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TRANSFER OF TECHNOLOGY BY THE U.S. SEED INDUSTRY

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ABSTRACT

This paper focus on the structure and organization of the seed industry in the United States, and the importance of the transfer of technology in the case of corn. The main objective of the study was to better understand the role of the private seed sector in developing and transferring new technology, specifically in corn. The first section of the paper focus on the organization, major laws, concentration and relationship between private and public sector in the U.S. seed industry. The second section focus on the origins and value of hybrid corn, the corn productivity in 30 selected countries, and the empirical results of measuring the impact of the transfer of technology by the U.S. private corn seed sector. These results support the conclusion that U.S. corn seed sales, as well as fertilizer consumption and the level of education in the main 30 corn producing countries in the world, significantly explained corn yields during the period 1981-1983.

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A) STRUCTURE AND ORGANIZATION OF THE INDUSTRY

A.1) INTRODUCTION

The Seed Industry (SI) includes institutions, organizations, and business firms that perform four different types of activities: basic and applied research, seed production, and marketing and distribution. The SI in tl United States consists of approximately 500 companies. Most are solely seed firms, and few are traded publicly. Firms range in size from small, local, family owned distributors, to large, research oriented multinationals. The larger companies are fully integrated from applied research through production, conditioning, and distribution of a variety of genetically advanced products. They usually have full-time research staffs and spend millions for product development. Smaller firms often limit their activities to a single crop in a specific area and use seeds developed by the research efforts of state and federal organizations and public institutions such as the Land Grant Colleges (LGC). Improved seeds developed by the government are public property and therefore available to seed companies. Larger firms also take advantage of public basic research and the training of breeders at the LGC and Universities.

In the late 1970's U.S. farmers spent over $3 billion for seed purchases. Although this amount is not very big compared with other production expenses (like $6 billion for fertilizers or $ 13 billion for farm machinery) seeds represent an increasing share of agricultural input expenditures in the last twenty years. In 1964 seeds represented 2.1% of all farm production expenses, 3.1% in 1978 and above 4% is expected for 1984.[1]
This increase has two reasons: a rise in seed purchased by farmers instead of using own seed, and a rise in seed prices.[2]

Table 1: Average Seed Prices, 1960-1984. Corn, Soybeans, Wheat, Barley in $/bushel. Alfalfa, Sunflower, Sorghum, Cotton in $/100lbs.

	1960	1965	1970	1975	1980	1983	1984
Corn	11.3	12.2	15.7	36.5	52.5	64.6	70.2
[D]	12.7	12.9	13.5	22.6	21.3	21.6	22.6
Soyb.	3.28	4.22	4.02	10.5	10.4	10.1	—
[D]	3.69	4.44	3.47	6.52	4.21	3.39	
Wheat	2.59	2.57	2.47	6.90	7.07	7.07	6.40
[D]	2.91	2.71	2.13	4.29	2.86	2.37	2.06
Barl.	1.81	1.92	2.07	5.48	5.29	5.80	—
[D]	2.03	2.02	1.78	3.40	2.14	1.95	
Alf.	49.6	55.8	65.8	136	214	209	219
[D]	55.7	58.7	56.7	84.5	86.6	70.1	70.4
Sunf.	—	—	—	—	155	211	254
[D]					62.7	70.8	81.7
Sorg.	—	—	—	36.5	45.0	65.3	64.2
[D]				22.6	18.2	21.9	20.6
Cott.	—	—	15.7	28.5	35.2	—	—
[D]			13.5	17.7	14.2		
SEEDS	89	100	112	245	309	332	—

SEEDS is an index number of all seeds prices paid by farmers (1967=100).
[D] are figures deflated by CPI(1967=100).

Source: USDA Agricultural Statistics, various issues.

Table 1 shows a consistent upward trend of hybrid seed corn current prices, even though farmers received different prices for the commodity during the period. Deflated seed corn values in table 1 show a real increase up to 1975, with more stable prices above $21/bushel through the late 1970's abd early 1980's. The 1984 real seed corn price was similar to that one of 1975. Corn seed real prices have not increased recently because of the economic situation of a large number of farmers in the corn belt, and because seed companies are getting more returns selling the pure single crosses instead of the more expensive to produce double crosses. Wheat and soybean seed, and into some extent alfalfa

seed prices are more volatile. Cotton seed prices show something similar, from 1970 to 1980 price increased and then decreased in real terms. With respect to the other two hybrid seeds, sunflower and sorghum, the first one shows a consistent price increase in the 1980's, while sorghum deflated prices are more volatile. If we look at the index numbers of prices of all seeds, we see that prices increased faster during the 1970's than during the 1960's, with the first half of the 1970's showing the fastest increase in seed prices.

Table 2 shows the market estimates for agricultural seed and value added by the U.S. SI in 1979. Corn is the major source of income and profits for the private seed industry. The value of corn seed(stock) supplied by the industry ($947 M) was almost twice that of soybeans($490 M), which is roughly two times as much as the wheat value ($233 M), see column 6 in table 2. The table also shows that in a total market value of approximately $3.9 billion the seed industry is supplying more than two thirds of that value ($2.8 B). The industry is supplying 100% of the sugarbeet and lawn seed, 95% of the corn, sorghum, ryegrass, bluegrass, fescues, alfalfa, and sweet corn; 90% of the tobacco and 85% of the bean seed; 70% of the rice and peanut seed; 60% of the soybean seed and 50% fo the cotton and barley seed. Only 35% of wheat (taking into account all kinds: winter, spring and durum) is supplied by the industry, see column 5 in table 2. Column 10 shows that corn accounts for almost 50% of the total value added by the SI. Since it is a hybrid almost all seed is purchased each year from the industry and companies maintain exclusive rights for their varieties. Corn is the most widely planted crop in the U.S. and the private seed sector dominates the development and release of new corn hybrids. These factors help explain the high value added igure for corn relative to the other crops, being soybeans the second with 12.3% of total value added provided by the industry. Winter wheat is the third crop ranked, with a percentage of

Table: 2. Estimates of Market for Agricultural Seed and Value Added by U.S. Seed Industry. 1979.

	Amount Used (000s)	Unit	Ave. Price per unit of Seed ($)	Total Market Value ($000s)	% Market Supplied by Seed Industry	($000s) Value of Stock Supplied by Seed Industry	Ave. Price of Seed as Commodity ($)	% Value Added by Seed Industry	Value Added by Seed Industry ($000s)	% of T Value A by Seed Industry All Spec
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10
Corn	21903	80000 K	43.50	996,587	95	946757	2.41	95	899419	47.0
Sorghum	2800	50 lbs	20.50	57,400	95	54530	2.08	90	49077	2.6
Soybeans	68007	Bu	12.00	816,084	60	489650	6.19	48	235032	12.3
Winter Wheat	60000	Bu	7.54	452,400	35	158340	3.84	49	77587	4.1
Spring Wheat	20000	Bu	8.16	163,200	35	57120	3.62	56	31987	1.7
Durum Wheat	6000	Bu	8.18	49,080	35	17178	4.26	48	8245	0.4
Peas	21784	lbs	1.24	27,012	85	22960	0.25	80	18368	1.0
Cotton	7300	50 lbs	16.50	120,450	50	60225	2.86	83	49987	2.6
Beans	20664	lbs	1.24	25623	85	21780	0.11	91	19820	1.0
Ryegrasses	9350	lbs	0.32	2992	95	2842	0.16	50	1421	0.1
Alfalfa	89280	lbs	2.13	190166	95	180658	1.14	46	83103	4.3
Bluegrasses	4500	lbs	0.20	900	95	855	0.16	20	171	0
Fescues	18150	lbs	0.20	3630	95	3449	0.16	20	690	0
Barley	13621	Bu	5.13	69876	50	34938	2.37	54	18867	1.0
Tobacco	13	lbs	224.00	2912	90	2621	1.41	99	2595	0.1
Oats	36638	Bu	3.58	131164	30	39349	1.36	62	24397	1.3
Rice	402000	lbs	0.25	100500	70	70350	0.10	60	42210	2.2
Corn (Sweet)	160	80000 K	45.50	7280	95	6916	40.00	12	830	0
Peanuts	147250	lbs	0.54	79315	70	55661	0.21	61	33953	1.8
Other Field Seed	53720	lbs	0.77	41364	95	39296		50	19648	1.0
Other Forage	368740	lbs	0.20	73748	75	55311		95	42483	2.2
Sugarbeets	4500	lbs	5.00	22500	100	22500		95	21375	1.1
Lawn Seed	445000	lbs	0.67	298150	100	298150		50	249075	7.8
Other Vegetables	171252	lbs	0.81	138714	85	117907		60	70744	3.7
Flower and Other Seed	700	lbs	21.00	14700	100	14700		98	14406	0.8
Total				3885948	71.4	2774043		69.0	1914489	100.0

Note: Corn seed is sold in bags with approximately 80,000 kernels per bag.

Source: Up-dated from Harvard Business School Case Study 4-375-109 of Pioneer Hibred, Inc., 1978. Data for 1979 were obtained from various sources including ASTA and USDA. The percent market supplied by the seed industry (Column 5) was assumed to be the same as for the "mid seventies" as reported in the original case study. Percent value added by the seed industry (Column 8) is calculated as $P_s - P_c / P_s$ where P_s = the price of seed as seed and P_c = price of seed as a commodity. Hence, it is not the typical economic concept of value added. It may be interpreted as the value added by genetic improvement, production and marketing.

Source: Butler and Marion, 1983.

value added of 4.1.

Looking back to the beginnings of the SI structure and organization, as well as the major laws that affect the industry, the production and distribution of seed for commercial purposes began in the mid 1800's. Before that time, there was no organized system of production and distribution, and farmers saved their own seed.[3] The establishment of the United States Department of Agriculture (USDA)in 1862 and the State Agricultural Experiment Stations (SAES) played an important role in the creation of the seed certification programs and in the development of the seed sector in the U.S. agriculture. Yet improved seed was of relatively minor commercial importance until the development of hybrid corn seed technology in the 1930's. The dramatic corn yield increase summarize the change between 1930 and the late 1970's, during that period the yield/acre increased more than 3 times in the U.S., in large part due to improved seed, and a lower real price of nitrogen fertilizer.[4] Farmers derive substantial economic benefit using the improved seed, despite the increases in seed costs. There are estimations that under proper managed cultivation systems, high yielding varieties can bring returns of crops in excess of forty times the weight of the seed.[5]

Four important issues in the structure and organization of the seed industry are the major laws affecting it, the private and public associations and institutions which form the industry, its vertical and horizontal organization, as well as its concentration. These four topics -for the U.S. SI- are analyzed in the remaining of this section.

A.2) MAJOR LAWS

The major laws affecting the SI are:

Plant Patent Act of 1930; the purpose of the law was:

> "to afford agriculture, so far as practicable, the same opportunity to participate in the benefits of the patent system as has been given industry"

by permitting the patenting of plants propagated by asexual reproduction (grafting, budding, cutting, layering and division).[13] Patent protection for plants reproduced from seeds was excluded, because:

> "sexual reproduction results in plants genetically different and therefore not capable of identificacion"[8]

Federal Seed Act of 1939, replace the Seed Importation Act of 1912 with regulatory measures for the industry in order to:

> "protect farmers interests in securing good seeds; protect honest seedsmen; provide farmers facts they need regarding seeds; help control noxious weeds; and, protect the government's interests in securing good seeds for its projects." [13]

Although difficult to measure, the quality of seeds reaching the end user have improved over time, some authors report that 25% of the commercial seeds in 1940 were falsely labeled. By 1960 the percentage dropped to 13.[6]

Plant Variety Protection Act (PVPA) of 1970, the registration of varieties is ruled by international criteria (set forth by the Union for the Protection of New Plant Varieties) of:

> "a) novelty - able to be distinguished from all existing varieties of the species. b) uniformity - does not exhibit significant variation between individuals of the variety. c) stability - reproduces truly between generations. Besides that; participacion in PVPA is voluntary; enforcement is the sole responsibility of the breeder through civil law; legal protection extends for 18 years; and farmers may reproduce protected seed for their own use provided they do not sell or advertise the seed on a commercial basis."[7]

Some effects of this important law for the U.S. SI are discussed under sections A.3 and A.5.

A.3) PRIVATE AND PUBLIC SECTOR INVOLVEMENT

Figure 1 shows the interrelationships between public and private Associations and Institutions.

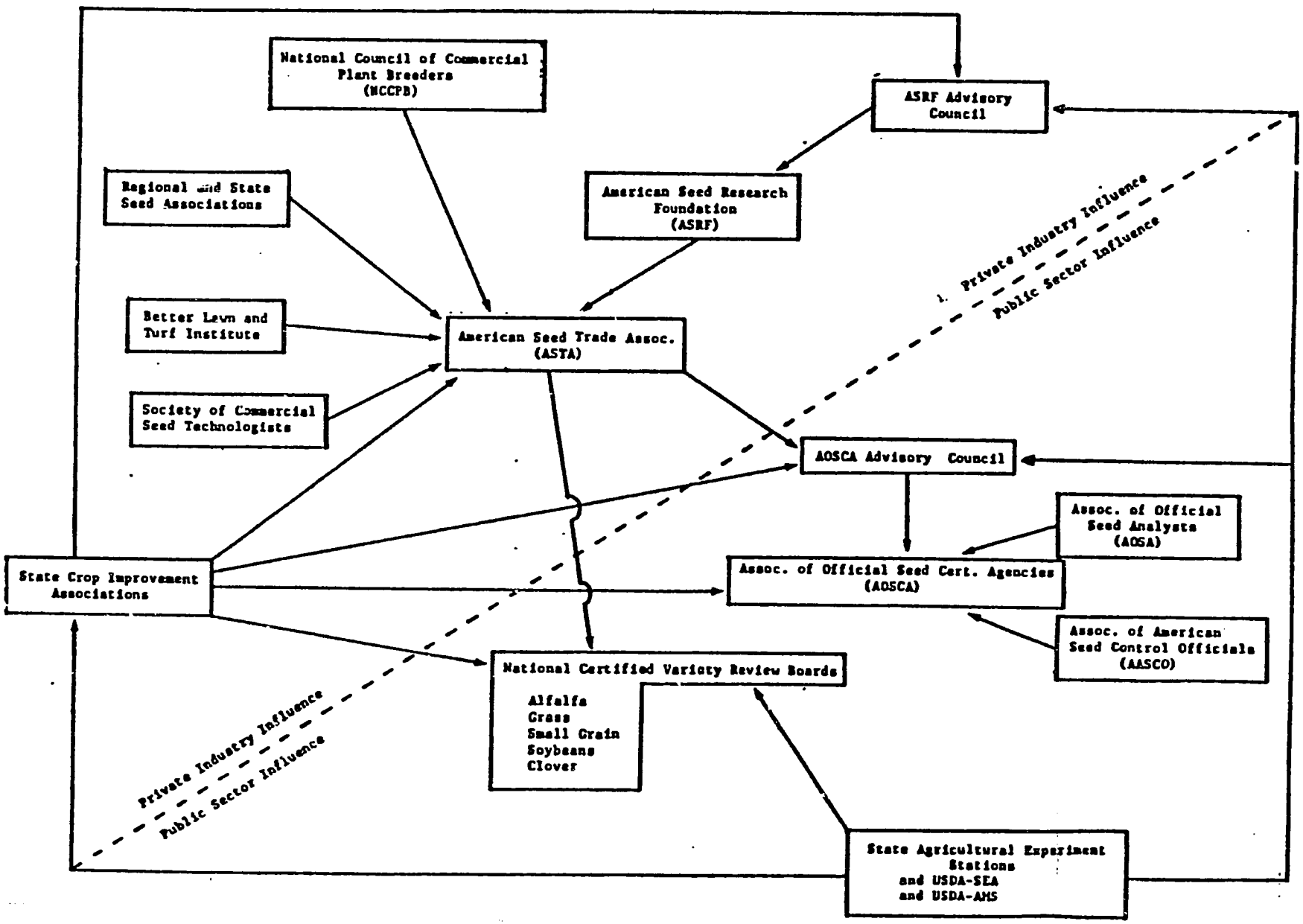
The economic as well as the political activities of the SI are dominated by the American Seed Trade Association (ASTA). The four major organizations are: A.S.T.A., State Crop Improvement Association (SCIA), SAES together with the Agricultural Research Service (ARS) of the U.S.D.A. and the Association of Official Seed Certification Agencies (AOSCA) The AOSCA coordinates the various seed programs of the Federal and State Departments of Agriculture. The SAES support a substantial crop variety research and development program. When a new public variety is going to be released to farmers, breeder seed is released to the SCIA for multiplication. The SCIA are nonprofit organizations whose owners are mostly farmers and small seed companies, and represent the official seed-certifying agency in most states of the U.S., providing the link between public plant breeders (SAES & USDA) and the private sector.

> "The seed-certification program secures the varietal purity and quality of seed developed by public and private breeders. The program main value to private breeders is that it assures the buyer of seed quality. For hybrid seed on which the private company attempts to develop its own brand name as a symbol of quality, the seed-certification process is not employed. ...the system (of seed certification) has been remarkably effective in the generation and distribution of new seed varieties in the U.S."[8]

The seed-certification program mentioned above has been important in maintaining a competitive structure in the SI, although has been highly dependent upon the level of public support for research at the SAES.

