in the Cauca Valley during 1965 and 1966, Conducted by the Soils Section of the Agricultural Experiment Station in Palmira.

APPENDIX III TABLE I. YIELDS, STANDARD DEVIATIONS, AND NUMBERS OF OBSERVATIONS ON DIACOL H-205 CORN ON REGIONAL TRIALS IN THE CAUCA VALLEY, 1965 BY SEMESTER, HERBICIDE, INSECTICIDE, AND FERTILIZER USE

Semester	First Semester						Second Semester					
Herbicide	No			Yes			No			No		
Insecticide	Yes			Yes			No			Yes		
Fertilizer Use[1]	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations
0-0-0	4,117	1007.46	8	5,379	784.30	12	4,867	375.61	8	3,774	729.93	16
50-0-0	4,324	969.53	8	5,187	1069.47	12	5,221	267.03	8	4,494	469.98	16
100-0-0	4,093	722.35	8	5,130	1028.22	12	5,241	169.33	8	5,057	581.66	16
200-0-0	4,065	816.90	8	5,483	1003.28	12	4,969	408.85	8	5,065	382.05	16
0-100-0	4,649	1028.68	8	5,468	800.60	12	4,843	181.76	8	3,780	837.75	16
50-100-0	4,399	1050.62	8	5,324	790.80	12	5,615	396.95	8	4,723	381.39	16
100-100-0	4,306	883,81	8	5,237	1036.69	12	5,466	224.31	11	4,927	344.86	16
200-100-0	3,975	900.83	8	5,397	920.22	12	5,426	452.76	8	5,122	546.93	16
100-100-100	3,890	685.53	12	5,381	974.35	16	5,346	469.66	17	5,127	385.72	36

[1] The first number refers to kilograms per hectare of nitrogen; the second number refers to kilograms of P_2O_5, and the third number refers to kilograms per hectare of K_2O.

[2] Yields are measured in kilograms of grain per hectare.

APPENDIX III TABLE II. YIELDS, STANDARD DEVIATIONS, AND NUMBERS OF OBSERVATIONS ON ICA H-207 CORN ON REGIONAL TRIALS IN THE CAUCA VALLEY DURING SECOND SEMESTER, 1966, BY HERBICIDE, INSECTICIDE, FERTILIZER AND PREVIOUS CROP

Herbicide	No			No			Yes			No			Yes		
Insecticide	Yes			Yes			Yes			No			Yes		
Previous Crop	Corn			Legume			Corn			Unknown			Legume		
Fertilize - Fertilizer[1]	Yield[2]	Std. Devi- ation	No. of Obser- vations	Yield[2]	Std. Devi- ation	No. of Obser- vations	Yield[2]	Std. Devi- ation	No. of Obser- vations	Yield[2]	Std. Devi- ation	No. of Obser- vations	Yield[2]	Std. Devi- ation	No. of Obser- vations
0-0-0	8,912	118.08	4	8,286	394.12	4	6,583	610.26	12	7,559	110.57	3	8,168	319.19	4
50-0-0	9,088	163.30	4	8,287	265.35	3	7,321	435.55	12	8,048	229.17	4	8,364	355.59	4
100-0-0	8,964	477.96	4	8,527	532.37	3	7,724	278.96	12	7,738	35.53	3	7,734	125.25	4
200-0-0	8,168	256.09	4	8,119	372.22	3	7,801	338.11	12	7,410	495.71	3	7,809	215.76	4
0-100-0	8,238	391.92	4	8,365	147.87	4	6,496	685.64	12	7,911	123.51	4	8.147	281.19	4
50-100-0	8.963	365.32	4	8.632	355.58	5	6,977	382.32	12	7,898	119.64	3	8,742	149.21	4
100-100-0	8,338	292.59	5	8,468	346.67	5	7,115	334.95	12	7,260	111.10	3	8,022	230.27	4
200-100-0	8,199	269.33	4	8,156	143.15	5	7,744	376.15	12	7,643	310.73	4	8,454	349.12	4
100-100-100	8,726	110.00	3	7,952	173.24	4	7,345	224.37	12	7,567	402.43	4	8,776	625.33	4

[1] The three numbers refer to kilograms per hectare of nitrogen, P_2O_5 (phosphate), and K_2O (potash) fertilizers, respectively.

[2] Yields are expressed in kilograms per hectare.

APPENDIX III TABLE III. YIELDS, STANDARD DEVIATIONS, AND NUMBERS OF OBSERVATIONS ON DIACOL H-205 CORN ON REGIONAL TRIALS IN THE CAUCA VALLEY, 1965, BY FERTILIZER AND CARBON-NITROGEN RATIOS

Carbon/ Nitrogen Ratio[3]	22.58			18.62			14.25			12.29		
Fertilizer[1]	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observation
0-0-0	4,343	902.834	11	4,119	781.066	11	4,180	885.724	11	5,249	1074.190	11
50-0-0	4,885	562.67	11	4,688	592.97	11	4,295	787.08	11	5,269	1057.81	11
100-0-0	5,126	412.35	11	5,027	534.19	11	4,310	868.85	11	5,277	974.56	11
200-0-0	4,934	335.72	11	5,002	294.73	11	4,410	883.47	11	5,573	1080.70	11
0-100-0	4,332	919.23	11	4,055	839.37	11	4,609	933.21	11	5,369	1035.91	11
50-100-0	5,246	661.68	11	4,949	447.40	11	4,489	848.27	11	5,277	911.51	11
100-100-0	5,381	217.63	12	5,013	437.64	12	4,386	721.49	12	5,355	1028.73	11
200-100-0	5,222	549.56	11	5,105	525.45	11	4,342	945.78	11	5,506	997.49	11
100-100-100	5,367	245.61	20	4,939	554.24	20	4,733	805.74	20	5,092	1113.09	21

[1] The three numbers refer to nitrogen; P_2O_5 (phosphate), and K_2O (potash) fertilizers in kilograms per hectare, respectively.

[2] Yields are expressed in kilograms per hectare.

[3] The carbon-nitrogen ratio in each column is the average of the c/n ratios for that column. For each fertilizer level, the data were arrayed according to magnitude of the c/n ratios, and then divided into four groups by size of c/n ratios.

APPENDIX III TABLE IV. YIELDS, STANDARD DEVIATIONS, AND NUMBERS OF OBSERVATIONS ON DIACOL H-205 CORN ON REGIONAL TRIALS IN THE CAUCA VALLEY IN 1965 BY FERTILIZER LEVEL AND CATION EXCHANGE CAPACITY OF THE SOIL

Cation Exchange Capacity	17.86 - 19.83			26.87 - 31.72			39.84 - 42.08			46.78 - 47.18		
Fertilizer[1]	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number Observation
0-0-0	3,707	801.726	11	4,483	741.126	11	4,577	1009.961	11	5,123	971.118	11
50-0-0	4,449	512.010	11	4,628	628.595	11	4,928	795.121	11	5,133	1163.353	11
100-0-0	5,006	584.879	11	4,839	826.988	11	4,919	914.714	11	4,976	941.646	11
200-0-0	4,939	267.689	11	4,847	654.944	11	5,115	1061.670	11	5,016	1148.213	11
0-100-0	3,701	907.850	11	4,488	638.890	11	5,087	1114.116	11	5,088	804.640	11
50-100-0	4,699	391.011	11	4,816	529.887	11	5,060	745.504	11	5,386	1155.554	11
100-100-0	4,978	345.057	12	4,748	553.187	12	5,133	1014.841	12	5,267	938.609	11
200-100-0	5,053	576.717	11	4,818	637.678	11	5,197	781.308	11	5,106	1358.906	11
100-100-100	5,149	464.079	20	5,011	440.029	20	4,990	750.966	20	5,011	1202.837	21

[1] The three numbers refer to kilograms per hectare of nitrogen, P_2O_5, (phosphate), and K_2O (potash) fertilizers respectively.