With respect to **public and private sector research** contributions, the conventional view is that there is a substantial complementarity between the two. Every government in the world is involved, in some way, in seed improvement and production, due to the importance of adequate supplies of high quality seeds to ensure food security. In some countries governments are involved in all

Figure: 1 . Structure of Organization of the Seed Industry. Private and Public Seed Organizations Composition



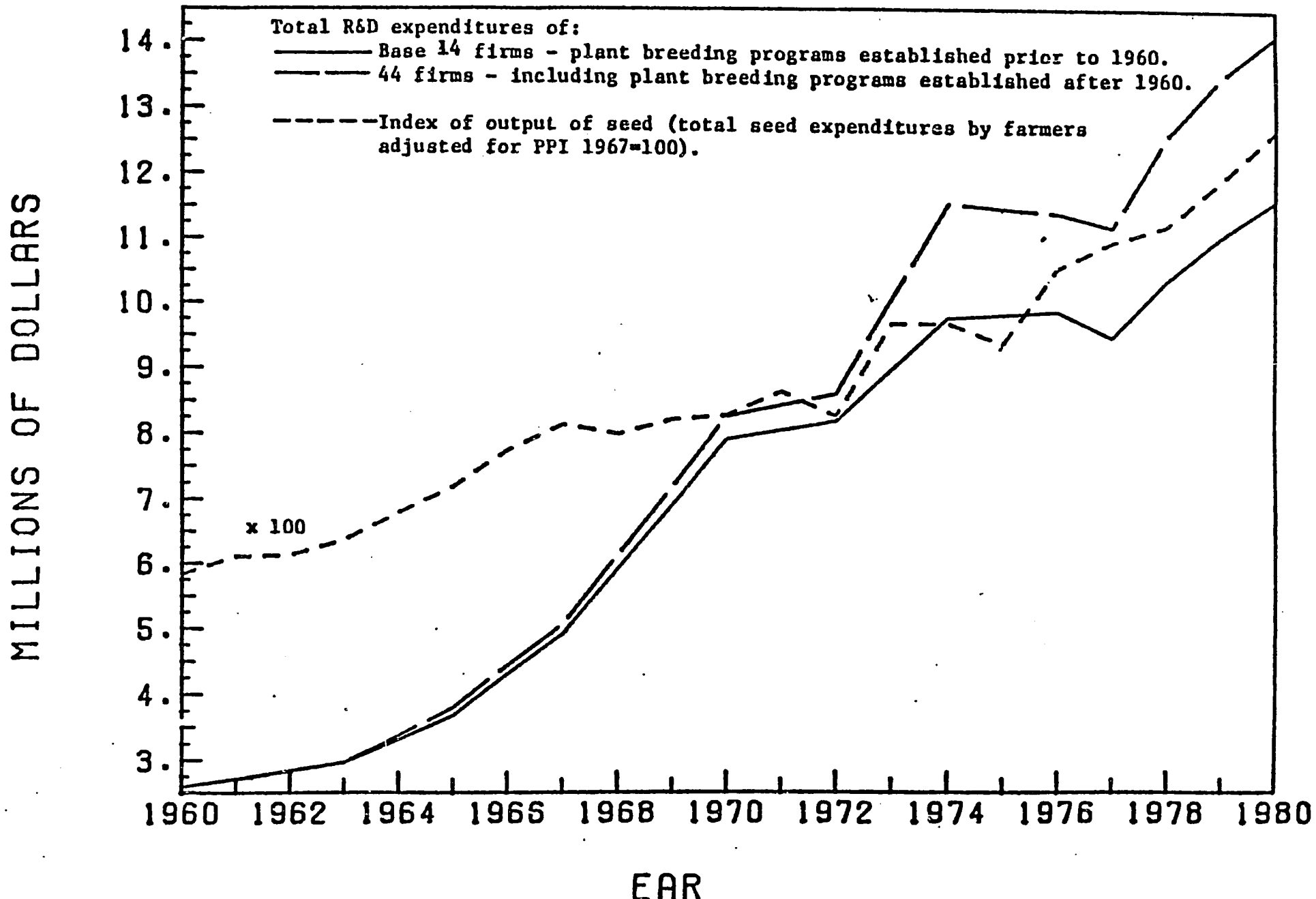
Source: Butler and Marion, 1983.

stages of production, in others the involvement is confined to activities in which the domestic private sector is not functioning.[9] At early levels of agricultural development the public research programs are typically the only significant forms of research. In the U.S. before 1920, commercial plant breeding was largely confined to the home garden market, while agricultural seeds were the responsibility of Federal and State breeding programs. In the past there was more differentiation of firms by activity; many small firms without research programs put emphasis on producing and distributing seeds developed by public research, or by foundation seed companies which were essentially research firms. In that way many small companies utilizing others research efforts distributed seeds of some crops in a specific area. Thus, seed firms have traditionally been small, specialized, independent and family owned. The history of the U.S. SI shows that in a competitive industry with no institutional arrangements to provide property rights to the inventor there was little incentive for individual firms to invest in research. There were many small seed firms throughout the country and little research was done by the private sector.[10]

It was only after the introduction of hybrid corn that the private SI began to grow and meet agricultural needs and, even at the present time, private varieties dominate a minority of crops in the U.S. [11]

In the U.S. the Research and Development (R&D) expenditures done by the private sector in agricultural inputs, food marketing and distribution have grown more rapidly than public sector expenditures since 1965, at that time plant breeding private expenditures were 55% of the total public and private expenditures. By 1979 that proportion increased to 65%.[8] Private sector plant breeding expenditures were approximately $100 million average (on a wide range from $55 M to $155 M) during 1978-79, according with Ruttan's estimations. Other higher

Figure 2: Private Firm R and D Expenditures (Deflated)** and Output Index for Seeds, 1960-1980.



** Deflated by CPI, 1967=100

Source: Butler and Marion, 1983.

estimations on the level of research expenditures indicate that in 1980 private sector research on seeds was about $150 million, and public sector expenditures around $250 M.[12]

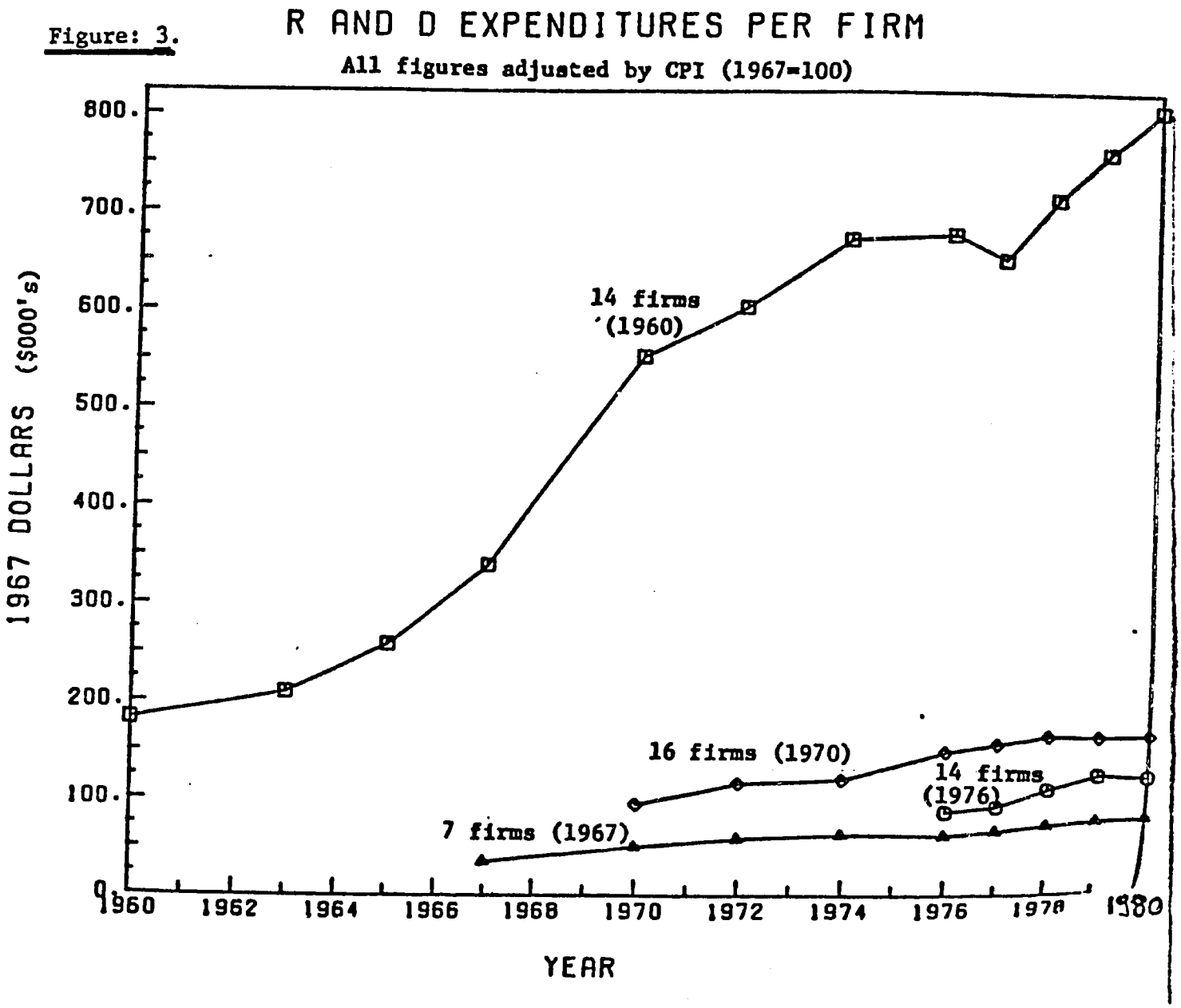
Research in the SI is closely related to sales.

Figure 2 (on page 14) shows the sharp increase of R&D expenditures by private seed firms during the period 1960-1980, as well as the increase in total seed expenditures by farmers. The U.S. SI has grown rapidly in that period. A study done in 1983 -[13]- has shown that firms with plant breeding programs prior to 1960 invested more in research than firms with programs established after 1960, and that many new firms started plant breeding programs, as can be seen in **Figure 3** (and Table 3.2, in Appendix 3). The fourteen firms with breeding programs prior to 1960 experienced sharp increases in real R&D expenditures in the periods 1967-1970 and 1977-1980. The first increase (largely concentrated on research facilities and non-personnel costs) was, perhaps, an anticipation of the PVPA, and the second one was probably a reaction to the commodities boom of the early 1970's.

During 1970-75 there was a significant increase in the number of plant breeders per firm. Since 1975, plant breeding R&D activities have had modest increases. Based on this analysis, the conclusion is that the PVPA has influenced the R&D activity in the private sector, especially in the development of new varieties of soybeans and in a lesser degree of wheat. Little change of R&D investments since 1970 is reported for other open pollinated crops.[13]

With respect to **public sector expenditures**, a modest decrease in new variety releases from SAES has occured in the last ten years. SAES represent the major source of new crop varieties (except of corn, sorghum, sugarbeets, cotton, alfalfa and tobacco where the breeding is dominated by private companies). Public funds allocated for plant breeding and genetics research since 1970 have

Figure: 3.



Source: Butler and Marion, 1983.

been approximately a constant percentage of total government research funds available. Plant breeding and genetic research expenditures at public institutions increased from $27.8 millions in 1970 to $36.8 M in 1979 (in constant dollars,CPI,1967=100). USDA funds as a percentage of the total decreased in the same period from 40% to 33%, but this decrease has been offset by increases in State funds.[14]

As it was mentioned above, in developed countries, the private sector -usually based on public sector basic research- produces a wide range of improved varieties for particular farming conditions. But in most developing countries, by far the greatest part of seed research is done by public sector institutions. In the LDC's of Africa, Asia and Latin America, government programs are the most important factor in the provision of improved seed to local farmers. This provision is in general enough for a small portion of their nations's seed needs. Most seed planted in LDC's is retained by local farmers from their own crops. Another characteristic of the LDC's seed programs is that public and private improved seed operations are generally focused on seed for export crop production. The small farmers using traditional agricultural practices seldom use improved seed. As the North America and Western Europe markets have matured, the large seed companies have been expanding rapidly internationally. Competition is intense in Western Europe where U.S. firms have gained substantial shares of the market. At the same time European companies are trying to penetrate the U.S. market. This competition is growing in LDC's too. European firms have been dominant in Northern Africa and Eastern Europe. U.S. seed companies are leaders in Latin America, sub-Saharan Africa, and Asia.

A.4) VERTICAL AND HORIZONTAL ORGANIZATION

Figure 4, shows the vertical organization of the U.S. SI. The main functions of the large number of firms and organizations that form the industry are breeding, growing and production, conditioning and wholesaling-retailing.[13]

> "There are usually at least 2 multiplication steps between plant breeding and seed conditioning. The number of companies involved increases rather sharply as one moves from plant breeding to wholesaling and retailing".

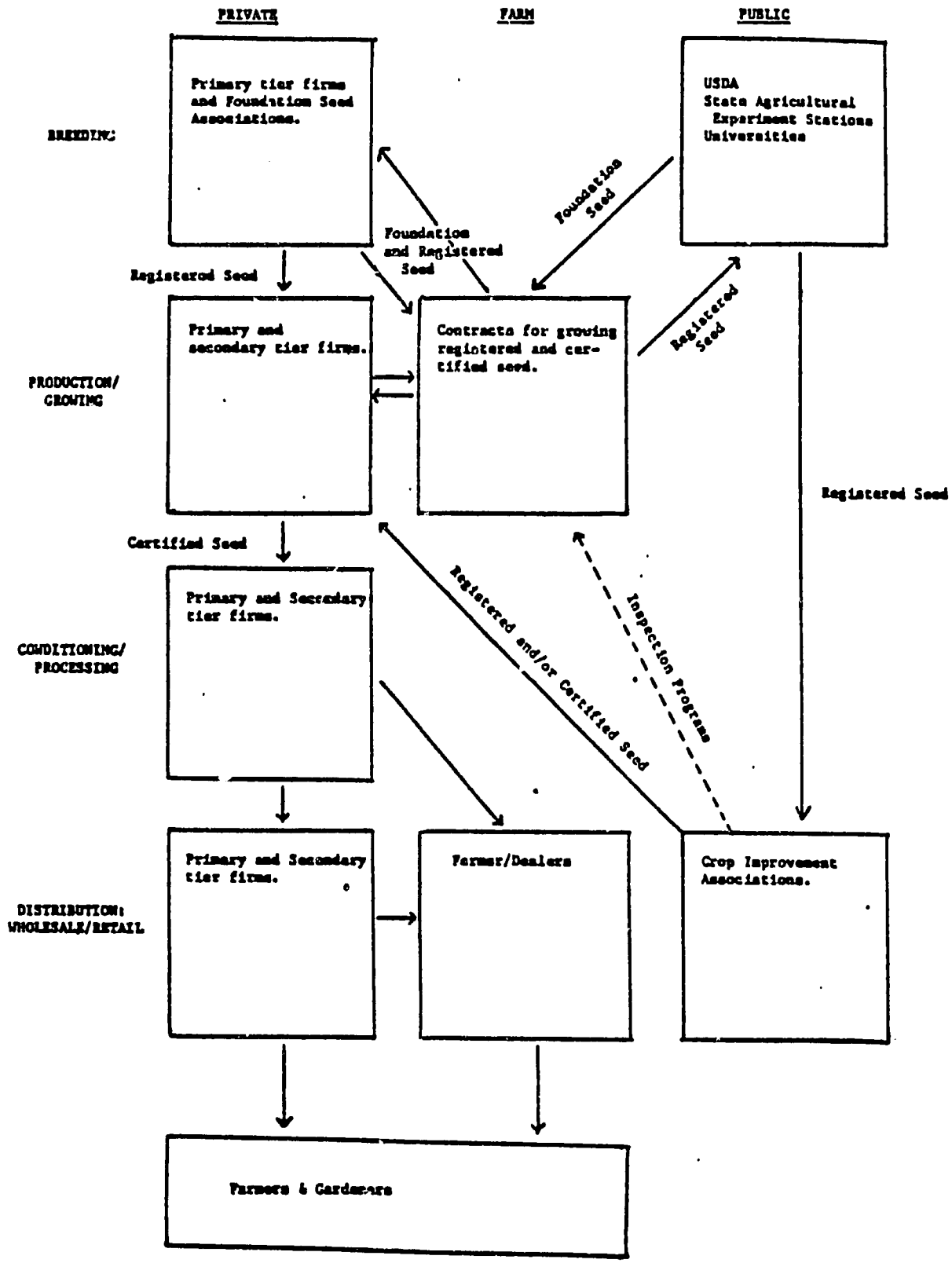
Once a variety is developed as a result of breeding, foundation seed is grown-out to provide registered seed, which in turn is grown-out to provide certified seed, which is sold to farmers.

Following Butler and Marion classification of firms based on the different functions performed, there are secondary tier firms which produce certified seed, and do the conditioning and distribution. Primary tier firms besides these functions are also involved in breeding and releasing new varieties:

> "These firms sell both private and public seed varieties. Private protected proprietary varieties are usually sold by the developing firm and its licensees. Primary tier firms may also be licencees, particularly of protected varieties developed by agricultural experiment stations, and may sell any unprotected public or private variety without licensing." [13]

Besides these two groups, there are farmers who multiply registered and certified seeds, and act as company dealers, especially for hybrid corn seed. Commercial seed production takes place in four stages: research, multiplication, processing and distribution. The leading seed companies have developed the ability to meet the peculiar technology, manpower and finance demands of seed production. This peculiarity derives from the fact that seed markets are highly diverse (no single variety accounts for as much as one percent of global seed sales) and that they change rapidly due to shifts in local farming conditions.

Figure: 4. Vertical Organization of the Seed Industry.



Source: Butler and Marion, 1983.

An example of the horizontal and vertical integration in the private sector is Cargill Corporation, who produces and sells seeds and does grain trade. Another example of the integration research-production-marketing within and between industries is Dekalb Ag.Research,Inc. producing and marketing hybrid seed, poultry and swine. [15]

A.5) CONCENTRATION AND STRUCTURAL CHANGE

Undoubtedly, the character of the seed industry is changing. The success of the PVPA in creating the incentive for private breeders to conduct their own research on self-fertilizing plants is reflected not only in the increase in research efforts but by the large number of seed company acquisitions by pharmaceutical, petrochemical and food firms, that took place in the last decade.[16] The merging and acquisitions activities have ranged from simple mergers of small seed companies trying to get some economies of scale, to the takeover of several of the largest companies in the seed industry by large corporations and transnational firms. In the U.S., over a hundred firms have been merged or acquired since the early 1970's, as table 3 shows. Other sources estimate that almost 150 seed firms have merged in the U.S and more than 250 in Europe.[17]

Table 3: U.S. Number of Seed Company Acquisitions,1971-1981

Reason	Seed Company Acquired	New Owners
Genetic-engineering company	10	1
Integrate with non-agricult. or food activities	41	13
Integrate with agricultural or food activity	18	8
Penetrate North-American market	8	6
Expand seed operations	17	6
To acquire non-seed assets	1	1
Unknown	6	4
Total	**101**	**39**

Source: Goodman et al. 1982.

The large multinationals corporations capable of mounting substantial research and development efforts, are playing an important role in developing new varieties. The large number of acquisitions of seed companies has increased the concern about market concentration. Some observers have worried that increased concentration will lead to less research, but there is no evidence that the purchase of seed companies by chemical, pharmaceutical and food companies has led to a decline in research. Total research investment by the private sector has clearly increased. The industry still is not very concentrated by some measures, there are hundreds of seed companies and the four and eight firm concentration ratios are not particularly high. In the most important market -hybrid corn- Pioneer has increased its share of the market from 24% in 1973 to approx. 37% in 1983. But the share of the largest eight firms has fallen from 72.5% to 64%, while the share of the largest four seed corn firms has fallen slightly from 60% to 55% in the same period.[18]

Some seed companies expanded their plant breeding program after they were purchased. Several of the scientists in companies which were purchased have mentioned that their research budget had been increased.[10]. Most firms have not reported any major shift in research priorities when they were purchased.

Table 4 shows percentage of area planted to different variety sources.[19]

Table 4: Percent Acreage Planted to Different Class of Variety, -1980-

	Private		Public		Unknown
	Prot.	Non-Prot.	Prot.	Non-Prot.	or na
Corn	76.7	--	--	--	23.3
Soybeans	6.6	1.0	23.3	46.9	22.2
Cotton	37.0	31.0	9.0	10.0	13.0
Rice	0.4	--	--	94.3	5.3
Wheat	1.1	3.4	10.1	48.8	36.6
Barley	3.0	5.1	--	75.8	16.1

[Prot.= protected, na= not available]

Source: Butler & Marion, 1983

Most of the crops are dominated by public varieties and there are more non-protected varieties than protected ones. Almost 80% of the corn and 40% of the cotton varieties are privately protected. Fifty percent of the soybeans, almost 95% of the rice, 75% of the barley, and 50% of the wheat varieties are under the category public non-protected.

With respect to the future structure of the industry and according with some seed industry analysts:

> "the new techniques to manipulate the genetics of crops would soon make the small, family owned or privately held seed companies a thing of the past; but those firms using biotechnology to develop improved varieties would also need the seed companies to deliver their innovations to the farmer".[20]

Following similar forecasts, another wave of acquisitions will occur as the major food companies try to incorporate genetic improvements into the crops that they use in their products. Another possible group of buyers will be the small biotechnology firms trying to have a good hold on seed companies and its clientele. There are reports, however, that some of the chemical and pharmaceutical companies are trying to sell their seed divisions.[21] Although many small seed firms have been purchased by larger seed companies, and

others have been purchased by chemical and pharmaceutical firms, there is little evidence that any firm or group of firms has enough power to set noncompetitive prices. The very low concentration ratios in the world seed market compared with other industries could be interpreted as: a) the seed industry does not have economies of scale; b) the concentration process is not over yet; or c) we are not measuring correctly the concentration process. For example in the U.S. Corn market, although the largest 8 and 4 firms share is not increasing, within those largest firms some are loosing markets and others are increasing its share. At the same time many small and medium size seed firms are being acquired by bigger firms without being captured in the largest 8 and 4 concentration figures. The main force leading to concentration, specially in the corn seed sector, appears to be more a matter of performance due to competition, rather than a matter of monopoly power.

At the same time that important structural changes are taking places among the private sector, changes are ocurring among both the national research organizations and the international research centers (IARCs). There is concern with respect to the funds for public sector plant research, particularly in the U.S., that they are not keeping up with the needs for basic research or for the maintenance of a diverse germplasm base from which public and private breeders can draw resources. The IARCs aso seem to face a critical period, due to the pressure on donors budgets and the dissatisfaction of some LDCs with the IARCs program, and their desire for more control of plant varieties and genetic research.[22] The private companies, the public sector research and the international institutes are in a period of greater transition than they faced in the 1960s and 1970s. Because of the strategic role of the seed industry in the world food system, a solution to some of the current problems would be desirable in order to protect the productivity of the industry.

FOOTNOTES SECTION A

1 According with USDA Statistics,1984 estimations.

2 Seed prices, however, have increased less than other agricultural inputs from 1970 to 1983, if we look at the index numbers of prices paid by farmers during that period, see table 3.1 in Appendix 3.

3 Crops have been planted almost exclusively from previous harvests saved seeds through most of human history. The small seed companies established in England and a few other countries in the 1700's and 1800's started the modern improved seed industry.

4 As the other crops improved too, there was an expansion of farmer demand for improved seeds and in the formation and growth of businesses capable of producing such seeds in large quantities. Corn, the original commercialized hybrid, is the most important product for the improved seed industry, representing almost 30% of the total market value of seeds sold in the U.S.. See Section B.2 for a more complete description of the origin and value of hybrid corn and its importance in the development of the seed industry; see also Sundquist,1982, for a complete assessment of the different technologies explaining the increase in corn productivity.

5 See Goodman et al.,1982. The improvement of seeds through hybrids also brings substantial benefits to seed companies since farmers must make new annual purchases due to the lack of vigor after one generation. This potential for a captive market has encouraged private companies to hybridize other crops, like sunflower, sorghum, and more recently wheat.

6 See USDA,1961."The Yearbook of Agriculture.Seeds",pg.482.

7 For a complete discussion of the effects of the PVPA see Butler and Marion,1983."The Impacts of Patent Protection on the U.S. SI and Public Plant Breeding."

8 See Ruttan V.W.,1982.Agricultural Research Policy, Ch.8, for a complete discussion of private and public roles in research.

9 In DC's, governments traditionally play an important role in seed research, and the private sector in the other stages of production. Public research focuses on plant genetics and developing improved varieties of self pollinating species. The national centers -like Fort Collins,Colorado,in USA- maintain plant populations and germplasm banks. The public involvement is different in countries where the state is the predominant economic actor, including developing nations and centrally planned economies. In these countries, government agencies are involved in nearly all stages of seed production, crop improvement and basic seed research is in general in a preliminary phase.

10 Pray,C. "Private Sector Innovation and Technology Transfer in the Agricultural Sector of Developing Countries", Draft 1985. University of Minnesota.

11 In the mid 1970's, over 80% of the corn and sorghum varieties and approximately 70% of the sugarbeet and cotton varieties used in commercial production were private. Over 80% of the ryes, wheats, oats, soybeans,rices, barleys, peanuts, dry edible beans, and forage grasses were public.

12 Proceedings of the 28th Annual Farm Seed Conference. American Seed Trade Association, 1982. In another study Kalton R.& Richardson P.(Land O'Lakes Research Farm) have estimated the annual research expenditures on private plant breeding in the U.S. for 1982 as approx. $115 million. Twenty three companies with expenditures of $1 million or more represented 70% of that amount.

13 Butler and Marion,1983.

14 See table 3.3 in Appendix 3 with details on public expenditures.

15 See Appendix 1-major US seed companies-for a description of the magnitude of operation of these companies.

16 See Appendix 2 for a complete list of companies and acquisitions.

17 Mooney,P.R. "The Law of the Seed",Pg.152.

18 See section B with more information on U.S. corn market shares.

19 See table 3.4(wheat shares), table 3.5(soybean shares), and table 3.11(corn shares) in Appendix 3, for a more complete analysis of market shares between public and private institutions and within the private firms.

20 Teweles,1976. Some Plain Talk About Seed Company Mergers and Acquisitions.

21 According with Butler & Marion(1983) conglomerates have probably had a negative influence on the seed industry by acquiring independent companies, reducing the number of competitors and the genetic diversity in some cases, and in other reducing the viability of the seed firms acquired because of little understanding of the seed business. The larger bureaucracy of the transnationals could also substract operativity to the seed firms.
There are, nevertheless, some advantages of being part of a conglomerate because their large financial resources and the fact that they operate in several industries in different countries. Large firms can engage in competitive practices not usually available to the specialized seed company. Resources are available to make greater investments in R&D or advertising, or in some cases to subsidize the seed operations from earnings in other industries.

22 Currently the dissatisfaction is centered on the International Board for Plant Genetic Resources, which according with LDC's, does not represent their interests adequately.

B) TRANSFER OF TECHNOLOGY, THE CASE OF CORN

B.1) INTRODUCTION

Three important policy questions in the transfer of technology are: a) the amount of technology to be transferred, b) the cost of that transfer and c) if the technology will be appropriate. The answers to these questions depend on the interaction between the transferer and the transferee. If the owner of the technology is a private firm, it would try to maximize its expected profits. These could be royalties from the sale of the right to use the technology, profits from exporting products which incorporate the technology, or from subsidiaries which produce specific products incorporating the technology. The firm is faced with decisions about which countries should receive the technology, through which institutional form the transfer should take place, and how much to charge for the technology.[1] Technology transfer is caused by a firm's desire to spread technology production costs over the largest possible market. The firm's decision to introduce an innovation in any particular market is determined by: a) the cost of the transfer (which is usually less than the cost of the original innovation but can be significant); b) expected profits in the country to which technology is transferred, and c) other benefits that the transferrer of technology derives (like obtaining germplasm from different regions that can be used elsewhere). Expected profits are a function of the same factors as the determinants of profits from innovative behavior plus factors determining the ability of the company to bring these profits out of the country. The transferee will try to maximize profits if it is a private firm, or net social benefits if it is a country. In deciding how to improve productivity, a country or firm has three primary options: **direct transfer**, screening and adoption of other countries techniques; **adaptive research**, screen technology

from abroad and modify or redesign the borrowed techniques to suit its own resource endowments; and comprehensive research to produce its own techniques. The three main obstacles of direct transfer of technology are: 1)the cost of acquiring information, screeening technology and training manpower. 2)Environmental adaptation of the technology and 3) absence of research capacity at the applied level. The cost and benefits of overcoming these obstacles have to be balanced against the net benefits of doing adaptive or comprehensive research.

Following Hayami and Ruttan's distinction of three phases of international technology transfer - material, design and capacity - seeds are a clear example of the first phase, where a simple transfer or export of the new material occurs without too much local adaptation. In the second phase specific plant materials are imported and subject to tests in order to start multiplication locally.[2] Scientific capacity is transferred in the third phase. Plant varieties are bred in the place in order to adapt them to local conditions.[3]

In summary, the seed industry transfers technology through commercial varieties, germplasm and information. Companies export varieties from the U.S. and other countries, if the varieties or hybrids fit into the agriculture of the country and there are no official barriers to entry. They transfer elite lines and scientific information to countries where they have breeding programs, joint ventures with other firms that have breeding programs, or licensing agreements with firms that breed crops. The new information may consist of new breeding techniques or new basic knowledge about the crop.

The seed companies interviewed confirmed the importance of economic factors in their decision to transfer technology. They are willing to sell their seeds wherever demand exists. When a company decides to make a major marketing

effort, go into a joint venture, start producing seed in a country or doing research there, some factors are thoroughly analized, mainly potential market size and infrastructure of the local seed industry, local regulations and business climate in the country.[4]

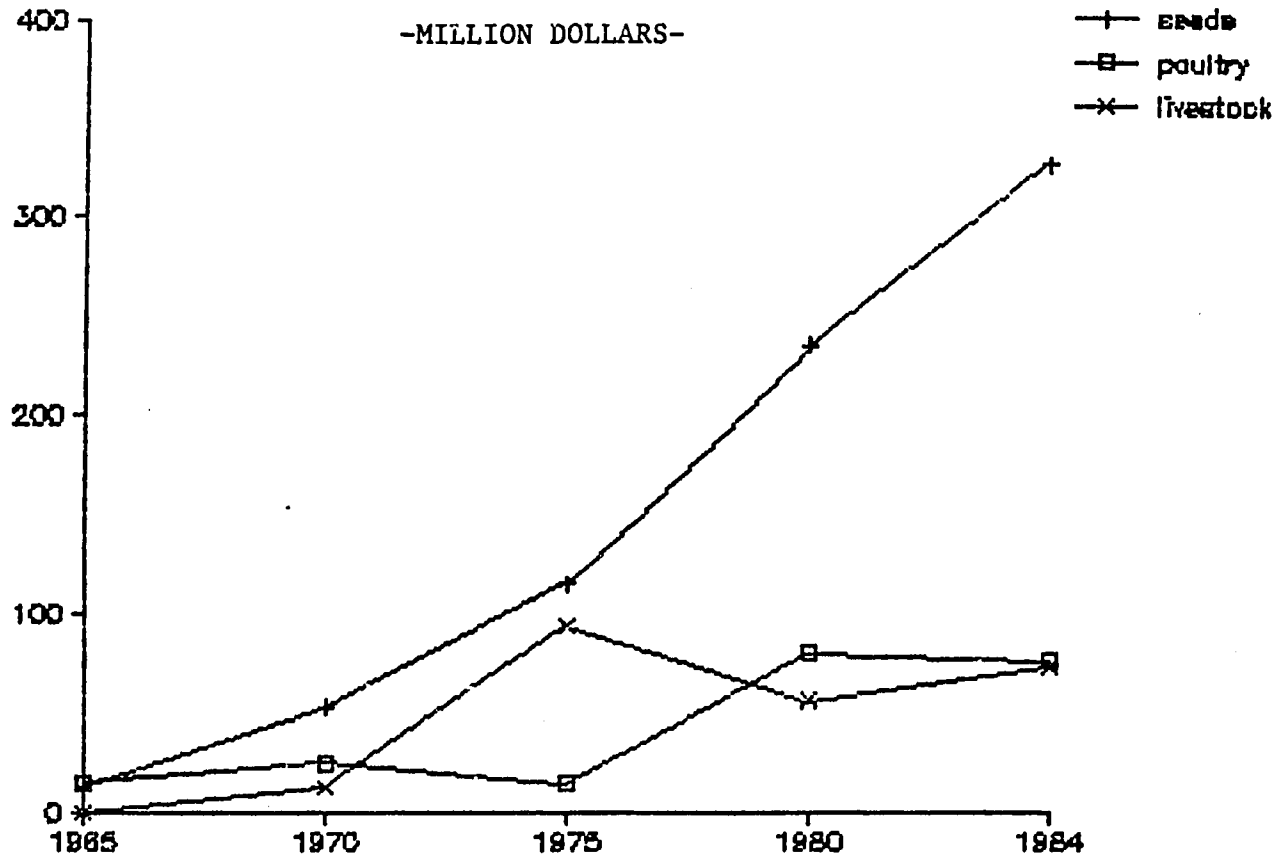
A seed company also considers the cost of setting up business, how much research would be required to develop a hybrid or variety that fits the major markets of the country.

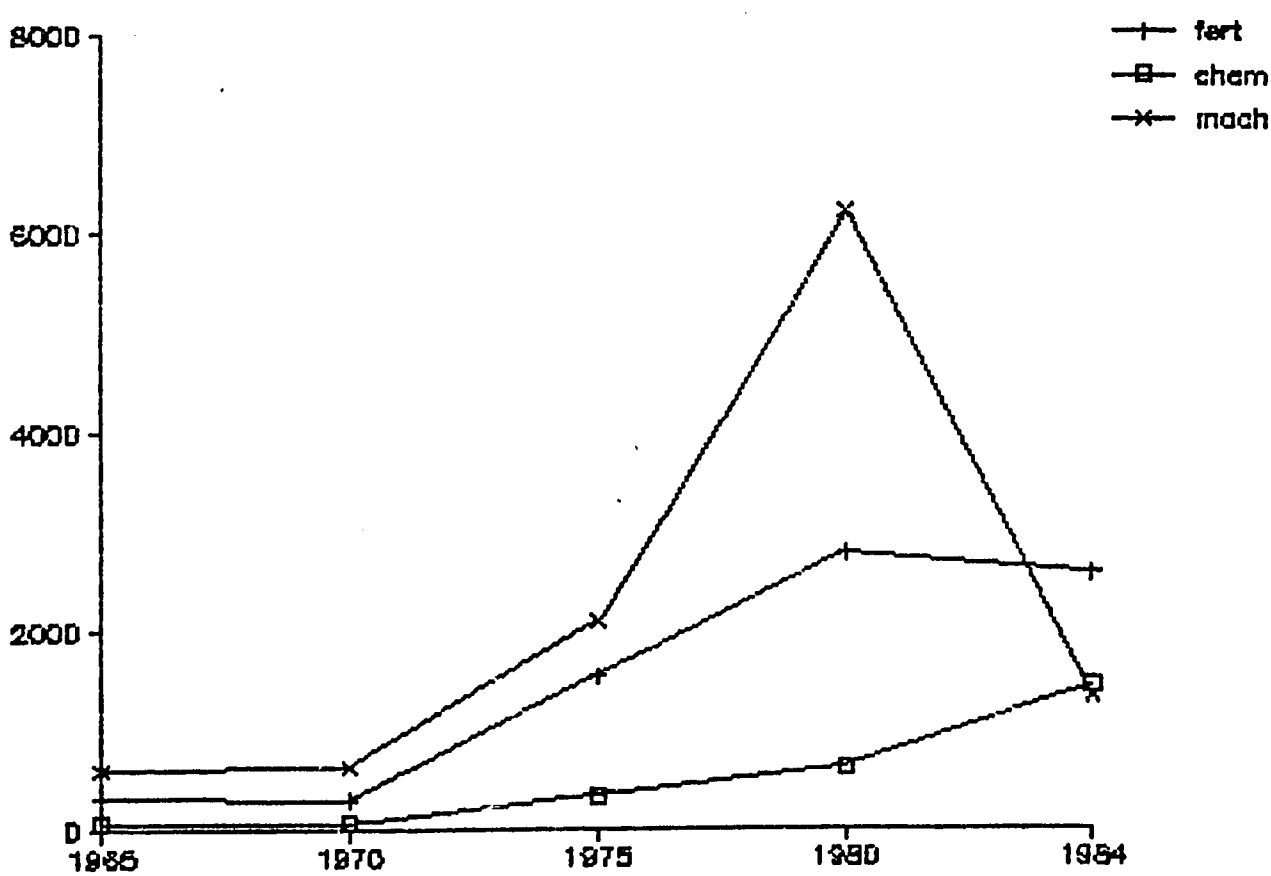
The recent changes in the international seed industry structure with respect to its internationalization and research based competition has coincided with the growth of national seed programs together with the regulation of foreign participation in LDC's seed industries. There are marked differences in seed regulations in different countries. Governments regulate the industry basically in order to guarantee seed quality, to set prices and to promote investments in research. The basic concerns -according with Government officials- in most of the seed regulations are:

> 1)Quality control, to protect buyers against inferior seeds. 2)Trade control, for quality reasons, imports restrictions for protection of the national industry, or exports restrictions to maintain local supply. 3)Price controls, in order to create incentives in agriculture. 4)Quarantine, to prevent diseases. 5)Patenting, to grant breeders exclusive rights to market varieties they develop.[5]

In the U.S., seed regulation is extensive but less centralized than that of other countries, and relies on a combination of voluntary and mandatory controls rather than on a fully mandatory system.[6] European seed industries are much more tightly regulted than those of North America. Usually, official lists of seeds are prepared and seed cannot be sold by varietal name unless is published in the list and has gone through official certification procedures. In LDC's most seed industry control consists of truth-in labeling laws which require that labels appropriately represent seed quality. The evolution of this legislation

FIGURE 5. Total Value of U.S. Exports of Agricultural Inputs, 1965-1984





Source: USDA/USD of Commerce

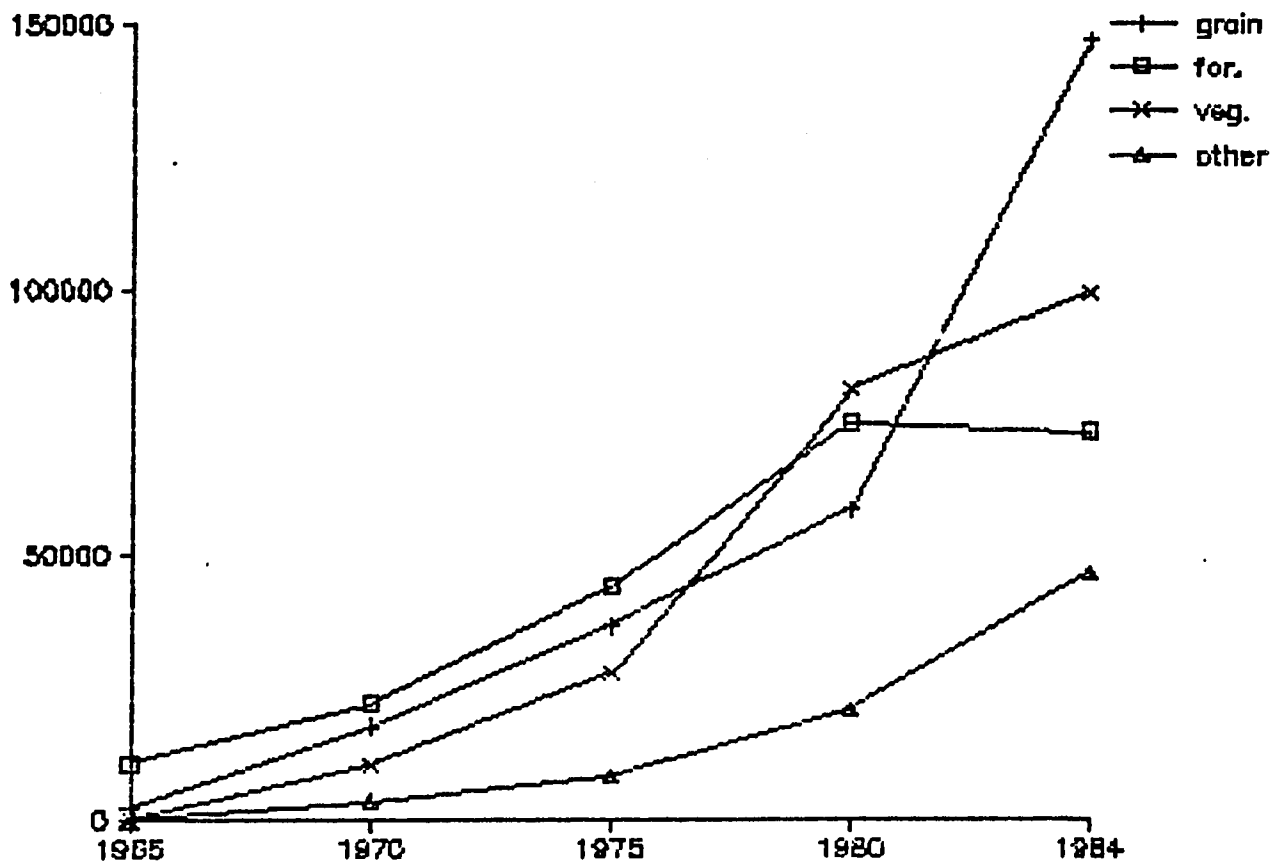
usually leads to the centralized mandatory European regulation type, rather than to the decentralized, mixed mandatory-voluntary pattern of the U.S..

There exists, also, transnational seed companies pressure on LDC's to institute legislation guaranteeing seed breeders patent rights. Many countries like Brazil and Mexico have not yet passed such laws arguing that it would facilitate the dominance of national strategic industries by transnational seed companies.[7]

With respect to the importance of seeds in the total U.S. direct transfer of technology by sales of different agricultural inputs, figure 5 shows the total value of seeds, poultry (eggs & chicks for breeding), livestock (for breeding), fertilizer, chemicals and machinery sales since 1965.[8] The first graph illustrates how the value of seed exports have increased compared with poultry and livestock. Total sales of seeds went from $13 million to $326 M in the twenty year period. Poultry and livestock inputs have a different trend, with poultry increasing in the 1975-80 period and then being stable at a level of about $80 M; livestock sales had an earlier increment stabilizing later on at levels above $70 M. The bottom graph of figure 5 shows fertilizer, chemical and machinery sales. Fertilizer sales have been increasing up to values more than $2.5 billion in 1980, and declining more recently, while chemicals sales have gradually increased from $83 M in 1965 to $1444 M in 1984. Agricultural Machinery sales show a sharp decline from $6207 M in 1980 to $1330 M in 1984. According with these values, U.S. seed sales accounted, on average, 5% or less of total sales of important agricultural inputs during the period. The retail market value of all seeds planted around the world in 1980 was approximately $42 billion. Sales of commercial improved seeds account for 25 to 30% of that total. The U.S. is the largest market for commercial seed with sales of about $4 billion in the early 1980's. As it was mentioned before no more than a dozen large transnational corporations based in the U.S. and Western Europe

FIGURE 6: VALUE OF U.S. SEED EXPORTS, BY TYPE OF SEED, 1965-1984.

-IN THOUSAND DOLLARS-



SOURCE: U.S.D.A.

dominate the international seed trade. The U.S. is the world's largest exporter of seed.

Figure 6 shows that in 1984 the U.S. exported roughly 363 thousand metric tons of seed of all types valued at $365 million. Grain seed is the main export, followed by vegetables and forages. The total value of exports shows an increasing trend during the last two decades, with the main increase being in grain seed, which jumped from less than $60 M in 1980 to almost $147 M in 1984. Forage seed sales have been higher than the rest, up to 1980, where vegetable seed sales became important. In 1984 grain seed represented 40% of sales, vegetables 27% and forage seeds were 20% of the total value of U.S. seed sales.[9]

Figure 7 shows how these exports are distributed around the world. In 1984 the U.S. exports of seeds of all types to Latin America were valued at about $95 million, while Europe and Asia each imported seeds from the U.S. at a value of roughly $90 M. [10] During the last two decades Europe and Latin America were the main seed buyers. Sales to Asia have had the fastest growth, specially in the last decade, where sales jumped from $14 M in 1975 to $89 M in 1984.

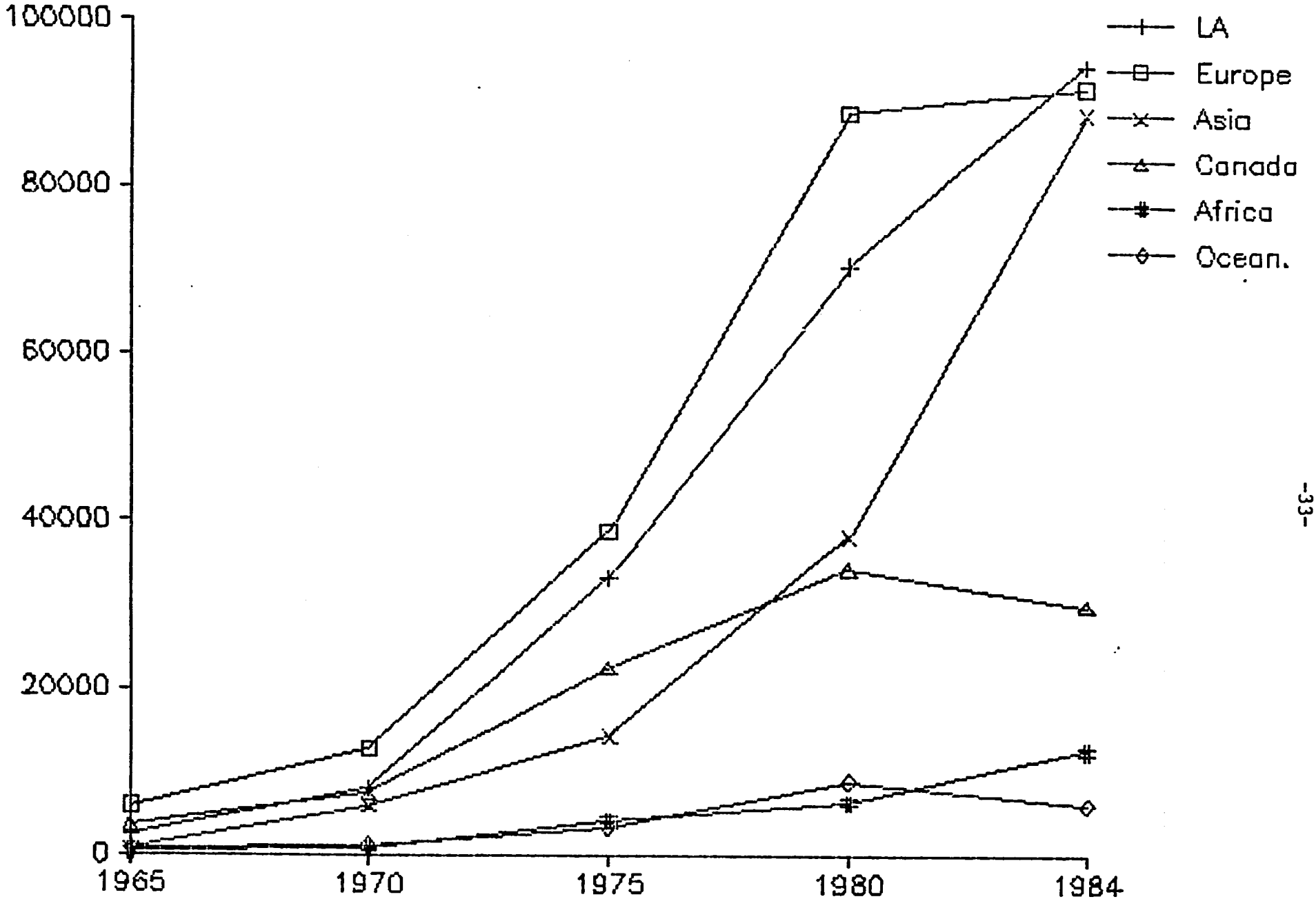
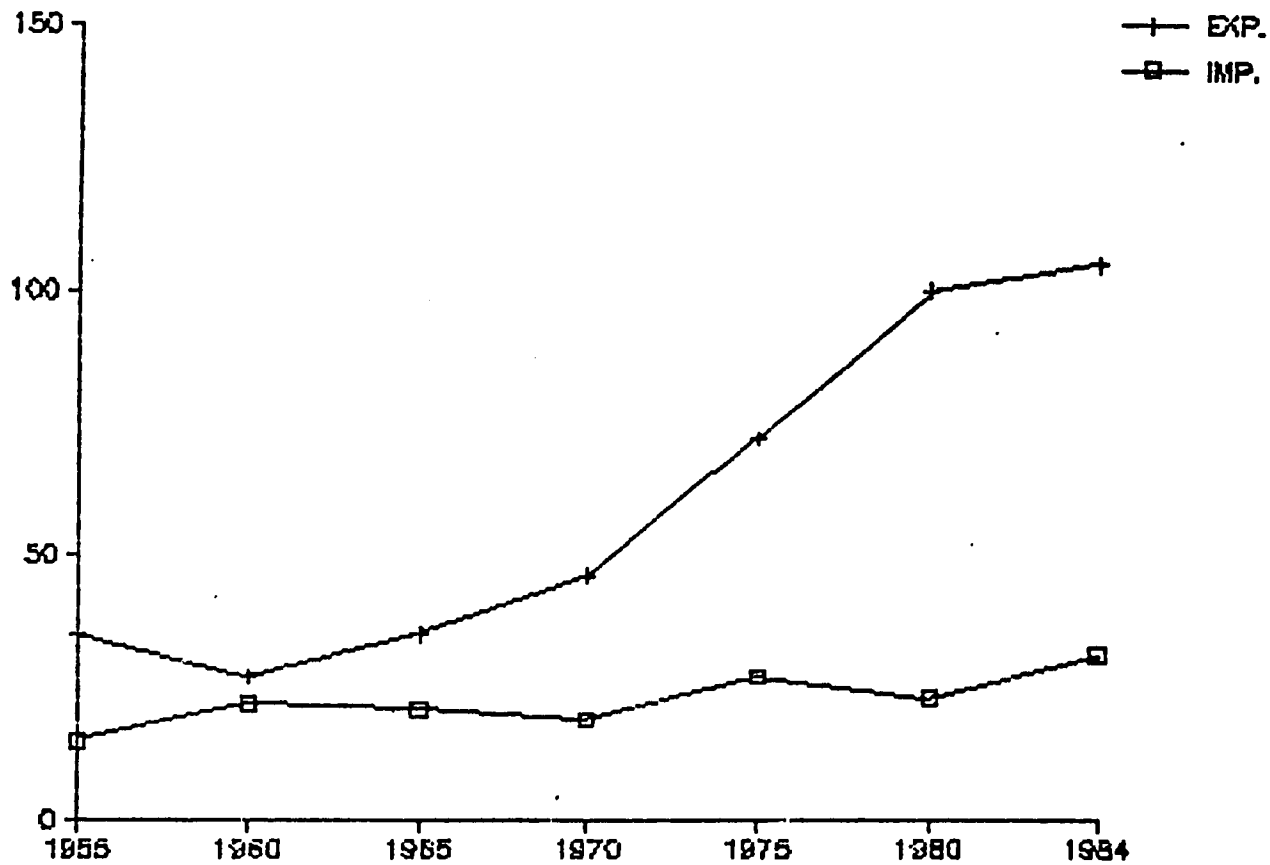


FIGURE 7. Value of U.S. Seed Exports, by Continent. 1965-1984. (Thousand Dollars) Source: USDA.

FIGURE 8: TOTAL DFLATED VALUE OF U.S. SEED TRADE, 1955-1984.

-MILLION DOLLARS-



SOURCE: U.S.D.A.