[2] Yields are expressed in kilograms per hectare.

APPENDIX III TABLE V. YIELDS, STANDARD DEVIATIONS, AND NUMBERS OF OBSERVATIONS ON ICA H-207 CORN ON REGIONAL TRIALS IN THE CAUCA VALLEY BY FERTILIZER LEVEL AND CATION EXCHANGE CAPACITY OF THE SOIL

Cation Exchange Capacity	22.13 - 22.47			25.66 - 25.76			29.79 - 31.13			41.99 - 42.75		
Fertilizer[1]	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations
0-0-0	8,065	565.649	7	7,765	684.123	7	8,451	660.933	7	5,529	2650.033	6
50-0-0	7,592	792.283	7	8,364	1387.513	7	8,698	449.791	7	6,924	1217.013	6
100-0-0	7,336	714.274	6	8,334	881.857	7	8,691	723.096	7	7,516	685.014	6
200-0-0	7,442	831.471	6	7,426	1158.898	7	8,591	519.306	7	7,892	387.816	6
0-100-0	7,779	804.590	7	7,903	1541.244	7	8,301	681.318	7	5,935	2537.210	7
50-100-0	7,773	1428.448	7	8,393	950.679	7	8,352	604.246	7	7,112	1662.673	7
100-100-0	7,504	1231.338	7	7,324	838.638	7	8,357	632.166	8	7,518	1203.381	7
200-100-0	7,654	1623.220	7	7,429	549.310	7	8,267	421.612	8	8,456	400.090	7
200-100-100	7,963	955.395	7	7,487	1072.500	7	8,061	660.553	7	7,309	566.244	6

[1] The three numbers refer to kilograms per hectare of nitrogen, P_2O_5 (phosphate), K_2O (potash) fertilizers, respectively.

[2] Yields are expressed in kilograms per hectare.

APPENDIX III TABLE VI. YIELDS, STANDARD DEVIATIONS, AND NUMBERS OF OBSERVATIONS ON ICA H-207 CORN ON REGIONAL TRIALS IN THE CAUCA VALLEY BY FERTILIZER LEVEL AND CARBON-NITROGEN RATIO OF THE SOIL

Carbon-Nitrogen Ratio	9.33 - 9.92			10.82 - 11.03			11.68 - 11.95			13.91 - 14.02		
Fertilizer[1]	Yields[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations	Yield[2]	Standard Deviation	Number of Observations
0-0-0	7,841	1134.240	6	7,304	2052.199	7	7,465	1949.833	7	7,530	1794.893	7
50-0-0	8,026	332.466	7	7,653	1521.170	8	8,209	659.947	7	8,006	843.313	6
100-0-0	7,938	517.065	7	7,709	692.220	6	7,766	705.242	6	7,958	1483.855	7
200-0-0	7,938	583.679	6	7,462	996.455	7	8,154	729.104	7	7,356	946.550	7
0-100-0	8,137	967.984	7	6,874	1296.412	7	7,891	843.684	7	7,871	672.525	8
50-100-0	8,010	666.633	7	8,085	1239.234	6	8,005	917.794	6	7,954	1021.002	7
100-100-0	7,242	1679.385	7	7,063	2106.090	7	7,877	1461.583	7	7,640	2076.575	7
200-100-0	8,169	1130.698	7	7,719	1660.205	7	7,954	1243.855	7	7,788	1271.295	7
100-100-100	8,232	766.259	6	7,554	1316.961	7	8,147	869.322	7	7,745	1709.576	7

[1] The three numbers refer to kilograms per hectare of nitrogen, P_2O_5 (phosphate), and K_2) (potash) fertilizers, respectively.

[2] Yields are expressed in kilograms per hectare.

APPENDIX III TABLE VII. COMPARISON OF AMOUNTS AND TIMES OF APPLICATION OF NITROGEN TO CORN YIELDS

Amount of Nitrogen	All N at Planting Time		1/3 of N at Planting Time 2/3 of N when Corn was 70 cm.		All N when Corn was 70 cm.	
	Mean	Standard Deviation	Mean	Standard Deviation	Mean	Standard Deviation
			kilograms per hectare			
			Experiment I			
50	5,310	267.65	5,933	359.91	6,106	451.37
100	6,219	537.72	6,415	339.84	6,227	613.50
150	6,904	560.88	6,357	366.72	5,908	660.82
0(check)[1]	4,164	427.75				
			Experiment II			
50	2,909	163.22	3,186	120.86	3,241	417.48
100	3,930	130.16	4,175	233.09	4,098	197.34
150	4,359	84.91	4,371	181.55	4,215	230.57
0(check)[1]	2,471	170.11				
0(check)[2]	2,369	145.00				

[1] No fertilizer applied.

[2] No nitrogen, 100 kilograms P_2O_5 and 100 kilograms K_2O per hectare.

All means and variances are based on four observations each.

APPENDIX III TABLE VIII. COMPARISON OF CORN YIELDS OF DIACOL H-253 WITH VARIOUS FERTILIZERS APPLIED ON SOILS WITH DIFFERENT CATION EXCHANGE CAPACITIES ON REGIONAL TRIALS IN THE CAUCA VALLEY, 1966

Fertilizer	Cation Exchange Capacity							
	33.4	33.9	34.6	34.8	35.6	35.7	36.0	36.8
	kilograms per hectare							
0-0-0	7,773	7,754	8,674	7,061	7,727	9,779	8,562	9,219
50-0-0	7,465	9,149	8,204	7,253	7,244	9,829	8,062	8,286
100-0-0	7,265	8,774	7,308	7,627	8,769	9,370	8,929	8,986
200-0-0	7,827	9,141	8,529	7,948	8,490	8,412	9.020	8,257
0-100-0	7,902	8,608	8,712	7,123	7,827	7,258	8,449	7,611
50-100-0	7,861	7,670	8,737	7,686	6,882	7,654	8,041	7,415
100-100-0	8,273	7,624	8,399	8,919	8,619	6,512	8,174	7,494
200-100-0	6,919	8,354	9,487	7,450	8,123	8,183	7,966	8,015
100-100-100	7,327	7,991	8,079	8,269	7,461	7,483	7,570	7,011

APPENDIX III TABLE IX. COMPARISON OF YIELDS OF DIACOL H-205 CORN TO FERTILIZER USE AND CATION EXCHANGE CAPACITY OF THE SOILS ON REGIONAL TRIALS IN THE CAUCA VALLEY, 1966

Fertilizer	Cation Exchange Capacity							
	22.8	24.4	24.8	30.6	36.8	38.4	40.8	56.4
	kilograms per hectare							
0-0-0	4,920	6,640	5,257	6,348	6,682	8,073	7,573	6,878
50-0-0	6,903	5,465	6,890	6,919	7,302	7,273	8,152	7,307
100-0-0	5,653	5,111	6,848	7,623	7,315	7,165	7,348	7,857
200-0-0	7,282	6,074	6,740	8,053	6,790	6,748	6,819	7,598
0-100-0	6,107	5,424	6,657	7,032	6,507	6,194	7,423	7,044
50-100-0	7,761	6,140	6,144	7,498	7,398	6,432	7,032	6,898
100-100-0	6,861	6,373	7,311	7,577	7,986	6,944	7,361	7,213
200-100-0	5,732	6,503	5,953	7,973	7,290	7,373	6,965	7,194
100-100-100	7,302	6,303	7,011	7,965	7,265	7,698	7,028	7,161

APPENDIX III TABLE X. EFFECT OF HERBICIDE USE IN CORN ON REGIONAL TRIALS, IN THE CAUCA VALLEY USING DIACOL H-205 CORN

Fertilizer	With Herbicide	Without Herbicide
	- - - - kilograms per hectare	- - - -
0-0-0	4,117	5,379
50-0-0	4,324	5,187
100-0-0	4,093	5,130
200-0-0	4,065	5,483
0-100-0	4,649	5,468
50-100-0	4,399	5,324
100-100-0	4,306	5,237
200-100-0	3,975	5,397
100-100-100	3,890	5,381

APPENDIX IV

Data Taken from a Planting Date, Irrigation, Nitrogen Fertilizer, and Plant Population Experiment on the Agricultural Experiment Station, Palmira, 1963 and 1964.

APPENDIX IV TABLE I. YIELDS AND STANDARD DEVIATIONS OF DIACOL H-205 CORN DURING 1963-64 BY PLANTING DATE AND NITROGEN FERTILIZER APPLICATION

Nitrogen Fertilizer[5]		0		50		100		200	
Planting Date	Irri-gation	Yield[6]	Standard Deviation	Yield[6]	Standard Deviation	Yield[6]	Standard Deviation	Yield[6]	Standard Deviation
March[1]	no	2,447	1010.69	2,085	839.81	2,212	603.67	2,038	340.70
March[1]	yes	3,264	842.96	3,710	565.49	3,790	596.47	4,080	493.03
September[2]	no	5,144	994.83	5,213	1037.33	4,652	1176.35	4,728	815.24
September[2]	yes	5,210	1575.27	5,697	735.68	6,056	1055.81	6,251	1044.30
April to August[3]	no	1,344	1033.96	1,685	1187.79	1,576	1365.39	1,830	1333.27
April to August[3]	yes	3,599	2020.41	4,075	1208.56	4,166	1242.91	4,319	1157.05
October to February[4]	no	2,018	1323.15	2,004	1134.89	1,660	1150.89	1,886	1128.86
October to February[4]	yes	3,291	1781.77	3,961	1673.69	3,923	1797.42	4,077	1508.90

[1] Each yield of corn for this planting date is based on six observations.

[2] Each yield of corn for this planting date is based on twelve observations.

[3] Each yield of corn for this planting date is based on thirty-six observations.

[4] Each yield of corn for this planting date is based on eighteen observations.

[5] Nitrogen fertilizer levels are expressed in kilograms per hectare.

[6] Yields are expressed in kilograms per hectare.

APPENDIX IV TABLE II. YIELDS OF CORN WITH AND WITHOUT IRRIGATION FOR VARIOUS PLANTING DATES

Planting Date	With Irrigation	Without Irrigation
	- - - - - metric tons	per hectare - - - -
May 21, 1963	3.65	0.72
July 2, 1963	5.10	0.15
August 17, 1963	5.15	3.02
September 28, 1963	6.28	4.60
November 6, 1963	5.45	3.17
December 19, 1963	3.52	1.25
January 28, 1964	2.16	1.20
March 9, 1964	3.17	2.19
April 24, 1964	4.04	2.52
June 9, 1964	2.70	1.21
July 16, 1964	3.53	1.71
August 28, 1964	5.21	5.27

Adapted from Gómez, Jarió A., and McClung, Colin, "Influjo de la Irrigacion de la Poblacion y la Fertilizacion con Nitrógeno en la Produccion y Otras Características del Maiz," Unpublished paper, Soils Section of the Agricultural Experiment Station, Palmira, 1965.

APPENDIX V

Average Rainfall for Each Ten-day Interval in the Year, and Average Hours of Sunshine per Day for Each Ten-day Interval Through the Year, for the years 1954 to 1964, at the Agricultural Experiment Station at Palmira, in the Cauca Valley.

APPENDIX V TABLE I. AVERAGE HOURS OF SUNSHINE PER DAY FOR THIRTY-SIX TEN-DAY PERIODS IN THE YEAR, AND VARIANCE OF HOURS OF SUNSHINE PER DAY FOR EACH PERIOD IN PALMIRA, CAUCA VALLEY[1]

Interval	Average Hours	Standard Deviation	Interval	Average Hours	Standard Deviation
Jan. 1-10	6.43	1.232	July. 1-10	5.79	0.838
Jan. 11-20	6.67	0.632	Jul. 11-20	5.86	1.055
Jan. 21-31	5.99	2.371	Jul. 21-31	6.01	0.478
Feb. 1-10	6.20	1.423	Aug. 1-10	6.27	0.849
Feb. 11-20	6.38	1.527	Aug. 11-20	5.67	0.561
Feb. 21-28	6.02	1.813	Aug. 21-31	5.85	1.047
Mar. 1-10	6.00	1.237	Sept. 1-10	5.90	0.543
Mar. 11-20	5.34	0.359	Sept. 11-20	5.45	0.378
Mar. 21-31	5.08	0.726	Sept. 21-30	6.02	0.273
Apr. 1-10	4.78	0.277	Oct. 1-10	5.35	1.110
Apr. 11-20	4.74	0.640	Oct. 11-20	4.50	1.003
Apr. 21-30	4.91	1.627	Oct. 21-31	5.66	1.200
May 1-10	4.98	1.124	Nov. 1-10	5.16	1.679
May 11-20	5.18	1.067	Nov. 11-20	4.76	1.494
May 21-31	4.98	0.601	Nov. 21-30	5.25	1.362
Jun. 1-10	4.67	1.081	Dec. 1-10	5.32	0.874
Jun. 11-20	5.29	0.594	Dec. 11-20	5.56	1.198
Jun. 21-30	5.78	0.748	Dec. 21-31	5.81	0.927

[1] Based on daily observations for the years 1954 to 1964 on the Agricultural Experiment Station, Palmira, Cauca Valley.

APPENDIX V TABLE II. AVERAGE RAINFALL IN MILLIMETERS PER THIRTY-SIX INTERVALS DURING THE YEAR AT THE AGRICULTURAL EXPERIMENT STATION, PALMIRA[1]

Interval	Average Rainfall	Variance	Interval	Average Rainfall	Variance
Jan. 1-10	28.85	1227.34	Jul. 1-10	16.73	287.49
Jan. 11-20	14.32	100.20	Jul. 11-20	5.48	27.28
Jan. 21-31	18.70	278.84	Jul. 21-31	12.11	405.32
Feb. 1-10	21.17	244.13	Aug. 1-10	8.05	38.08
Feb. 11-20	15.53	199.31	Aug. 11-20	6.82	50.70
Feb. 21-28	34.14	1101.93	Aug. 21-31	8.38	39.83
Mar. 1-10	34.11	883.86	Sept. 1-10	13.12	305.60
Mar. 11-20	23.02	335.63	Sept. 11-20	15.05	335.76
Mar. 21-31	24.88	492.61	Sept. 21-30	20.83	485.66
Apr. 1-10	35.13	674.72	Oct. 1-10	37.77	647.76
Apr. 11-20	69.32	1614.96	Oct. 11-20	57.43	549.38
Apr. 21-30	57.66	1442.81	Oct. 21-31	54.60	2705.92
May 1-10	47.94	3327.12	Nov. 1-10	31.43	454.39
May 11-20	28.96	607.26	Nov. 11-20	26.82	260.13
May 21-31	48.85	2549.33	Nov. 21-30	28.05	406.28
Jun. 1-10	32.12	1161.61	Dec. 1-10	24.26	222.10
Jun. 11-20	33.61	1007.46	Dec. 11-20	16.65	220.20
Jun. 21-30	24.91	956.31	Dec. 21-31	36.15	899.90