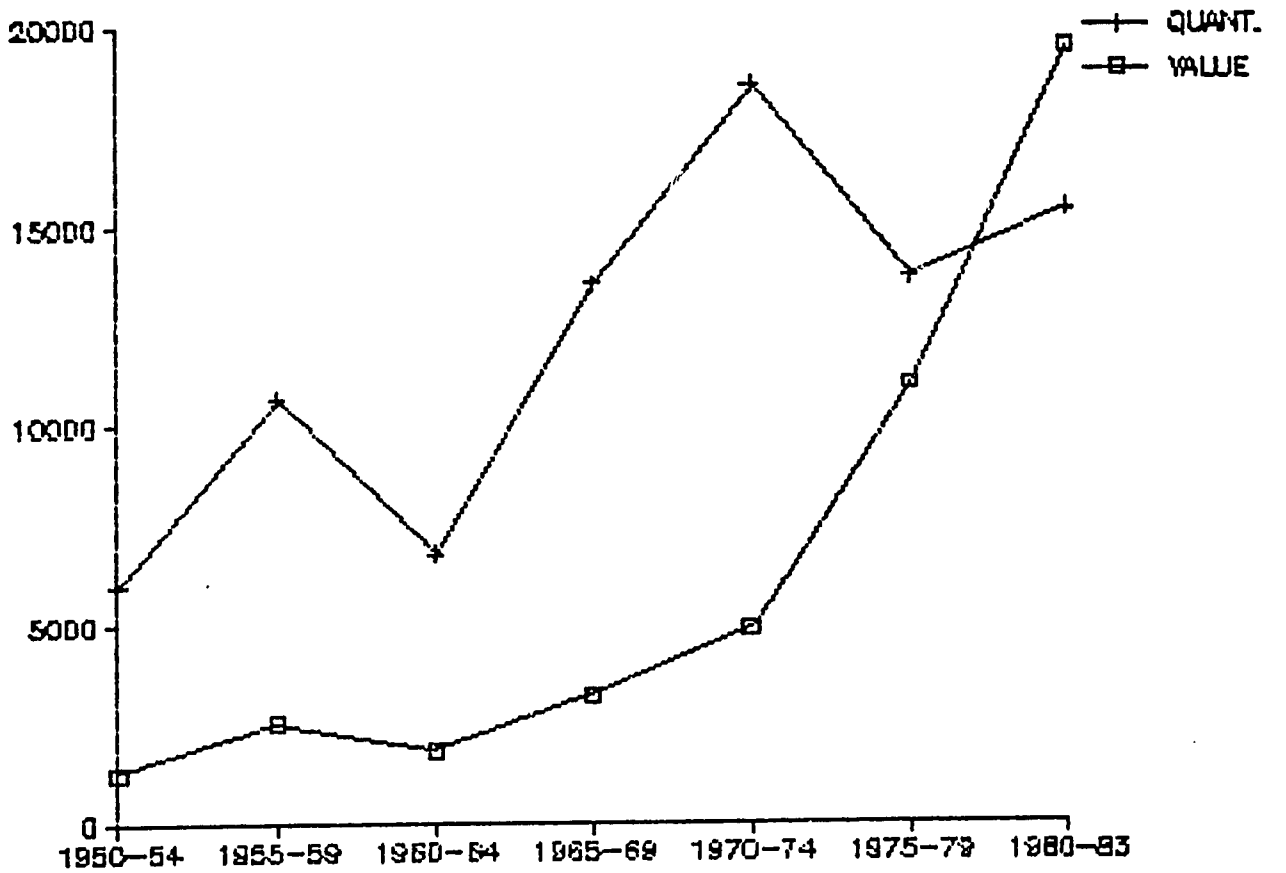
Figure 8 shows the deflated total value of U.S. seed trade since 1955.[11] The export deflated values increased more than 35% in the period 1970-75, and 28% during 1975-80. In the 1980's sales have only increased by 4%.[12] The figure also shows that the main increment in seed imports were during the period 1970-75 and again in the 1980's, although there is much more variation. The value of exports/value of imports ratio has increased from an average of about 1.5 in the period 1955-1970 to a value of more than 3 in 1975-1984.

With respect to the U.S. **Corn Seed Exports, Figure 9** and **Table 5**, show the quantities and values from 1950 to 1983. During the 1950's, quantity and value of exports increased by 43 and 49% respectively. A sharp decline in exports took place in the late 1950's and early 1960's. During the rest of the 1960's exports went up again by about 50%. The value of these corn seed exports increased by 35%, 55% and 57% during the last 3 periods, see figure 9. The quantities, however, increased by 27%, decreased by 35% and increased by 11% during the same periods. Table 6 also shows that the deflated values of corn seed exports were roughly fifteen times greater in 1983 than in 1950. The direction of these exports and their effects on the productivity of corn in different countries will be discussed in B.3.

FIGURE 9: UNITED STATES CORN SEED EXPORTS, 1950-1983

QUANTITY IN MT

VALUE IN $1000 DEFLATED BY CPI, 1967=100



(Except Sweet Corn)

SOURCE: U.S.D.A.

Table: 5

U.S. Corn Seed* Exports, 1950-1983.

Year	Q	V	V^d	Year	Q	V	V^d
1950-54	6066	1008	1292	1971	10354	3652	3011
1955-59	10703	2139	2546	1972	26896	6705	5351
1960	6424	1503	1694	1973	26163	10125	7607
1961	6464	1456	1625	1974	16718	8148	5517
1962	5665	1226	1353	1975	14921	13143	8153
1963	7231	1901	2073	1976	13248	23281	13655
1964	8449	2376	2558	1977	20694	19302	10635
1965	11563	2801	2964	1978	9805	17656	9036
1966[a]	11215	2780	2860	1979	9966	29707	13665
1967	10868	2758	2758	1980	10924	41555	16838
1968	12948	3373	3237	1981	14631	53750	19732
1969	21266	4709	4289	1982	16478	62926	21766
1970	12570	3684	3168	1983	19524	58196	19503

Source: USDA/Foreign Agricultural Circulars, FFSV.

* except sweet corn

a average 1965-1967

Q= QUANTITY IN MT

V= VALUE IN $1000

V^d= VALUE DEFLATED BY CPI, 1967=100

The main U.S. **corn seed companies** spend, as it was mentioned in section A, several million dollars each year to develop new hybrids. After looking at the seed sales carried-out by this firms in the U.S. (see table 2, section A) and internationally (table 5), in order to have an approximated idea of profits, table 6 shows an estimated cost structure of a typical hybrid.

Table6: An Estimated Cost Structure of a Typical Hybrid.

Net price after discounts and commissions:		100%
Less production costs		
Variable: detassling		5-7
payments to farmers for seed		30
Fixed: plant overhead		15
Total production costs:	50-52%	
Gross margin		48-50
Less expenses: res. & development		3
selling		10
general and administrative		5
Pretax margin:	30-32%	

Source: Leibenluft. 1981.

Production costs represent 50-52% of the net price, and other expenses take care of another 18%. The pretax margin for the producer is estimated then, in 30-32%. These costs are taken from Pioneer data. The large pretax margins and cost structure of this company, however, are not typical of the industry because Pioneer is believed to be one of the most profitable firm in the seed industry, and it main crop is corn, which in turn is the most profitable crop. The table, therefore, may show an upward bias in the estimations, but it gives an approximate idea of profits in the U.S. corn seed industry.

The companies involved in the U.S. seed corn market and their share over the last decade can be seen in **figure 10**. Pioneer, Dekalb and Funk together, had more than 50% of the U.S. share in 1983. Pioneer's share has increased over the period almost 40% (from 23.8% in 1973 to 38.1% in 1983). Dekalb and Funk had decreased from 21% to 10.3% and from 8.8% to 3.9% respectively in the 1973-83

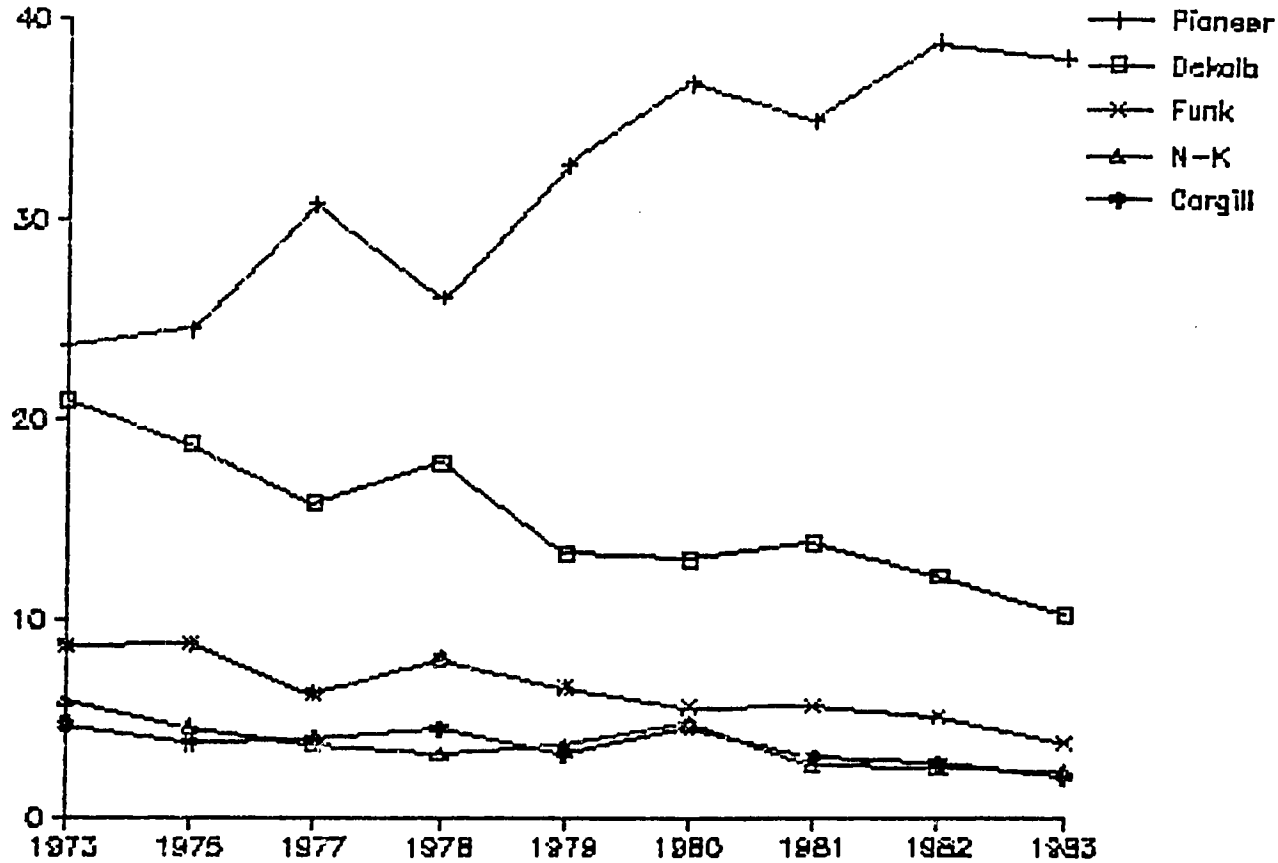
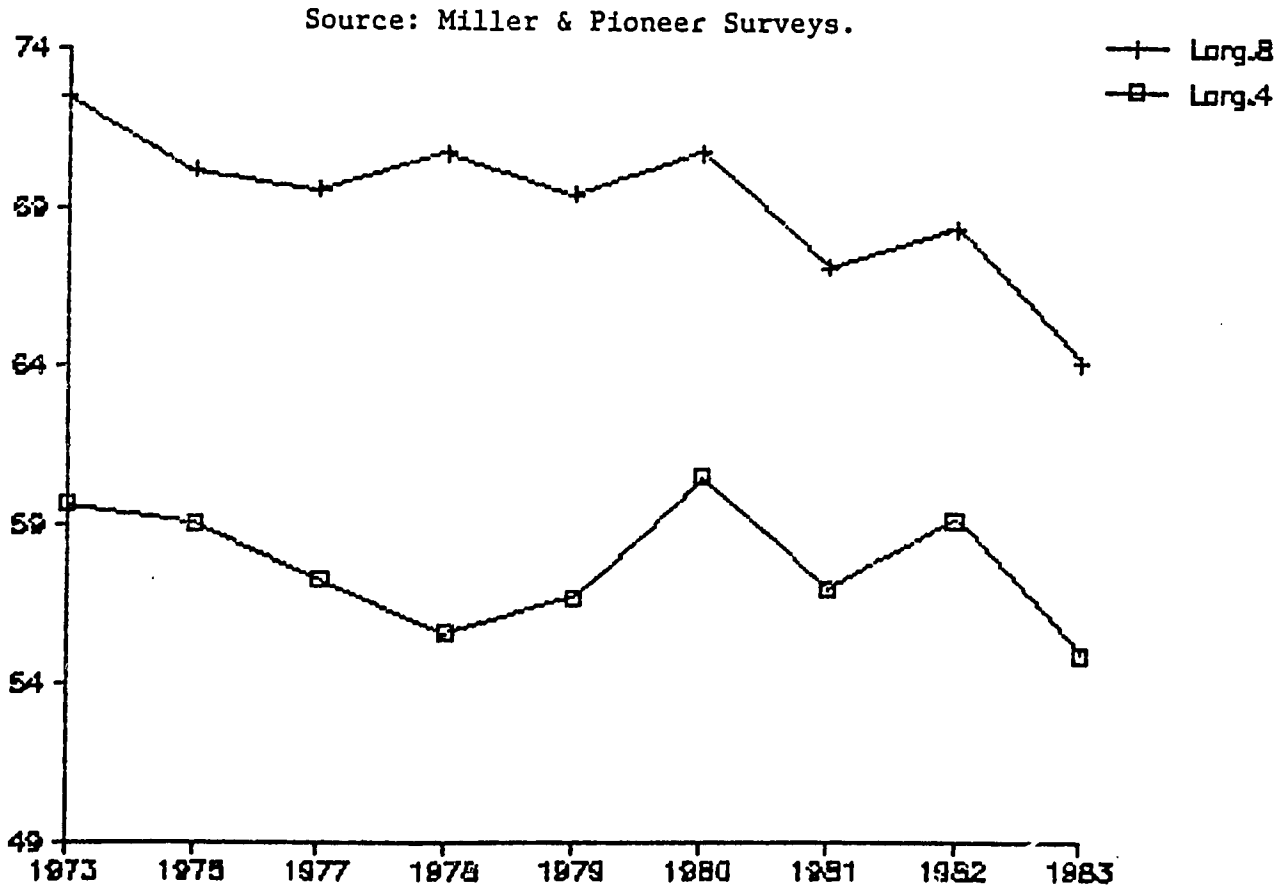


FIGURE 10. U.S. Seed Corn Market Shares, 1973-1983. (In Percentage)
Main five companies, and largest 8 and four together

Source: Miller & Pioneer Surveys.



period. Northrup-King and Cargill with smaller shares than the other 3 companies, have experienced a decrease in sales too, from 6.1% to 2.5% and from 4.8% to 2.2% respectively. The bottom graph on figure 10 shows that the concentration in the seed corn market has been decreasing since 1973. The largest 8 firms went from 72.5% to 64%, while the largest 4 firms had a slight decrease on sales from 59.7% of the total to 54.9% in 1983.[13]

The increased share of Pioneer could be an example of the two important factors in the success in the corn SI, a strong genetic research program and an effective distribution system (or in other words, a successful blend of science and business). Pioneer's corn R&D investments in 1983 were about $16 million, the company has developed almost 400 hybrids since it was founded in 1926. With respect to the distribution system, in the midwest where 75% of the corn acreage is concentrated, seed companies use local farmers as part-time dealers. In the south where acreage is dispersed, agricultural supply stores are the primary means of distribution.

B.2) HYBRID CORN, ORIGIN AND VALUE

The origin of corn is lost in antiquity.[14]
It has been concluded that cultivated varieties of corn have arisen from a wild pod corn that itself had a remote grass-like ancestor which gave rise on the South American continent to a simple species -Zea mays(indian corn)- and on the North American continent to Tripsacum.[15]

Corn varieties in the U.S. corn belt originated by selection from crosses of a New England 8 rowed flint with a late, many rowed type dent. Such a broad basis of parentage furnishes a logical reason for the wide diversity among varieties.[16] In 1906, Dr.E.M.East, from the Connecticut Agricultural Experiment Station, and Dr.G.H.Shull, professor at Princeton University, started studies of inbreeding and cross-breeding of corn. East and Shull independently concluded that the use of hybrid vigor could be commercially developed. The beginning of hybrid corn is based to a large extent on the efforts of these two scientists.[17]
Three broad periods may be recognized during which the biological concepts and techniques underlying hybrid maize were developed. There is, first, the period during which Darwin, Mendel, and Johannsen worked.[18] The second period was dominated by the experimental work of Shull and East, whose critical investigations were carried out between 1905 and 1912. The third stage in the evolution of hybrid corn was characterized by adaptive research, concerned with numerous and varied technological problems encountered by breeders, the answers to which were not forthcoming either from genetic theory or from prior experience in developing open pollinated varieties. This stage began with D.F.Jones' key discovery, in 1917, of the double cross as a practical means of producing commercial seed.[19] It also marked a turning point in the attitude of agricultural leaders in the U.S. toward the economic possibilities of hybrid

corn. As a result, in the decade that followed, large scale corn breeding programs were funded and developed throughout the U.S. Corn Belt. Some of these programs were publicly supported, others were privately financed.[20]

> "Henry Wallace, more than any other single individual, introduced hybrid corn to the American farmer and fervently promoted its adoption. The advantages of hybrid corn over the open pollinated varieties in use in the early 1900's were so great that eventually hybrids would have been used by even the most conservative farmers. Yet, the continuous editorial support in Wallace's "Farmer" magazine for this new kind of corn undoubtedly had a major effect on corn belt farmers and helped accelerate the adoption of hybrids in Iowa and other midwestern states."[21]

The Land-Grant College Experiment Stations and Extension Services and the U.S. Bureau of Plant Industry increased efforts after 1900 to improve corn yields through selection and diffusion of the best varieties produced by farmers and to develop better cultivation practices. The successful development and diffusion of commercial hybrid corn varieties was characterized by the evolution of an increasingly complex research, development, distribution, and educational system involving close cooperation among public sector research and extension agencies, public, semi-public, and cooperative seed producing organizations, and private sector research and marketing agencies.[22]

With respect to the evolution of corn production in the U.S., Table 7 shows that the hectares grown were over 40 million in the first 2 periods (1920-24 and 1930-34). Approximately 37 million hectares of corn were grown in 1940-44. Since then, the area under corn has been declining until a decade ago when it increased again.

Table7: U.S. Corn Area(1000 HA), Production(1000 MT) and Yield(MT/HA), 1920-83.

Period	Area	Production	Yield	% yield increase
1920-24	41018	70215	1.71	-
1930-34	42097	58211	1.37	-20.0
1940-44	36787	72365	2.00	31.5
1950-54	33382	79122	2.41	17.0
1955-59	31858	92998	2.97	18.8
1960-64	24225	94564	3.92	24.2
1965-69	22963	113118	4.92	20.3
1970-74	24808	130817	5.27	6.6
1975-79	28734	171927	5.97	11.7
1980-83	27561	174300	6.23	4.2

Source: U.S.D.A.

Yields have increased from less than 2 MT in the early 1920's to more than 6 MT at the present time. Yields increased more than 30% during 1940-44, and kept increasing during the next 40 years at different rates. During the 1970s and early 1980s yields have increased less than during the period 1940-1970. In 1920-24 the average production was aprox. 70 million tons. In 1930-34 total production dropped to about 58 million MT, only a small area of hybrid corn was grown and there was a period of severe drought. In 1950-54 and 1955-59 total production increased to 79 and 93 million MT respectively, and has been increasing since.[23] Area decreased until the early 1970s and increased slightly during the 1970s. Yields in 1980/83 were more than 4 times greater than in 1930/34. The U.S. hybrid corn adoption rates and yield increases up to 1959 can be seen in Table 8

Table 8: U.S. yields & hybrid corn adoption rates,1929-1959.