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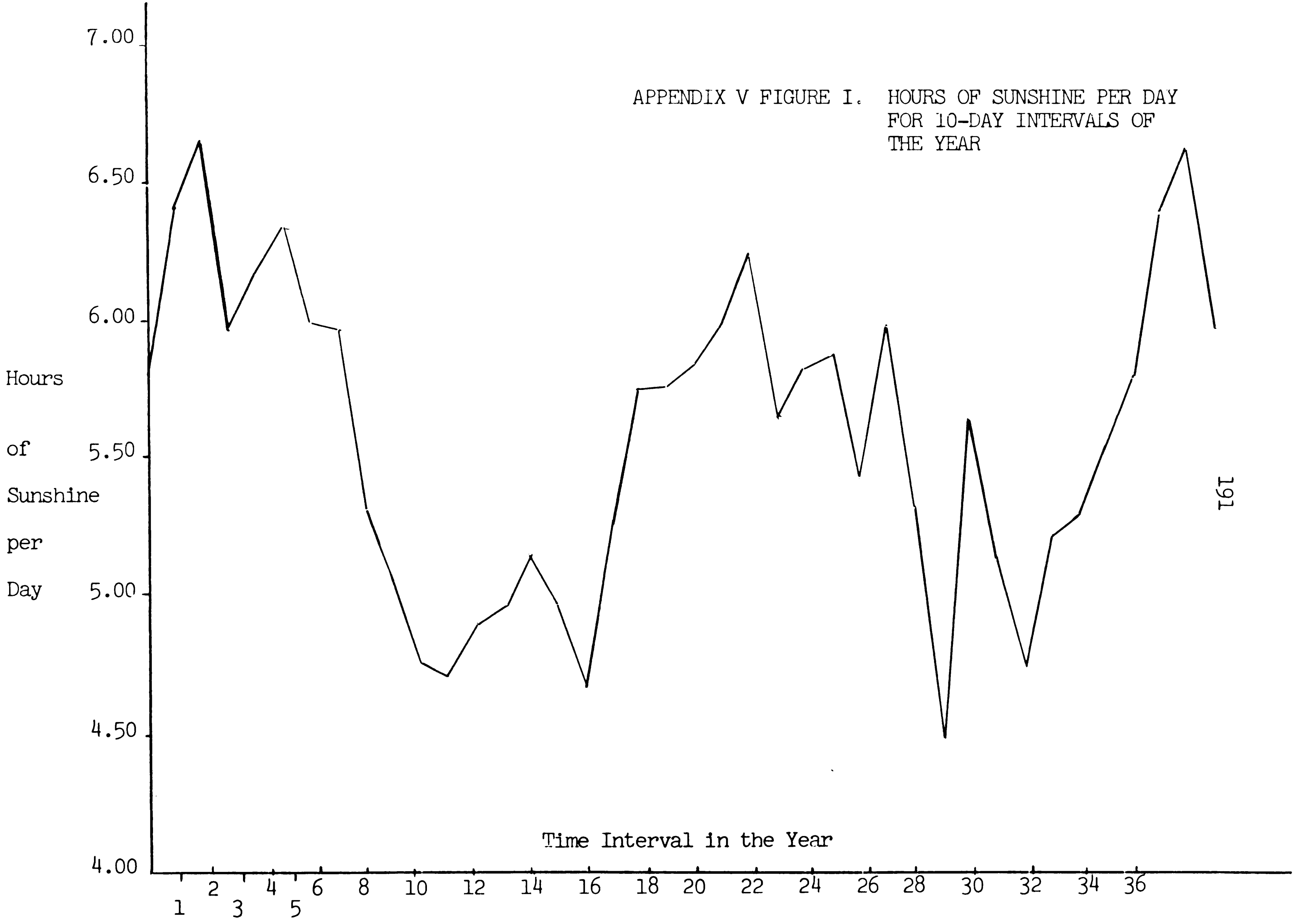
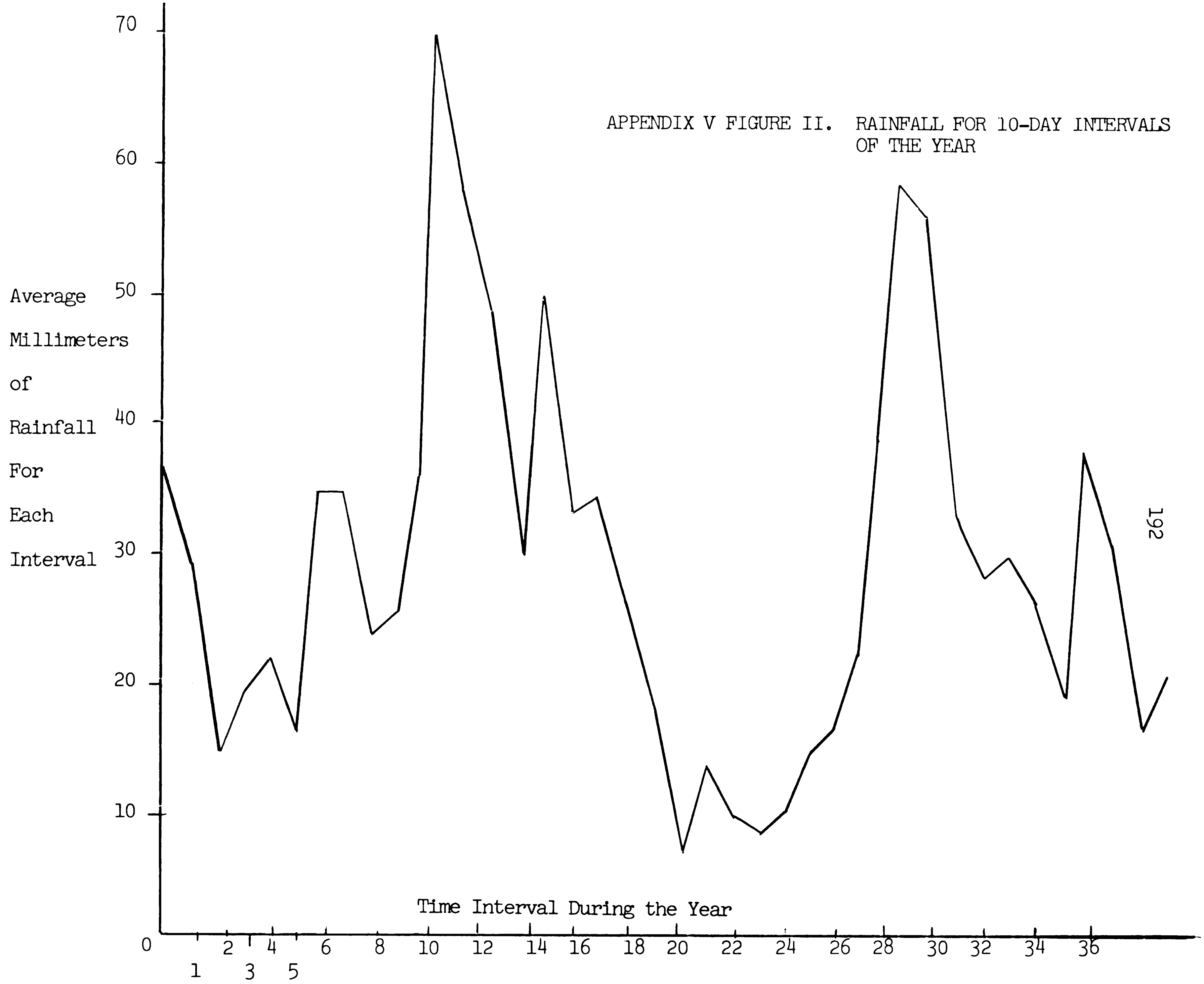
[1] Based on daily observations at the Agricultural Experiment Station, Palmira, for the years 1954 to 1964.



APPENDIX V FIGURE I. HOURS OF SUNSHINE PER DAY FOR 10-DAY INTERVALS OF THE YEAR



APPENDIX V FIGURE II. RAINFALL FOR 10-DAY INTERVALS OF THE YEAR

APPENDIX VI

Calculated Economic Optima for Nitrogen, Corn Yield, and Profit for Thirty-six Intervals of the Year.

APPENDIX VI TABLE I. OPTIMUM NITROGEN LEVELS FOR THREE LEVELS OF PLANT DENSITY AND VARIOUS LEVELS OF IRRIGATION[1]

Irrigation Level[2]		No Irrigation			In First Four Periods Irrigation to 80 mm[4]			Irrigation to 80 mm in First Seven Periods after Planting [5]		
Plant Density		45,000	55,000	65,000	45,000	55,000	65,000	45,000	55,000	65,000
Planting Interval[3]		kilograms per hectare[6]								
	1	19.5	35.9	52.3	-	-	-	88.0	127.6	167.1
January	2	-	-	-	-	-	-	1.0	40.5	80.1
	3	20.7	41.1	61.3	-	-	-	12.2	51.7	91.3
	4	-	23.9	51.5	-	-	-	22.1	61.6	101.2
February	5	151.7	210.6	269.5	21.2	51.1	81.0	58.0	97.6	137.1
	6	17.7	52.3	87.2	-	-	-	24.0	63.5	103.1
	7	42.1	71.8	101.5	-	-	-	65.5	105.0	144.6
March	8	64.2	97.2	130.1	-	-	-	59.6	99.2	138.7
	9	114.6	159.9	205.4	-	-	-	68.0	107.6	147.1
	10	16.0	35.1	54.2	-	-	-	78.7	118.3	157.8
April 11	11	-	-	-	-	-	-	124.4	163.9	203.5
	12	-	-	-	-	-	-	121.7	161.2	200.8
	13	-	-	-	-	-	-	131.4	170.9	210.5
May	14	-	-	-	-	-	-	138.5	178.0	217.6
	15	-	-	-	-	-	-	138.5	178.1	217.6
	16	-	-	-	-	-	-	134.2	173.7	213.3
June	17	-	-	-	-	-	-	114.5	154.0	193.6
	18	-	-	-	-	-	-	101.6	141.1	180.7
	19	-	-	-	-	-	-	70.6	110.2	149.7
July 20	20	-	-	-	-	-	-	33.5	73.1	112.6
	21	-	-	-	-	-	-	29.0	68.6	108.1
	22	69.6	102.1	134.7	-	-	-	71.2	110.8	150.3
Aug.	23	129.9	181.8	233.9	-	1.3	20.5	60.7	100.2	139.8
	24	153.7	203.9	254.2	2.2	18.8	35.4	86.7	126.3	165.8
	25	76.6	108.3	139.9	-	-	-	79.5	119.1	158.6
Sept.	26	86.2	119.1	151.9	-	-	-	83.2	122.7	162.3

APPENDIX VI TABLE I. (Continued)

Irrigation Level[2]		No Irrigation			In First Four Periods Irrigation to 80 mm[4]			Irrigation to 80 mm in First Seven Periods after Planting[5]		
Plant Density		45,000	55,000	65,000	45,000	55,000	65,000	45,000	55,000	65,000
Planting Inverval[3]		kilograms per hectare[6]								
	27	34.5	63.1	91.6	-	-	-	48.1	87.6	127.2
	28	-	-	-	-	-	-	60.5	100.0	139.6
October	29	-	-	-	-	-	-	105.6	145.1	184.7
	30	-	-	-	-	-	-	106.0	145.6	185.1
	31	29.4	32.1	50.9	-	-	-	116.2	155.7	195.3
November	32	9.0	7.4	5.8	-	-	-	136.8	176.4	215.9
	33	-	-	-	-	-	-	71.9	111.4	151.0
	34	-	7.5	18.3	-	-	-	78.4	117.9	157.5
December	35	22.9	29.3	35.7	-	-	-	118.2	157.8	197.3
	36	8.7	19.1	29.1	-	-	-	106.2	145.7	185.3

[1] These economic optima for nitrogen were calculated using the price ratio of $\frac{4.25}{1.00}$ i.e., the price of nitrogen (Pn) was 4.25 pesos per kilo and the price of corn (Pc) was 1.00 peso in the formula $MPP_n = Pn/Pc$ where MPP_n = marginal physical product for nitrogen in the production of corn.

[2] The irrigation level refers to the total amount of water added, during one or more 10-day periods after planting, including both rainfall and irrigation.

[3] The interval refers to the particular 10-day period during the year.

[4] Irrigation is used to raise the total water available during the first four periods after planting to 80 millimeters.

APPENDIX VI TABLE L. (Continued)

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[5] For the optimal level of nitrogen when the plant density is 55,000 per hectare, add 39.6 kilograms to the optimum given in column one (45,000) for each planting interval of the year. For the optimal level of nitrogen when the plant density is 65,000, add 79.1 kilograms to each entry in column one.

For the optimal level of nitrogen with plant density of 55,000, add 49.4 kilograms to each entry in column two. For the optimal level of nitrogen with plant density of 65,000, add 99.0 kilograms to each entry in column two.

For the optimal level of nitrogen with plant density of 55,000, add 61.8 kilograms to each entry in column three. For the optimal level of nitrogen with plant density of 65,000, add 123.6 kilograms to each entry in column three.

[6] If no entry occurs the calculated economic optima for nitrogen was zero or negative.

APPENDIX VI TABLE II. PREDICTED CORN YIELDS FOR THREE PLANT DENSITIES WHEN NO IRRIGATION IS APPLIED AND WHEN IRRIGATION IS USED ONE TO TEN DAYS AFTER PLANTING

Planting Interval	Plant Density per Hectare			Plant Density per Hectare[1]		
	45,000	55,000	65,000	45,000	55,000	65,000
1	-	-	-	-	-	-
Jan. 2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
Feb. 5	-	9	588	-	-	-
6	-	-	-	-	-	-
7	1,400	1,655	1,830	1,085	1,294	1,298
March 8	168	-	-	-	-	-
9	2,640	2,952	3,264	1,840	1,995	1,935
10	3,751	3,846	4,135	3,603	3,846	3,873
Apr. 11	3,378	3,625	3,655	3,378	3,625	3,655
12	414	-	-	414	-	-
13	3,998	4,000	3,786	3,998	4,000	3,786
May 14	3,887	3,906	3,709	3,887	3,906	3,709
15	1,945	1,798	1,435	1,945	1,798	1,435
16	270	-	-	270	-	-
June 17	142	-	-	142	-	-
18	-	-	-	-	-	-
19	-	-	-	-	-	-
July 20	-	-	-	-	-	-
21	-	-	-	-	-	-
22	-	-	-	-	-	-
Aug. 23	-	-	-	-	-	-
24	-	-	-	-	-	-
25	-	-	-	-	-	-
Sept. 26	4,204	4,345	4,421	3,629	3,686	3,527
27	-	-	-	-	-	-
28	2,134	2,232	2,115	2,134	2,232	2,115
Oct. 29	2,066	2,499	2,715	2,066	2,499	2,715
30	-	-	-	-	-	-
31	-	-	-	-	-	-
Nov. 32	1,182	1,283	1,162	1,150	1,251	1,136
33	-	-	-	-	-	-
34	-	-	-	-	-	-
Dec. 35	-	-	-	-	-	-
36	-	-	-	-	-	-

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[1] Water used in the first ten days after planting was 80 millimeters, thereafter only rainfall.