Period	Yield t/ha	Yield in % of 1929	Hybrid Corn %
1929	1.61	100	0
1939	1.86	116	22.9
1949	2.37	147	78.3
1959	3.23	200	94.8

Source: Hayes, 1963.

In 1929 hybrids covered less than 1% of the corn hectareage. By the 1960's practically all corn area was planted with hybrids, which explains a large pa of the yield increase (twice as much in 1959 compared with 1929), according w Hayes.

Griliches(1957) has shown that a substantial proportion of the rate of acceptance of hybrid corn is explainable by differences in the profitability open pollinated and hybrid seed, in different parts of the country. The hybri seed industry expanded allocating its resources first to the areas of highest returns.[24]

In Minnesota, before 1930, corn yields averaged 2010 kg/ha, during the next 5 years yields in that state increased to an average of 6290 kg/ha, which represents an annual increase of 85 kg/ha. Yield improvement began in the 193 with adoption of hybrids, which replaced open pollinated cultivars.[25]

Table 9 shows the adoption rate of hybrids and other production practices in Minnesota.

Table9: Minnesota hybrid corn & other practices, adoption rates, 1930-1979.

Period	30's	40's	50's	60's	70's	1979
1)Corn hybrids	8	82	96	100	100	100
2)Seeding rate	31	33	39	40	46	50
3)Fertilizer	na	na	14	67	93	95
4)Herbicide	na	na	12	58	89	93
5)Insecticide	na	na	4	29	32	33
6)Corn Yields	2.0	2.5	3.1	4.3	5.3	6.3

[1 in % area planted, 2 in 1000 plants/ha, 3 in % area fertilized, 4 & 5 in % area treated, 6 in mt/ha, na:not available]

Source: Cardwell, 1982.

The technologies adopted by farmers during the 50 year period have increased average corn yields in Minnesota from 2 to more than 6 metric tons per hectare (similar to what we have seen in table 7 for the U.S.). The comparative yield advantage of hybrids compared with open pollinated varieties by 1930 was about 20 to 25%. Genetic gain in yield potential through plant breeding has been more significant than the adoption of hybrid per se.[26] The major contributions to yield, have come from plant breeding, fertilizer usage, weed control, and increases in plant density.[27]

According with the USDA, in 1950, 78% of the US corn acreage and 99% of the acreage in the Corn Belt were planted with hybrid seed. Farmers continued switching from open-pollinated varieties to hybrids in the early fifties, the hybrids were more productive, and more responsive to favorable cropping practices than traditional varieties. Research has continued to develop new hybrids more responsive to high levels of fertilization, high plant populations, and other improved cropping practices. Much of the plant breeding research has involved yellow corn, and as a result, over 99% of the corn harvested for grain in the US is a yellow type.[28]

Looking at corn improvement in relation with the general progress in biological science and technology, Hayami & Ruttan (1971) have shown the relationship between mechanization, the invention of hybrid corn and the drastic

decline in costs of commercial fertilizer production as three important developments that were occurring by the mid-1920's and "were beginning to call into question the implications of projections based on the classical model".[29] The corn yield explosion of 1940-70 explained by the decline in fertilizer price, together with the shift in the fertilizer response curve resulting from the new hybrids, led them to hypothesize that:

> "the advances in fertilizer technology were themselves induced, at least in part, by the same technical and economic forces that led to the introduction of hybrid corn. Both were part of the effort to overcome the technical stagnation in corn production and the rising relative prices of corn, and of agricultural commodities generally, in the latter part of the nineteenth and early part of the twentieth centuries."[30]

B.3) CORN PRODUCTIVITY IN 30 SELECTED COUNTRIES

Table 10 shows the world production, area and yield of wheat, rice, corn, sorghum and sunflower for the period 1981/83.

Table 10: **World Production** (million MT), **Area** (million HA) and **Yield** (MT/HA) of Wheat, Rice, Corn, Sorghum and Sunflower, average 1981-1983.

	Wheat	**Rice**	**Corn**	**SG**	**SF**
Production	479.5	428.4	415.7	68.2	15.4
Area	236.6	143.6	126.7	47.6	12.6
Yield	2.03	2.98	3.28	1.43	1.22

Source: FAO, Production Yearbooks.

Corn was the third largest crop with 416 million mt, after wheat and rice with about 480 and 428 M mt of production. Sorghum and Sunflower, the other two crops where hybrid seed has been developed, show world production values of 68 and 15 M mt respectively for the 1981/83 period. The world area of corn was about 127 million hectares with an estimated yield of 3.28 mt/ha in that period.[31] World corn production increased almost 191 million metric tons in the last two decades, from 225 M mt in 1960-65; area has increased 20 M ha and yield has gone from 2.1 to 3.28 mt/ha in the same period. Table 10 also shows that world production and area decreased from wheat to sunflower, while corn has the higher productivity per hectare among those five crops.

Figure 11 disaggregates these figures by continent for the last 30 years. In 1983, America (North, Central & South) produced almost half of the world total, while Europe, Asia, Africa & Oceania produced the other half. North & Central America and Asia produced roughly 65% of the corn being produced in the world in 1983. The figures show that corn area has been almost constant in Europe, has declined in North & Central America and increased in South America during the 1955-83 period. **Yields** had sharply increased in Europe from less than 2 mt/ha

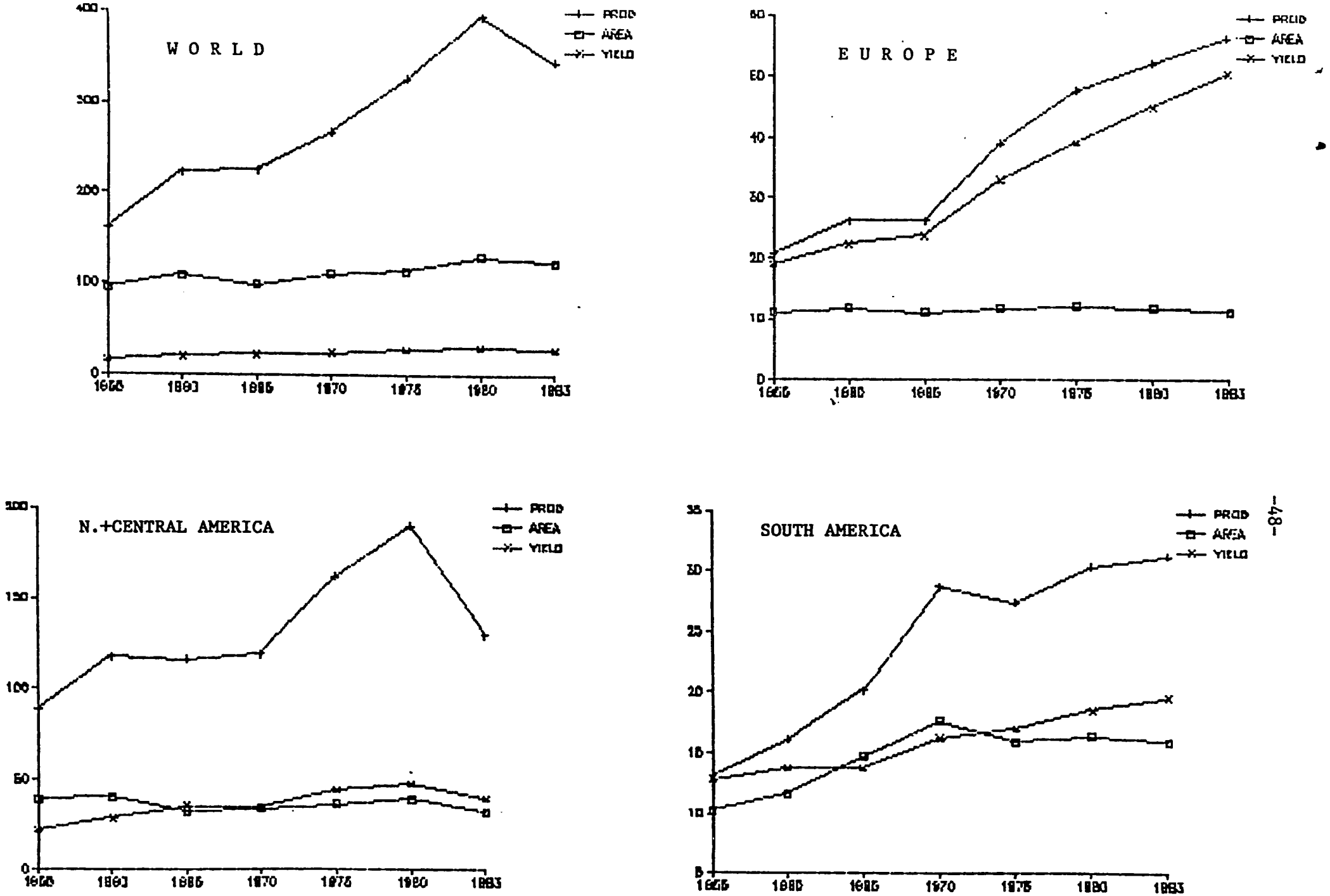
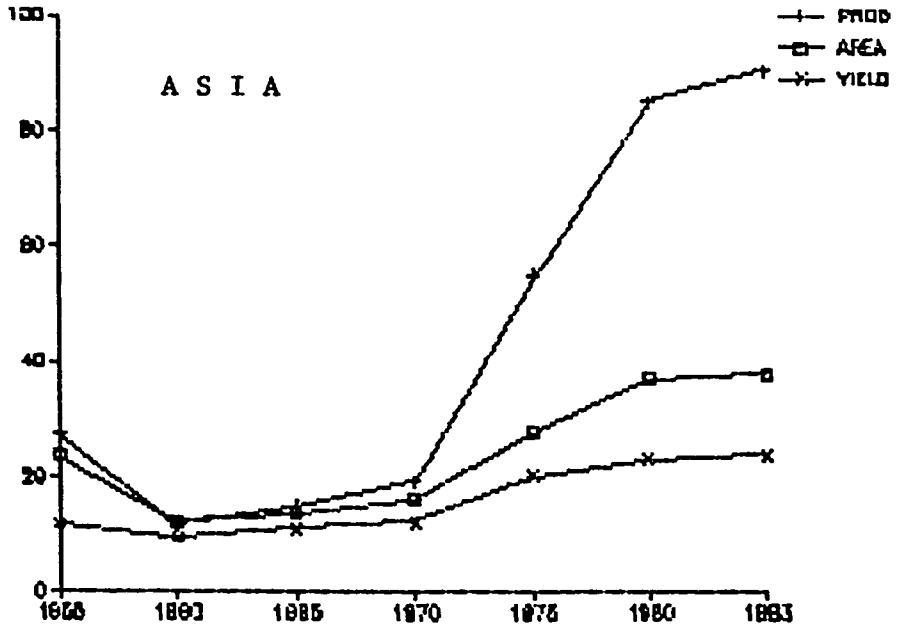
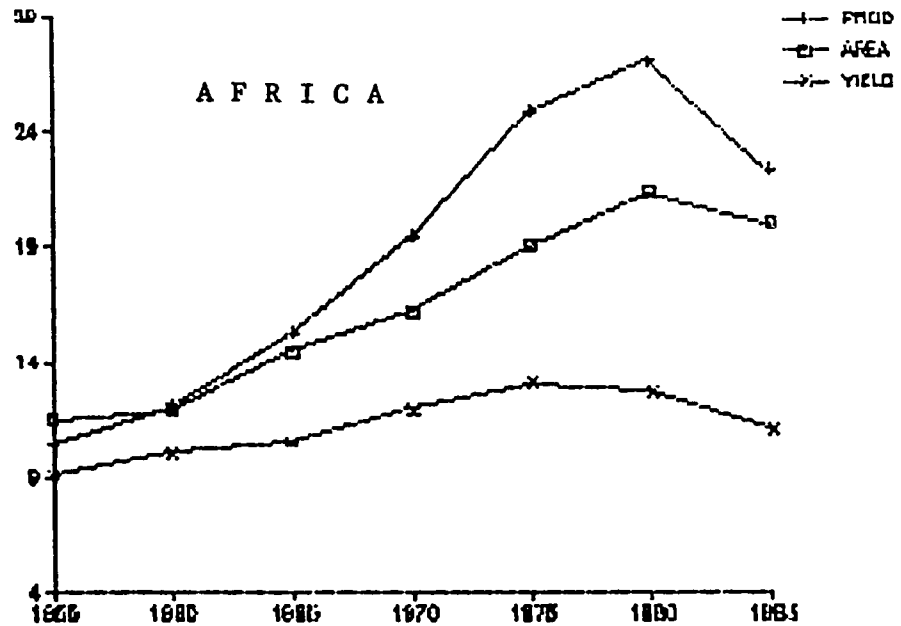


FIGURE 11. Corn Production (Million MT), Area (Million HA), and Yield (100 kg/ha) by Continent, 1955-1983. Source: FAO





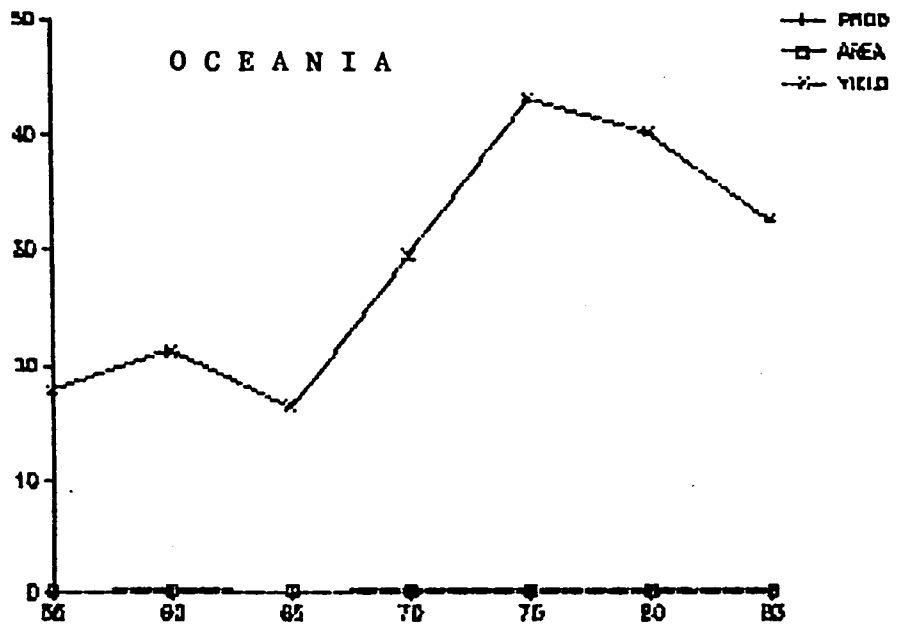


FIGURE 11. Cont.

in 1955 to more than 5 mt/ha in 1983. The increment in North & Central America has been smaller, from little over 2 mt/ha to more than 4 mt/ha in the late 1970's. In South America yields have had a poor performance, staying below 2 mt/ha during the whole period. Asia, since 1970, has had a substantial production increase, explained by the increase in area (from 16 million hectares in 1970 to almost 38 M in 1983) and the increase in yield from below 1 mt/ha in 1960 to 2.4 mt/ha in 1983. Africa's low yields have not changed much, although area has increased. Oceania having a small area, has had substantial yield increments.[32]

Table 11 shows corn production, area and yield for 30 selected countries for 1981-1983. The growth rates of those values for the 1970s (12 years: 1969/71 to 1981/83), and the growth rates for the 1960s (10 years: 1959/61 to 1969/71) are also shown in table 11. The countries are ranked by average production during 1981-1983, from the U.S. with 176 million mt to Venezuela with less than half a million mt. The U.S. corn production was 42% of the world total, while all DCs had 54% and LDCs 37% of the total corn average production during 1981-83.[33] For an average world yield of 3.28 mt/ha, DCs have almost 3 times more yield than LDCs (5.80 vs. 1.98 mt/ha respectively). Developed countries were producing 70 million mt of corn more than Less Developed Countries in less than half of the area, for the 1981-83 period.

Table 11: **Corn Production and Growth Rates in 30 Selected Countries.** Production in 1000 MT, Area in 1000 HA, Yield in MT/HA. P. A. and Y. are averages 1981-1983.

	Prod	Area	Yield	WaY	WaA	WbY	WbA
U.S.A.	175817	26880	6.40	1.8	1.0	3.7	-1.4
China	61283	19290	3.18	1.5	5.0	0.6	1.4
Brazil	20579	11618	1.77	2.2	1.2	0.5	3.9
Mexico	12941	7400	1.75	3.0	0.0	3.0	2.0
Romania	11671	3127	3.74	3.9	-0.1	3.7	-1.0
USSR	11333	4298	2.61	-0.5	1.4	5.3	-11.2
Yugosl.	10540	2271	4.64	3.4	-0.4	3.1	-0.7
Argent.	10447	3178	3.27	3.1	-1.7	2.3	3.9
France	9827	1598	6.14	1.5	0.9	6.0	5.3
S.Afr.	8976	4555	1.91	3.5	-1.2	0.2	3.6
Hungary	7519	1170	6.43	4.9	-0.7	4.1	-0.7
Italy	6981	992	7.04	3.4	0.0	3.6	-1.9
India	6824	5876	1.16	0.8	0.1	1.3	2.8
Canada	6354	1108	5.73	1.0	6.8	2.3	9.5
Indon.	3905	2740	1.44	3.4	0.2	0.4	0.7
Egypt	3388	792	4.29	1.1	1.8	2.8	-0.7
Thail.	3334	1487	2.25	-1.1	5.5	3.6	10.6
Philip.	3267	3306	0.99	1.7	2.8	3.0	1.8
Bulgar.	2973	593	4.99	2.0	-0.4	5.8	-0.7
Korea S	2360	400	5.90	11.7	18.9	3.8	-2.9
Spain	2092	399	5.23	3.5	-2.3	3.7	2.1
Greece	1469	164	8.92	8.9	0.1	8.0	-1.8
Austria	1454	197	7.37	2.4	4.0	4.5	8.5
Guatem.	1048	758	1.41	1.9	1.0	3.7	0.5
Pakist.	979	770	1.27	1.3	1.5	1.1	2.8
Colomb.	882	621	1.42	1.1	-0.8	1.1	-0.1
Czech.	785	170	4.60	1.1	2.4	3.7	-3.8
Peru	598	335	1.79	0.8	-0.9	1.8	4.0
Chile	485	126	3.84	1.7	4.9	4.5	-0.6
Venez.	461	289	1.60	2.7	-6.2	0.2	5.3

Wa is growth rate 1969/71 to 1981/83, in percentage per year.
Wb is growth rate 1959/61 to 1969/71, in percentage per year.
Growth rate = 100 x [LN(Xt/Xto)]/t
where: Xt is average most recent period, Xto is average earlier period, t is the number of years between mid-points of periods.