APPENDIX VI TABLE III. PREDICTED CORN YIELDS FOR THREE PLANT DENSITIES WHEN IRRIGATION IS USED 1-20 AND 1-30 DAYS AFTER PLANTING

Planting Interval		Plant Density per Hectare[1]			Plant Density per Hectare[2]		
		45,000	55,000	65,000	45,000	55,000	65,000
	1	-	-	-	-	-	-
Jan.	2	-	-	-	-	-	-
	3	-	-	-	1,236	1,087	722
	4	146	-	-	747	578	193
Feb.	5	85	277	253	692	884	860
	6	-	-	-	-	-	-
	7	2,845	3,045	3,047	4,055	4,265	4,258
March	8	1,342	983	409	2,158	1,800	1,226
	9	3,081	3,236	3,176	3,095	3,251	3,190
	10	3,896	4,139	4,165	4,038	4,281	4,308
Apr.	11	4,012	4,259	4,289	4,362	4,609	4,639
	12	1,337	857	161	2,332	1,852	1,156
	13	5,527	5,529	5,315	5,853	5,855	5,641
May	14	4,785	4,803	4,606	5,751	5,771	5,574
	15	3,238	3,091	2,728	4,011	3,864	3,501
	16	1,689	1,335	765	2,724	2,370	1,801
June	17	1,984	1,746	1,294	3,428	3,191	2,738
	18	-	-	-	1,812	1,430	833
	19	-	-	-	-	-	-
July	20	-	-	-	-	-	-
	21	-	-	-	-	-	-
	22	110	715	1,105	2,024	2,629	3,019
Aug.	23	-	-	-	540	486	215
	24	-	-	-	-	-	-
	25	825	539	37	1,994	1,708	1,206
Sept.	26	5,689	5,746	5,587	6,294	6,351	6,191
	27	593	-	-	781	-	-
	28	2,721	2,820	2,702	2,836	2,935	2,871
Oct.	29	2,898	3,330	3,546	3,788	4,221	4,437
	30	161	-	-	1,354	1,160	750
	31	862	682	286	1,881	1,701	1,305
Nov.	32	2,727	2,829	2,714	3,908	4,010	3,895
	33	-	-	-	486	-	-
	34	1,111	1,115	902	1,684	1,687	1,474
Dec.	35	916	1,098	1,064	1,626	1,809	1,775
	36	-	-	-	-	-	-

[1] Water use in each of the first two 10-day periods after planting was 80 millimeters, thereafter only rainfall.

[2] Water use in each of the first three 10-day periods was 80 millimeters, thereafter only rainfall.

APPENDIX VI TABLE IV. PREDICTED CORN YIELDS FOR THREE PLANT DENSITIES WHEN IRRIGATION IS USED 1-40 AND 1-50 DAYS AFTER PLANTING

Planting Interval	Plant Density per Hectare[1]			Plant Density per Hectare[2]		
	45,000	55,000	65,000	45,000	55,000	65,000
1	684	16	-	5,767	5,099	4,213
Jan. 2	-	-	-	1,675	137	-
3	2,273	2,124	1,758	5,727	5,578	5,213
4	1,784	1,615	1,230	4,613	4,444	4,059
Feb. 5	2,074	2,172	2,148	4,408	4,506	4,482
6	-	-	-	-	-	-
7	5,070	5,279	5,272	5,618	5,827	5,821
March 8	2,400	2,041	1,467	3,556	3,197	2,623
9	3,600	3,756	3,695	5,189	5,345	5,284
10	4,763	5,006	5,032	7,177	7,420	7,447
Apr. 11	5,516	5,762	5,793	7,072	7,319	7,350
12	3,036	2,556	1,860	4,604	4,124	3,428
13	6,935	6,937	6,723	9,386	9,388	9,174
May 14	6,800	6,819	6,622	10,340	10,359	10,163
15	5,257	5,109	4,746	9,110	8,963	8,600
16	4,154	3,801	3,231	8,480	8,126	7,556
June 17	5,113	4,876	4,423	9,574	9,337	8,884
18	3,346	2,965	2,367	8,528	8,147	7,550
19	1,089	291	-	4,946	4,148	3,134
July 20	-	-	-	4,108	3,141	1,957
21	30	-	-	4,225	3,751	3,060
22	3,536	4,141	4,530	6,752	7,357	7,746
Aug. 23	2,008	1,954	1,683	6,147	6,093	5,822
24	783	356	-	3,173	2,745	2,110
25	2,948	2,662	2,160	3,824	3,538	3,036
Sept. 26	6,804	6,861	6,702	8,679	8,736	8,577
27	1,356	572	-	3,677	2,893	1,894
28	3,934	4,033	3,915	5,699	5,798	5,681
Oct. 29	4,990	5,423	5,639	7,540	7,973	8,189
30	2,528	2,335	1,925	5,292	5,098	4,688
31	3,141	2,961	2,565	6,542	6,361	5,965
Nov. 32	5,340	5,442	5,327	8,421	8,522	8,408
33	1,477	834	-	5,895	5,252	4,373
34	2,840	2,843	2,630	8,578	8,581	8,368
Dec. 35	3,111	3,294	3,260	7,282	7,465	7,431
36	789	369	-	5,244	4,824	4,187

[1] Water use in each of the first four 10-day periods was 80 millimeters, thereafter only rainfall.

[2] Water use in each of the first five 10-day periods was 80 millimeters, thereafter only rainfall.

APPENDIX VI TABLE V. PREDICTED CORN YIELDS FOR THREE PLANT DENSITIES WHEN IRRIGATION IS USED 1-70 AND 1-80 DAYS AFTER PLANTING

Planting Interval	Plant Density per Hectare[1]			Plant Density per Hectare[2]		
	45,000	55,000	65,000	45,000	55,000	65,000
1	3,947	3,539	2,948	3,331	2,922	2,330
Jan. 2	-	-	-	-	-	-
3	3,045	3,091	2,955	3,230	3,275	3,138
4	2,485	2,520	2,372	2,979	3,013	2,866
Feb. 5	4,066	4,493	4,737	4,778	5,205	5,449
6	-	-	-	-	-	-
7	4,351	4,801	5,070	4,173	4,623	4,890
March 8	1,314	1,192	887	1,969	1,846	1,541
9	3,982	4,381	4,597	4,002	4,400	4,616
10	5,202	5,697	6,010	5,306	5,801	6,113
Apr. 11	5,466	6,004	6,344	4,998	5,535	5,876
12	2,547	2,356	1,980	1,373	1,181	803
13	6,991	7,290	7,361	4,575	4,873	4,943
May 14	7,437	7,760	7,822	5,791	6,112	6,173
15	6,536	6,693	6,589	4,431	4,587	4,481
16	5,674	5,620	5,325	3,422	3,367	3,071
June 17	6,570	6,616	6,480	4,504	4,549	4,412
18	5,517	5,407	5,115	3,978	3,868	3,574
19	1,980	1,428	693	641	87	-
July 20	1,039	285	-	239	-	-
21	1,421	1,156	709	1,732	1,467	1,019
22	5,013	5,864	6,533	5,726	6,577	7,245
Aug. 23	5,324	5,507	5,507	6,038	6,220	6,220
24	2,353	2,193	1,851	2,331	2,171	1,828
25	1,819	1,787	1,571	1,494	1,461	1,245
Sept. 26	6,468	6,781	6,912	6,229	6,541	6,671
27	1,327	770	30	810	252	-
28	3,230	3,565	3,718	2,048	2,382	2,534
Oct. 29	4,965	5,673	6,198	5,201	5,907	6,432
30	3,687	3,769	3,667	3,501	3,592	3,481
31	4,642	4,747	4,669	3,228	3,331	3,252
Nov. 32	5,945	6,348	6,499	4,955	5,358	5,508
33	3,214	2,817	2,239	2,444	2,046	1,466
34	6,058	6,313	6,386	4,765	5,019	5,091
Dec. 35	4,736	5,205	5,491	4,868	5,336	5,622
36	3,541	3,396	3,069	3,672	3,526	3,199

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[1] Water use in each of the first seven 10-day periods was 80 millimeter, thereafter only rainfall.

[2] Water use in each of the first eight 10-day periods was 80 millimeter, thereafter only rainfall.

APPENDIX VI TABLE VI. PREDICTED CORN YIELDS FOR THREE PLANT DENSITIES AND TWO LEVELS OF IRRIGATION DURING THE 21-40 DAYS AFTER PLANTING

Planting Interval	Plant Density per Hectare[1]			Plant Density per Hectare[2]		
	45,000	55,000	65,000	45,000	55,000	65,000
1	774	76	-	258	-	-
Jan. 2	-	-	-	-	-	-
3	2,297	2,148	1,783	1,767	1,618	1,252
4	1,841	1,672	1,287	1,351	1,182	797
Feb. 5	2,038	2,231	2,207	1,551	1,743	1,719
6	-	-	-	-	-	-
7	5,211	5,421	5,414	4,827	5,037	5,030
March 8	2,569	2,210	1,636	2,218	1,860	1,286
9	3,774	3,929	3,869	3,429	3,585	3,524
10	4,920	5,163	5,190	4,555	4,798	4,825
Apr. 11	5,667	5,913	5,944	5,294	5,541	5,571
12	3,168	2,689	1,992	2,773	2,293	1,597
13	7,086	7,099	6,874	6,713	6,715	6,501
May 14	6,979	6,998	6,801	6,641	6,660	6,463
15	5,379	5,232	4,869	4,972	4,825	4,461
16	4,233	3,879	3,309	3,770	3,416	2,847
June 17	5,190	4,954	4,501	4,726	4,490	4,037
18	3,418	3,036	2,439	2,946	2,564	1,967
19	1,147	349	-	658	-	-
July 20	-	-	-	-	-	-
21	119	-	-	-	-	-
22	3,608	4,214	4,603	3,138	3,743	4,132
Aug. 23	2,076	2,022	1,751	1,600	1,545	1,275
24	883	464	-	457	38	-
25	3,005	2,719	2,217	2,515	2,229	1,727
Sept. 26	6,921	6,978	6,819	6,507	6,564	6,405
27	1,550	767	-	1,231	448	-
28	4,023	4,122	4,005	3,574	3,673	3,555
Oct. 29	5,125	5,557	5,774	4,732	5,164	5,381
30	2,699	2,505	2,095	2,351	2,157	1,747
31	3,268	3,088	2,692	2,865	2,685	2,289
Nov. 32	5,460	5,562	5,447	5,049	5,151	5,036
33	1,576	933	74	1,138	495	-
34	2,916	2,919	2,706	2,450	2,453	2,240
Dec. 35	3,131	3,314	3,280	2,595	2,778	2,744
36	788	367	-	224	-	-

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[1] Water use of 80 mm in each of the first two and water use of 100 mm during the third and fourth 10-day periods after planting, thereafter only rain.

[2] Water use of 80 mm in each of the first two, and water use to 125 mm during the third and fourth 10-day periods after planting, thereafter only rain.

APPENDIX VI TABLE VII. CALCULATED PROFIT FOR THREE PLANT DENSITIES FOR NORMAL RAINFALL AND WATER USE TO 80 MILLIMETERS DURING 1-10 DAYS AFTER PLANTING

Planting Interval		Plant Density per Hectare[1]			Plant Density per Hectare[2]		
		45,000	55,000	65,000	45,000	55,000	65,000
	1	-	-	-	-	-	-
Jan.	2	-	-	-	-	-	-
	3	-	-	-	-	-	-
	4	-[3]	-	-	-	-	-
Feb.	5	-	-	-	-	-	-
	6	-	-	-	-	-	-
	7	1,136	1,246	-	945	1,111	1,056
March	8	-	-	-	-	-	-
	9	2,068	2,168	2,291	1,689	1,801	1,692
	10	3,598	3,593	3,732	3,462	3,664	3,642
Apr.	11	3,293	3,521	3,532	3,280	3,484	3,465
	12	-	-	-	-	-	-
	13	-	-	-	-	-	-
May	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
	16	-	-	-	-	-	-
June	17	-	-	-	-	-	-
	18	-	-	-	-	-	-
	19	-	-	-	-	-	-
July	20	-	-	-	-	-	-
	21	-	-	-	-	-	-
	22	-	-	-	-	-	-
Aug.	23	-	-	-	-	-	-
	24	-	-	-	-	-	-
	25	-	-	-	-	-	-
Sept.	26	3,753	3,735	3,652	3,466	3,480	3,272
	27	-	-	-	-	-	-
	28	2,049	2,128	1,992	1,998	2,053	1,887
Oct.	29	1,981	2,395	2,592	1,954	2,344	2,511
	30	-	-	-	-	-	-
	31	-	-	-	-	-	-
Nov.	32	-	-	-	-	-	-
	33	-	-	-	-	-	-
	34	-	-	-	-	-	-
Dec.	35	-	-	-	-	-	-
	36	-	-	-	-	-	-

[1] No irrigation was used, only average rainfall.

[2] Water use was 80 millimeters in first 10-days after planting, thereafter only rainfall.

[3] Where no entry occurs, calculated profit was less than zero.

APPENDIX VI TABLE VIII. CALCULATED PROFIT FOR THREE DENSITIES FOR WATER USE TO 80 MILLIMETERS DURING 1-20 AND 1-30 DAYS AFTER PLANTING

Planting Interval		Plant Density per Hectare[1]			Plant Density per Hectare[2]		
		45,000	55,000	65,000	45,000	55,000	65,000
	1	-	-	-	-	-	-
Jan.	2	-	-	-	-	-	-
	3	-	-	-	-	-	-
	4	-[3]	-	-	-	-	-
Feb.	5	-	41	-	420	593	550
	6	-	-	-	-	-	-
	7	2,637	2,818	2,801	3,781	3,972	3,946
March	8	1,123	745	152	1,885	1,508	915
	9	2,876	3,012	2,933	2,877	3,014	2,934
	10	3,744	3,968	3,975	3,859	4,083	4,091
Apr.	11	3,887	4,115	4,126	4,199	4,427	4,439
	12	1,187	688	-	2,121	1,622	907
	13	-	-	-	-	-	-
May	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
	16	-	-	-	-	-	-
June	17	-	-	-	-	-	-
	18	-	-	-	-	-	-
	19	-	-	-	-	-	-
July	20	-	-	-	-	-	-
	21	-	-	-	-	-	-
	22	-	-	-	-	-	-
Aug.	23	-	-	-	-	-	-
	24	-	-	-	-	-	-
	25	582	277	-	1,680	1,375	854
Sept.	26	5,455	5,493	5,315	6,009	6,047	5,868
	27	386	-	-	547	-	-
	28	2,558	2,638	2,501	2,643	2,723	2,640
Oct.	29	2,756	3,169	3,366	3,588	4,002	4,199
	30	-	-	-	1,117	904	475
	31	-	-	-	-	-	-
Nov.	32	-	-	-	-	-	-
	33	-	-	-	-	-	-
	34	-	-	-	-	-	-
Dec.	35	-	-	-	-	-	-
	36	-	-	-	-	-	-

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[1] Water use was 80 mm in each of the first two 10-day periods after planting, thereafter only rainfall.