Source: FAO, Production Yearbooks.

In the first part of the table, there are 14 countries (from USA to Canada) with an average corn **production** of 6 million mt or more, while in the second part of table 12, production decreases from almost 4 million mt for Indonesia to Venezuela with 461 thousands mt. For the first group of 14 countries, corn area ranges from roughly 27 million ha in the U.S. to 1 million ha in Italy. For the second group of 16 countries, area varies from more than 3 million ha in the Philippines to 0.126 M ha in Chile.

Yields show also variation from 6 mt/ha or more in USA, France, Hungary, Italy, Greece and Austria; to less than 2 mt/ha in Brazil, Mexico, India, Indonesia, Philippines, Guatemala, Pakistan, Colombia, Peru and Venezuela. Greece followed by Austria and Italy (with 8.9, 7.4 and 7.0 mt/ha respectively) had the highest yields for the period, while Philippines, India and Pakistan had the lowest ones (with 1.0, 1.2 and 1.3 mt/ha respectively).

Looking at the **growth rates of production** (Growth Production = Growth Yield + Growth Area) **for the 1970s**, China, Canada, Greece, Austria and Chile have rates between 6% and 9% per year. Brazil, Mexico, Romania, Yugoslavia, Hungary, Indonesia, Thailand, Philippines, Korea D.P.R., and Czechoslovakia have growth rates of production between 3% and 6% per year. USA, USSR, Argentina, France, South Africa, India, Egypt, Bulgaria, Spain, Guatemala, Pakistan and Colombia have positive rates below 3%, while Peru and Venezuela show negative production rates. Most of the growth in global corn production in the last two decades was achieved through yield improvements, only USSR and Thailand show a negative growth rate of yield for the 1970s. Greece with 9% yield increase per year during the 1970s has the highest rate, followed by Hungary with 4.9%, the rest of the countries have growth rates of yields below 4%. A third of the 30 countries selected by production in 1981-83 had a decrease in the area harvested of corn during the 1970s. The **growth rates of production for the 1960s** show

a different picture than a decade later. France, Canada, Thailand and Austria have rates between 11% and 14%. Only two countries now (USSR & Czechoslovaquia) show negative production growth rates. Without discussing all the countries figures presented in table 11, we can roughly summarize it saying that yields and area for the 30 countries increased faster in the 1960s than in the 1970s, while the variation between countries was higher in the 1960s also, specially in area. Looking at the countries' differences between the two decades, the table illustrates, that in general, countries with high yield growth in the 1960s slowed down in the 1970s (like USA, USSR, France, Thailand, Bulgaria, Austria, Guatemala, Czechoslovakia and Chile) while some other countries increased corn productivity faster in the 1970s (like China, Brazil, Argentina, S.Africa and Indonesia). Mexico has had a rate of 3% yield growth during the 22 year period, while Greece had an yield growth rate of more than 8% in the entire period. Table 12 shows the value of U.S. corn seed exports to the same 30 selected countries seen before, since 1963. The 20 year period 1963-83 was divided, approximately, in 5 subperiods, in which (when data was available) the values of seed corn exports were averaged. There is a lot of variation in exports over time, with some countries buying seed corn continually and some other ones only sporadically. The EEC as a group have increased imports of seed corn from the U.S. throughout the period, from half a million dollars in 1963-64 to more than $21 M recently. France, Italy, Spain and Greece are the main buyers. Mexico with imports of more than $10 M in 1980-83 and Canada with more than $4 M are the other main buyers of U.S. seed corn.[34] The significance of these seed sales in the transfer of technology by the U.S. Seed Industry will be tested in Section B.4.

Table: 12 . Value of U.S. Corn Seed Exports to 30 Selected Countries, 1963-1983 ($1000)

Country	1963-64	1965-69	1970-7	1975-79	1980-83
China	--	1/	--	--	--
Brazil	1/	9	86	106	10
EEC	502	1,173	2,227	6,504	21,315
Mexico	422	477	507	815	10,835
Romania	--	--	6[a]	81	747
USSR	--	--	1[a]	2,880	--
Yugoslavia	--	6	249	51	120
Argentina	56	64	112	42	80
France	71	117	404	1,288	4,106
S. Africa	8	18	39	30	129
Hungary	8	23	166	345	431
Italy	116	654	1,225	4,384	13,279
India	--	1/	--	--	--
Canada	891	1,056	1,918	4,283	4,110
Indonesia	--	--	33[a]	--	2[a]
Egypt	17[a]	--	--	226[a]	769
Thailand	--	12	4	13[a]	1
Philippines	1[a]	1/	--	11	1[a]
Bulgaria	--	1	31[a]	93	111
Korea R.	--	33	1	6	135
Spain	32	156	417	1,453	1,715
Greece	1[a]	--	5[a]	1,009	4,978
Austria	2[a]	14	2	276	1,079
Guatemala	--	5	4	10	42
Pakistan	1[a]	--	9[a]	--	--
Colombia	1[a]	1	4[a]	34[a]	37
Czechoslovakia	59	22	--	--	160[a]
Peru	1[a]/	12	16	23[a]	15
Chile	3	9	88	311	910
Venezuela	1	2	10	38	14

Source: USDA/Foreign Agricultural Circulars, FFSV.

(1/:$500 or less, a: only one year)

B.4) EMPIRICAL RESULTS

After analyzing the U.S. corn seed sales to different countries and the corn production and growth rates in different periods in those countries, we will focus now on two questions related to the transfer of technology in the case of hybrid corn. a) Can foreigners benefit by letting U.S. companies sell seed plus do research in their countries? b) is the U.S. farmer loosing comparative advantage because of the international activities of the U.S. seed companies? In order to answer them objectively, the importance of the different means of technology transfer and the effect of that transfer has to be measured. To analyze the transfer of technology from the U.S. seed corn industry to the major corn producing countries, an aggregate cross-sectional Cobb-Doublas function with corn productivity as a dependent variable was utilized. To measure the flow of technology to a particular country, two different variables were constructed: a) the imports of U.S. corn seed and b) the research being done in the country by five major private seed companies.[35]

Intuitively, the production function describes the transformation of a set of inputs into output. It represents, for each combination of inputs and output, the minimum quantity of inputs that yields a given quantity of output. The popularity of the Cobb-Douglas function can be attributed largely to its basic consistency with the established body of economic theory, especially to its computational simplicity. The C-D function is of this form: $Y = A\prod_{i=1}^{n} X_i^{b_i}$ where Y is the output, X_i are the inputs, A is a constant term, and b_i defines the transformation parameter for the level of input, X_i. All variables are measured in physical units. The computationally attractive characteristic of this form is that it becomes linear in the logarithms of the variables.

Thus $\text{LOG } Y = \text{LOG } A + \sum b_i \text{LOG } X_i \quad (i=1...n)$

The marginal productivity (MPP, the change in output that results from a small

change in any one input, when all the other inputs are held constant) expressed by the partial derivative of output with respect to (w.r.t.) an input is positive and generally declines as the level of the input increases, assuming that $0<b<1$.

$\partial Y/\partial X_i = b_i(Y/X_i)$ the MPP is employed in the derivation of the elasticity of production (Ep) w.r.t. an input, which is defined as the percentage (%) change in output w.r.t. a % change in input.

$$\eta_{yx_i} = \frac{\partial Y/Y}{\partial X_i/X_i} = (b \frac{Y}{X_i}) \frac{X_i}{y} = b_i$$

In the C-D case, the Ep w.r.t. any (and all) input(s) is constant and directly estimable in terms of the exponents of the respective inputs. The assumption that $0<b<1$ implies that a one % increase in any input (holding other inputs constant) will always increase output by less than 1%. With both A and b_i (for all i) assumed to be constant, an increase in all inputs by 1% increases output by the percent indicated by the sum of the input coefficients. [36]

The <u>production function</u> model utilized was:

$$[CP]_h = A \quad [SI]_h^{\alpha_h} [FERT]_h^{\beta_h} [IRR]_h^{\gamma_h} [PSC]_h^{\delta_h} [ED]_h^{\varepsilon_h} [TECH]_h^{\zeta_h} [RAIN]_h^{\eta_h} E^{\mu_h}$$

where:

h=1...27, <u>selected countries</u>

CP is <u>corn productivity</u> in each country, measured by the average yield in mt/ha, 1981-83.

A is the <u>constant</u> term.

SI represents the average 1981-83 hybrid <u>seed imports</u> from the U.S. in mt/ha harvested of corn.

FERT is <u>fertilizer</u> consumption in 1981, measured in hundreds of grams of plant nutrient per hectare of arable land.

IRR is <u>irrigation</u> measured as a percentage of irrigated land on total arable and permanent crop land in 1982.

PSC stands for five major private seed companies (Pioneer, N-K, Dekalb,Cargill and Funk) doing corn research in each country. This variable was measured in number of years and number of research stations up to 1977.[37]

ED is education utilizing as proxies: a)enrollment in secondary school as a percentage of age group, and b)literacy ratio, both in 1981.

TECH is existent agricultural technology in the country approximated using: a)number of publications of corn & sorghum during the period 1948-1973, b)number of agricultural college graduates per 10,000 male farm workers in 1980.

RAIN is the long run annual average precipitation in inches/year, for the main agricultural areas of each country.

E is the random error term.

Using these same variables and substituting fertilizer consumption by the price of corn in the right-hand-side of the equation, a supply function model was constructed. The price of corn (PC) was measured by kilograms of nitrogenous fertilizer (urea in most of the countries) that could be purchased with 100 kgs of corn equivalents, average 1977-1980.

A DUMMY variable was also utilized to try to account for differences between Developed and Less Developed Countries (1 for DCs and 0 for LDCs).[38]

The irrigation and rain variables, tried in different regressions, were not significant, showing coefficients close to zero. This is probably because total irrigation was a very rough measure and not specific for corn crops, due to unavailability of such information. Rain on the other hand was approximated by averaging annual precipitation data of different weather stations in agricultural regions in each country without a precise knowledge of specific corn areas in these countries.

Some other variables were also tested without too much success: an international land quality index was used to try to account for quality of the

land input.[39] Also the number of maize publications in the period 1948-1968 was used to measure the level of technology, instead of corn & sorghum publications 1948-73. Because not all the variables that we would like to have in the function were included, the model becomes a partial function. Due to the exclusion of relevant variables and mismeasurement errors, the results are likely to have some specification bias. For example, the fertilizer consumption coefficient may have an upward bias because rainfall was not included (being rain and fertilizer positively correlated, the bigger the rainfall, more fertilizer can be applied). By the same token, and because land quality was not included, the fertilizer coefficient could also be downward biased. The seed imports coefficient is also likely to have some directional bias if we think in the importance of some of the left out variables in explaining yields, and their correlation with seed imports.

The coefficients were calculated from the following regressions:

For the partial production function:

$$L[CP]_h = C + \alpha_h L[SI]_h + \beta_h L[FERT]_h + \delta_h L[PSC]_h + \epsilon_h L[ED]_h + \gamma_h L[TECH]_h + e$$

For the partial supply function:

$$L[CP] = C + \alpha_h L[SI]_h + \theta_h L[PC]_h + \delta_h L[PSC]_h + \epsilon_h L[ED]_h + \gamma_h L[TECH]_h + e$$

where L is logarithm, C is a constant and e is the error term.

Table 13 summarizes the results obtained using Ordinary Least Squares. The first four regressions are the result of fitting an aggregate Cobb-Douglas partial production function. Regression five is obtained using the partial supply function. Hybrid corn seed exports from the U.S. to the 27 countries in the cross-section show highly significant results (P=0.01 level) in regressions 1, 3, 4, 5; and significant results (at the 0.05 level) in regression 2. According with this, then, the simple transfer of new genetic materials plays a significant role in explaining the variation in corn yields between the

TABLE 13: REGRESSION RESULTS. ((Dependent Variable is YIELD.))

Regression Number:	1	2	3	4	5
SEED (hybrid corn imports mt/ha, average 1981-1983)	.088*** (.029)	.086** (.035)	.083*** (.026)	.102*** (.024)	.104*** (.026)
FERTILIZER (consumption, hundreds of grams of plant nutrient/ha of arable land)	.15* (.080)	.21** (.089)	.074ns (.078)	-	-
REAL PRICE OF CORN (kgs of fertilizer purchased with 100 kgs. of corn, 1977-80)	-	-	-	-	.055ns (.159)
SEED COMPANIES (# of years & res. stations, up to 1977)	.006ns (.06)	.052ns (.06)	-	-	-
EDUCATION a) enrollment in sec.school, 1981	.49** (.21)	-	.32ns (.20)	-	-
b) literacy ratio, 1981	-	.48* (.25)	-	-	-
TECHNOLOGY a) # of publications/ha of corn	.025ns (.060)	-	-	-	-
b) # of agric. graduates	-	.057ns (.061)	-	-	-
D.C. Dummy	-	-	.39* (.21)	.605*** (.166)	.609*** (.17)
Adjusted R^2	66	65	72	71	70
S.E. of Regression	.39	.40	.35	.36	.37

Note: Equations are linear, in logarithms.
Parentheses enclose standard errors of the estimated coefficients.
T-values are for (n-p) degrees of freedom, n is # of obs., p is # of regressors.

ns not significant (Two tail test)

* significant at P=0.10

** " " P=0.05

*** " " P=0.01

countries included in this study. The value of the coefficient ranges from 0.083 in R.#3 to 0.104 in R.#5.[40]

R.#1 shows significant coefficients for fertilizer consumption and education. Seed companies doing research in the country and technology coefficients do not show statistical significance. The adjusted coefficient of determination -$\bar{R}^2$ is 66% and the standard error of the regression is 0.39.[41]

R.#2 shows pretty similar results to the first one, using two different proxies, literacy ratio instead of enrollment in secondary school for Education; and number of agricultural graduates instead of number of publications for Technology. Seed imports, fertilizer consumption and education appears to be the main explanation of yields according with these first 2 regressions.

In R.#3 a dummy variable for DCs is included, and it picks-up enough variation to be significant turning education and fertilizer to non-significance. The adjusted R^2 increased to 72% in this regression.

R.#4 analizes only seed imports and the DC dummy variable, both are highly significant. At this stage, therefore, yields could simply be explained by the imports of U.S. seed corn and all the DC/LDC differences (cultural practices, education, technology, etc) represented by the DC dummy.

R.#5 for the partial supply function does not show a significant coefficient for real price of corn. Seed imports and education or seed imports and the dummy variable show, again, highly significant results.[42]

Looking at the correlation between the different variables, yield and seeds have less than 15% correlation. Yield and fertilizer are correlated by almost 64%. Real price of corn shows a correlation with yield of 27%, while education & yield are almost 70% correlated. The highest correlations among right-hand-side variables are between seed and price of corn (47%) and fertilizer and publications (43%).[43] Although multicollinearity does not seem to be a problem

in this study, the figures could be interpreted in the following way: the higher the real price of corn, more hybrid seed corn a country would be willing to import from the U.S., in order to increase its yields. Increasing number of publications showing the benefits of fertilization would increase fertilizer consumption. Farmers' skills play an important role in the yields obtained trough the use of better seeds and more fertilizer.

In fact, if we consider the DC dummy variable as picking-up all the variation due to differences in technology, the different corn yields could be interpreted as the result of using the U.S. hybrid seed plus all the required technology to capitalize on the high yielding genetic potential.

With respect to the variables that did not show significant coefficients, the results could be interpreted as follows. The presence of the seed company research in the different countries as a way to measure the seed technology being utilized (as it was mentioned, seed research is location specific) has three main measurement problems. 1)Probably these five, are not the only private companies doing research in the country (besides this research, there is domestic private and public sector research too). 2) There is spillover effect which was not measured. New hybrid corn, for example, could be developed in Brazil after 10 years of research and take it to similar growing conditions in Thailand. Measuring the presence of the companies by number of years involved in research times number of stations does not account for this factor. 3) It is too early for company research to have much impact on yields since most of the companies included in this study began overseas operations by the mid 1970s. [44] The other proxies for technology utilized, publications and number of graduates, did not helped much explaining corn yields. More recent data on corn publications in each country could help in this regard. The number of agricultural graduates in 1980 in different countries is also a crude

estimation. The agricultural sectors are different in different countries, and within the sector the importance of corn as a crop, for example, is not the same in Chile as it is in Brazil.

The exports of U.S. corn seed, together with fertilizer and education, significantly explained yields in this study. In order to measure the impact of the direct transfer of technology -by the U.S. sales of seed- the marginal physical productivity (MPP) was calculated.[45] The MPP for the imports of hybrid corn seed was obtained using the following formula:

$$MPP = \hat{\alpha}_h \times (\bar{Y}_h / \bar{SI}_h)$$

where:

h=1...27, selected countries.