[2] Water use was 80 mm in each of the first three 10-day periods after planting, thereafter only rainfall.

[3] Where no entry occurs, calculated profit was less than zero.

APPENDIX VI TABLE IX. CALCULATED PROFIT FOR THREE PLANT DENSITIES FOR WATER USE TO 80 MILLIMETERS DURING 1-40 AND 1-50 DAYS AFTER PLANTING

Planting Interval		Plant Density per Hectare[1]			Plant Density per Hectare[2]	
	45,000	55,000	65,000	45,000	55,000	65,000
1	-	-	-	-	-	-
Jan. 2	-	-	-	-	-	-
3	-	-	-	-	-	-
4	-	-	-	-	-	-
Feb. 5	1,644	1,596	1,426	3,904	3,864	3,694
6	-[3]	-	-	-	-	-
7	4,742	4,932	4,906	5,277	5,467	5,442
March 8	2,114	1,736	1,143	3,243	2,865	2,272
9	3,355	3,492	3,412	4,906	5,043	4,963
10	4,546	4,770	4,777	6,899	7,123	7,131
Apr. 11	5,292	5,519	5,531	6,811	7,039	7,051
12	2,825	2,289	1,574	4,299	3,800	3,085
13	-	-	-	-	-	-
May 14	-	-	-	-	-	-
15	-	-	-	-	-	-
16	-	-	-	-	-	-
June 17	-	-	-	-	-	-
18	-	-	-	-	-	-
19	-	-	-	-	-	-
July 20	-	-	-	-	-	-
21	-	-	-	-	-	-
22	-	-	-	-	-	-
Aug. 23	-	-	-	-	-	-
24	374	-	-	2,713	2,195	1,471
25	2,583	2,278	1,757	3,432	3,127	2,606
Sept. 26	6,492	6,530	6,352	8,337	8,375	8,197
27	1,092	289	-	8,355	2,552	1,534
28	3,683	3,763	3,626	5,384	5,464	5,328
Oct. 29	4,726	5,140	5,337	7,214	7,628	7,825
30	2,229	2,017	1,588	4,926	4,713	4,284
31	-	-	-	-	-	-
Nov. 32	-	-	-	-	-	-
33	-	-	-	-	-	-
34	-	-	-	-	-	-
Dec. 35	-	-	-	-	-	-
36	-	-	-	-	-	-

[1] Water use was 80 mm in each of the first four 10-day periods after planting, thereafter only rainfall.

[2] Water use was 80 mm in each of the first five 10-day periods after planting, thereafter only rainfall.

[3] Where no entry occurs, calculated profit was less than zero.

APPENDIX VI TABLE X. CALCULATED PROFIT FOR THREE PLANT DENSITIES FOR WATER USE TO 80 MILLIMETERS DURING 1-70 AND 1-80 DAYS AFTER PLANTING

Planting Interval		Plant Density per Hectare[1]			Plant Density per Hectare[2]		
		45,000	55,000	65,000	45,000	55,000	65,000
	1	-	-	-	-	-	-
Jan.	2	-	-	-	-	-	-
	3	-	-	-	-	-	-
	4	-	-	-	-	-	-
Feb.	5	3,346	3,586	3,643	4,031	4,271	4,328
	6	-[3]	-	-	-	-	-
	7	3,667	3,930	4,012	3,428	3,691	3,771
March	8	649	340	-	1,267	957	465
	9	3,312	3,524	3,553	3,275	3,486	3,515
	10	4,495	4,803	4,921	4,543	4,851	4,976
Apr.	11	4,563	4,914	5,067	4,029	4,379	4,533
	12	1,603	1,225	662	353	-	-
	13	-	-	-	-	-	-
May	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
	16	-	-	-	-	-	-
June	17	-	-	-	-	-	-
	18	-	-	-	-	-	-
	19	-	-	-	-	-	-
July	20	-	-	-	-	-	-
	21	-	-	-	-	-	-
	22	-	-	-	-	-	-
Aug.	23	-	-	-	-	-	-
	24	1,476	1,129	600	1,396	1,049	519
	25	1,001	782	379	612	392	-
Sept.	26	5,651	5,777	5,721	5,350	5,475	5,418
	27	675	-	-	91	-	-
	28	2,529	2,677	2,643	1,271	1,418	1,381
Oct.	29	4,047	4,568	4,906	4,230	4,749	5,087
	30	2,741	2,636	2,347	2,494	2,388	2,100
	31	-	-	-	-	-	-
Nov.	32	-	-	-	-	-	-
	33	-	-	-	-	-	-
	34	-	-	-	-	-	-
Dec.	35	-	-	-	-	-	-
	36	-	-	-	-	-	-

[1] Water use was 80 millimeters in each of the first seven 10-day periods after planting, thereafter only rainfall.

[2] Water use was 80 millimeters in each of the first eight 10-day periods after planting, thereafter only rainfall.

[3] Where no entry occurs, calculated profit was less than zero.

APPENDIX VI TABLE XI. CALCULATED PROFIT FOR THREE PLANT DENSITIES FOR TWO LEVELS OF WATER USE DURING 1-40 DAYS AFTER PLANTING

Planting Interval		Plant Density per Hectare[1]			Plant Density per Hectare[2]		
		45,000	55,000	65,000	45,000	55,000	65,000
	1	-	-	-	-	-	-
Jan.	2	-	-	-	-	-	-
	3	-	-	-	-	-	-
	4	-	-	-	-	-	-
Feb.	5	1,650	1,824	1,781	1,101	1,274	1,231
	6	-[3]	-	-	-	-	-
	7	4,835	5,026	5,000	4,391	4,582	4,556
March	8	2,235	1,957	1,264	1,824	1,447	854
	9	3,481	3,617	3,538	3,076	3,213	3,233
	10	4,655	4,879	4,887	4,230	4,454	4,462
Apr.	11	5,395	5,622	5,634	4,962	5,190	5,201
	12	2,872	2,374	1,658	2,417	1,918	1,203
	13	-	-	-	-	-	-
May	14	-	-	-	-	-	-
	15	-	-	-	-	-	-
	16	-	-	-	-	-	-
June	17	-	-	-	-	-	-
	18	-	-	-	-	-	-
	19	-	-	-	-	-	-
July	20	-	-	-	-	-	-
	21	-	-	-	-	-	-
	22	-	-	-	-	-	-
Aug.	23	-	-	-	-	-	-
	24	435	-	-	-	-	-
	25	2,592	2,287	1,766	2,042	1,737	1,216
Sept.	26	6,561	6,599	6,421	6,087	6,125	5,947
	27	1,238	436	-	589	-	-
	28	3,724	3,804	3,668	3,215	3,295	3,158
Oct.	29	4,813	5,226	5,424	4,360	4,773	4,971
	30	2,352	2,139	1,710	1,944	1,731	1,302
	31	-	-	-	-	-	-
Nov.	32	-	-	-	-	-	-
	33	-	-	-	-	-	-
	34	-	-	-	-	-	-
Dec.	35	-	-	-	-	-	-
	36	-	-	-	-	-	-

[1] Water use was 80 mm in each of the first two 10-day periods, and 100 mm in the third and fourth 10-day periods after planting, thereafter only rain.

[2] Water use was 80 mm in each of the first two 10-day periods, and 125 mm in the third and fourth 10-day periods after planting, thereafter only rain.

[3] Where no entry occurs, calculated profit was less than zero.