$\hat{\alpha}$ is the estimated coefficient of the seed import variable in the production function.

$(\bar{Y}_h / \bar{SI}_h)$ is the average product obtained dividing the geometric mean of yields by the geometric mean of seed imports per hectare for the 27 countries.[46]

The average product then, is:

AP = G.Mean Production/G.Mean Seed Imports. AP=61.69

MPP = 0.09 x 61.7 = 5.55

This MPP value could be interpreted not strictly as the MPP of seeds, but as the additional output that a country could get over and above the output obtained using domestic seed. Because imported seed significantly explains yields, the country could not only increase corn output, but save money importing seed and producing less seed locally. The benefits of an increased corn output for these corn producing countries are obvious. It is not necesary, of course, for the increased output to be marketed in the form of corn. The extra corn produced can be converted to livestock or poultry products. Or the same amount of corn can be produced with less conventional resources (land, labor, and capital) releasing

these inputs for the production of other products. For a small difference in prices between the imported and the locally produced seed, the MPP value obtained in this study (interpreted as the additional output because of using imported seed) demonstrates even better the benefits of importing hybrid corn seed.

Under profit maximizing conditions:

Price of Corn x MPP = Price of Seed

or: MPP = Price of Seed/Price of Corn [47]

Further research to test in each country if the Value Marginal Productivity (VMP= Price output x MPP) is higher or lower than the input price could help in the economic analysis of under or over utilization of the input.

Also, more analysis on the other two important phases of the international transfer of technology mentioned before (design and capacity), would also help to understand better the whole process of transfer of technology by the private seed industry.

FOOTNOTES SECTION B

1 Pray,C. 1985. Draft. Private Sector Innovation and Technology Transfer in the Agricultural Sector of Developing countries. University of Minnesota.

2 "This phase usually corresponds to an early stage of evolution of publicly supported agricultural research in that experiment stations conduct, primarily, simple tests and demonstrations". Hayami and Ruttan.1971.pg.175.

3 Also scientists migrate with their baggage of knowledge and expertise, with all the related consecuences for institutional development.

4 See Appendix 1 -major seed companies- with a more complete description of specific goals and strategies when planning investments.

5 Goodman et al.,1982

6 See -major laws- in the U.S. SI in section A.2.

7 Besides this pressure, and being licensing and direct investments, one of the most common institutional arrangements of technology transfer, the role of private foreign investment is, usually, subject to controversy. Oponents of direct investment argue that private investors take advantage of their business experience and monopolistic power to drain resources from LDC's, leaving them in worse condition than they originally were, often joining local elite groups to preserve the political and social status quo. Others argue, that only with substantial outside private investment and know-how, can a country be pulled out of poverty and stagnation. These two opposite views will not be discussed in this paper.

8 Poultry inputs are hatching eggs and baby chicks for breeders; livestock figures are for beef, dairy and swine for breeding purposes, plus bull semen; fertilizer is natural and manufactured; chemicals are pesticides, insecticides, fungicides and similars; machinery is all agricultural machinery plus tractors. See Table 3.6 in Appendix 3.

9 See Table 3.7 and 3.8a in Appendix 3 with more detailed information of U.S. Seed Trade in the last thirty years.

10 See Table 3.8 in Appendix 3 with complete information of U.S exports and imports by continent since 1965.

11 See Table 3.9 in Appendix 3.

12 The decrease in value of sales during the period 1955-1960 could perhaps be explained, among other factors, by European concern about the quality of the U.S. seed that was being exported to the continent. According with seed companies officials, some U.S. firms were sending to Europe, at that time, not very good quality products.

13 See table 3.10 in the Appendix, with complete information on the shares of U.S. seed corn market of these and other companies.

14 The plant is very highly specialized and could not reproduce itself without the aid of man, its origin could have been thousands of years ago. According with R.Jugenheimer (1976) corn may have originated in the highlands of Peru, Bolivia, and Ecuador because of the great diversity of native forms found in the region. Others investigators believe that corn originated in southern Mexico and Central America, primarily because this appears to be the native region of Euchlaena, and also because of the wide diversity of types existing in the region.

15 According with H.Hayes (1963) and following the views of Mangelsdorf and others who have concluded that Euchlaena, teosinte, the third american genus of the tribe Tripsacaeae, was produced by hybridization from crosses between tripsacum and zea. North America maize varieties, then, include two main groups: pure maize which descended from wild pod corn and tripsacum contaminated maize.

16 See Hayes,1963. A Professor's Story of Hybrid Corn, for a complete description of the U.S. Corn Belt history.

17 Hybrid corn breeding originated directly from studies on heredity by Shull, who was interested in the genetic basis of kernel-row number in corn. The experimental procedure he adopted involved inbreeding corn by continued self-fertilization, and crossbreeding.

18 The publication in 1859 of Darwin's Origin of Species started a new era in biology. Mendel's epoch-making studies on inheritance in the garden pea, which provided the key to understanding heredity, were reported in 1865.

19 Up to the time of Jones' invention there was little basis for thinking that the potential advantages of hybrid corn, could be broadly realized in practice. According to Brink (1968) both Shull and East eventually had concluded that the production of F1 hybrid seed directly by crossing two inbred lines would be prohibitively expensive. Jones' doble-cross method removed this block to the extensive use of controlled hybridization in corn. (Although until these findings hybrid corn was not considered practical, its development, however, is the culmination of the efforts of many individuals working at many public and private research institutions over a period of years. Therefore, the use and value of hybrid corn should not be accredited to any one person or to any one organization or institution).

20 In spite of the early research, hybrids did not reach farms until the 1930's. Once they did, there was a tremendous impact on corn yields.

21 From Brown,1983."H.Wallace and the Development of Hybrid Corn" in the Annals of Iowa. See this article for a complete analysis of those important years for the development of corn.

22 See Sundquist et al.,1982 for a complete assessment of the different technologies explaining the increase in corn productivity.

23 The yield increase between 1920-29 and 1946-54 was due in approximately equal proportions, to seed improvement, higher levels of fertilization, and increase in mechanization, according with Johnson and Gustafson, 1962.

24 Griliches explained the lag in the development of adaptable hybrids for particular areas and the lag in the entry of seed producers into these areas on the basis of varying profitability of entry. He concluded that private and public funds were allocated efficiently within the hybrid seed industry, looked as a part of the specialized sector providing technological change.

25 See Cardwell,1982."Fifty years of MN corn production...", for a complete analysis of the sources of yield increase in that State.

26 Cardwell,1982. The average genetic gain was estimated by Duvick (1977."Genetic rates of gain in hybrid maize yields during the past 40 years." Maydica 22) to be 57% to 60% of the 81.7 kg/ha annual yield gain recorded since 1930. Discounting the annual rate of genetic gain capitalized on by the average farmer due to delay in adopting new hybrids of superior yields and utilizing practices of production which limit the genetic potential of the new hybrids, the average genetic gain realized by farmers was estimated by Cardwell to be 36.5 kg/ha/year.

27 Minor contributions can be attributed to change from check-row planting to drilling, earlier planting date, increased area fall plowed, and narrower rows. Plant breeding and commercial fertilizer have made the major contributions to the yield improvement during 1930-1979.

28 This is the predominant type of corn grown in USA. White corn in the other hand, has become a specialty crop grown primarily for food uses, with an annual production below one million MT since 1975.

29 According with the evidence from corn yields during the first third of this century and following the classical model of diminishing returns to land and labor, Bray and Watkins (1964) have suggested that in the substantial increase in corn production that followed those years, the economic importance of hybrids has been overestimated. According with this authors failure to take capital depletion of natural fertility into account and without the introduction in the early 1940's of artificially manufactured, cheap nitrogen, the yield potential inherent in hybrids could not have been realized. The hybrids, by accelerating fertility removal made more urgent the need for finding a solution to the fundamental problem of fertility maintenance.

30 Hayami and Ruttan,1971.Agricultural Development: An International Perspective. Ch.7, pg.149-150.

31 See tables 3.12 to 3.16 in Appendix 3 with information by crop and by continent since 1960.

32 See table 3.14 in the Appendix with all the information of production, area and yield for these regions during the period 1955-1983.

33 For this study, LDCs are: a)all African countries except South Africa, b)all Asian countries except USSR and Japan, c)all Central, South America and Caribbean countries. DCs are: a)Eastern Europe and USSR (Bulgaria, Albania, German Dem.Rep. Poland, Czechoslovakia, Hungary, Romania, USSR). b)developed market economies (Australia, Austria, Canada, France, Greece, Italy, Belgium-Luxemburg, Denmark, Germany F.R., Ireland, Netherlands, United Kingdom, Finland, Greenland, Iceland, Israel, Japan, Malta, New Zealand, Norway, Portugal, South Africa, Spain, Sweden, Switzerland, USA, Yugoslavia)

34 See table 3.16 in the Appendix with more information on US seed exports to selected countries in 1980 and 1984.

35 See table 3.18 with the list of countries. From the original 30 selected countries, China and USSR were not analyzed because of lack of information; USA was left out because the analysis tends to measure, precisely, the US impact on the rest of countries.

36 Several properties of the C-D function are quite realistic; for example, the properties of positive but declining marginal productivities, variable returns to scale, the inverse relation between the marginal rate of substitution and factor proportions. There are also some properties that would intuitively seem unrealistic, however, such as the unitary elasticity of substitution among factors or the strictly linear expansion path.

37 Considering a five year lag in the development of new hybrids, and being 1982 the mid-point of the dependent variable average. Table 3.22 in the Appendix shows, approximately, the dates when the five seed companies began doing corn research in each country. Subsidiaries, licensees or variety trials were not taking into account.

38 Table 3.20 in the Appendix has the data for all the variables utilized in this study.

39 See Peterson,W.1984. Land Quality and Prices.

40 See complete regression results on table 3.21 in the Appendix.

41 The goodness of the fit of the overall relation is judged by the multiple coefficient of determination adjusted for degrees of freedom, and by the standard error of the regression.

42 Besides the simultaneous equation bias problem (correlation between independent variables and the error term) in supply functions, this particular one does not include other appropriate supply shifters like prices of alternative outputs using the same inputs. A price index of inputs used in corn production is also missing. The non significant results, obviously, do not mean that farmers do not concern on prices.

43 Correlation figures are on table 3.19 in Appendix 3. A potential problem in estimating a multiple regression is "high" correlation between some(or all) of the independent variables with one another.

Multicollinearity reduces the precision of the individual regression coefficients, because it is not possible to hold other things equal when we vary one independent variable in order to quantify the effect upon the dependent variable. A correlation coefficient between a pair of independent variables greater than 0.8 is usually taken as evidence of "high" multicollinearity.

44 See table 3.22 in the Appendix.

45 Marginal productivity (MPP) is defined as: MPP $\equiv df(x)/dx \equiv f'(x)$, whereas marginal product (MP) is defined as: MP $\equiv dy$ or MP $\equiv \Delta y$ depending on whether the change in x is arbitrarily small or lumpy. With a generalized Cobb-Douglas production function of the form: $y = Ax_1^{b_1}x_2^{b_2}$ we have $MPP_1 = \frac{b_1 Ax_1^{b_1}x_2^{b_2}}{x_1} = \frac{b_1 y}{x_1}$

46 The geometric mean (the nth root of the product of n numbers) like the arithmetic mean, is a measure of central tendency, but is a more appropriate average of distributions which tend to be logarithmic in form. When the mean of ratios is desired, the geometric mean is the correct average to use.

47 The profit-maximizing level of the input is obtained by equating VMP with factor price. Or, it can be expressed as equating MPP with the ratio of factor price to product price.

SUMMARY AND CONCLUSIONS

The U.S. seed industry includes institutions, organizations, and business firms that perform four different activities: research, production, marketing and distribution. Private research and development expenditures in agricultural inputs have grown faster than public expenditures in the last twenty years. The 1970s show a sharp increase of R&D expenditures by private seed firms as the industry was rapidly growing. This period also shows a slight decrease in the number of new varieties released by the public sector. The effect of the Plant Variety Protection Act of 1970 in increasing private breeders incentives to do research on self-fertilizing plants, is reflected not only in the increase of research efforts but also by the large number of seed company mergings and acquisitions that took place during the 1970s. U.S. seed sales increased in real terms more than 30% in the last twenty years, from $35 M in 1965 to $105 M in 1984. Europe and Latin America were the principal customers, with Asia having the fastest growth in seed imports. Corn is, at the present time, the major source of profits for the private seed industry. Pioneer, Dekalb and Funk represented more than 50% of the U.S. corn market share in 1983. Pioneer increased 40% its share during the period 1973-1983. The concentration in the corn seed market (measured as percentage of sales by the largest 8 and 4 firms) however, has been decreasing since 1973. Corn was the third world largest crop after wheat and rice in the early 1980s. A hundred and twenty seven million hectares yielding, on average, 3.3 metric tons each were harvested in the world during the period 1981/83. The U.S. and Asia represented about 65% of the total world corn production in this period. The main thirty corn producing countries selected for this study increased production faster in the 1960s than in the 1970s, although there were differences between

countries, specially in the yield growth rates. Some countries had high rates in the 1960s while others increased yields faster in the 1970s. Italy, Mexico, Greece, Canada, France and Spain were the main buyers of U.S. corn seed in the early 1980s. The seed industry transfers technology through commercial varieties, germplasm and information. The results of measuring the impact of the transfer of technology by the U.S. corn seed industry to 27 selected countries during 1981/83, show that seed sales significantly explain yield variations among those countries. The estimated value of the coefficient for the seed imports variable obtained in the production function was 0.09, with an standard error of 0.03. The marginal physical productivity of these seed imports, interpreted as the additional output that a country could get over and above the output obtained using domestic seed, was 5.55. Therefore, when imported and domestic corn seed prices are not very different, a country could not only increase corn output importing seed, but save money by not producing it locally. According with the empirical results presented in this study, foreign countries benefited by importing U.S. corn seed during the early 1980s. The transfer of technology from the U.S. seed industry to the main corn producing countries, through direct sales of seed had a substantial role in the corn yields obtained in those countries. The use of fertilizer and the level of education in these countries also played an important role explaining yields, during 1981-83. Because adaptive and comprehensive research is also ocurring as a way of transfering technology in the corn seed industry, further analysis in this area would be useful in understanding the implications and the impact of the different phases of the international technology transfer. The results of this study were not conclusive in this area.

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A P P E N D I X

1) MAJOR U.S. SEED COMPANIES

2) LIST OF COMPANIES AND ACQUISITIONS

3) GENERAL DATA

APPENDIX 1: MAJOR U.S. SEED COMPANIES

* Pioneer Hi-Bred International
* Dekalb Ag.Research Inc./Pfizer
* Cargill Corporation
* Northrup King/Sandoz
* Funk/Ciba-Geigy
* Agrigenetics Inc.
* Asgrow/UpJohn Corporation

PIONEER HI-BRED INTERNATIONA

Founded in 1926 by Henry A.Wallace to apply newly discovered genetic techniques to produce hybrid corn, today Pioneer (PI)is a leader in the genetic supply industry around the world. PI develops, produces and markets hybrids of corn and sorghum and proprietary varieties of soybeans, alfalfa and wheat. PI also develops and markets microbial products and electronic information systems, which account for approximately less than 10% of the total gross sales. PI has an excellent reputation for its field corn hybrids and for the marketing system (farmer/dealer arrangements) used to sold its seed in the mid-west region of the U.S. Pioneer Overseas Corporation (POC), a wholly owned subsidiary, markets products in approximately 90 countries around the world, its contributions to the total company's profits have grown steadily, see **table a and figure a** in page 1.3 and 1.4. In fiscal 1982 the contribution of POC was of about 10% of PI pre-tax income. The figure increased to 24% in 1983 because of increased overseas operations and a reduction of U.S. acreage due to government programs (PIK). Hybrid corn and sorghum seeds are the main products sold overseas, through a network of wholly-owned subsidiaries, joint ventures, and independent producer-distributors. PI research philosophy has followed a "small experiment station" approach, locating researchers in the field in a very decentralized manner. The Plant Breeding Division was employing 116 research scientists by mid-1983 (48 in corn, 7 in alfalfa, 15 in cereals, 8 in sorghum, 12 in soybeans, 2 in sunflowers, 8 specialists, 9 in administration and 7 in data management), while 36 were employed in POC, see table a for R&D expenditures.
Forty-eight research stations are located in the U.S. and 19 overseas, in France, Germany, Italy, Egypt, India, Phillipines, Thailand, Japan, Mexico, Brazil, Argentina and Australia. **Table b** shows POC worldwide market share.

For good results a research station must be well staffed and equipped, and that requires a sizeable investment.

*General foreign investment policies of the particular country.

> "As a business, investment in a seed industry should generate profits to the investors, it should be possible to repatriate dividends. Without good support from the government in terms of approval of varieties, favorable loans, technical assistance, favorable export/import policies and so on, it is difficul to expect private sector participation". (from PI interview)

TABLE a: Pioneer sales, income and R&D expenditures

(in thousands of US$)

	1979	1980	1981	1982	1983
net sales	327,511	405,884	477,995	577,398	505,434
pre-tax income	78,626	113,173	121,319	139,857	77,346
internat'l oper.income	2,916	4,660	9,470	13,984	18,710
R&D total expendit's	10,077	12,469	14,657	19,026	24,041
Corn R&D expendit's	—	—	9,635	13,309	15,859

Table: b . PIONEER OVERSEAS CORPORATION

Market Share

	Market Share 1981/1982	Estimated Market Share 1982/1983
WESTERN EUROPE		
Austria	10.0%	20.0%
Benelux & U.K.	40.0	43.5
France	26.0	35.4
Germany	4.6	7.0
Greece	65.0	69.3
Italy	5.4	9.7
Portugal	-	0
Spain	14.6	20.0
EAST EUROPE		
Bulgaria	2.8%	4.5%
USSR	28.0	28.4
Hungary	54.0	74.6
Romania	18.5	21.0
Yugoslavia	1.0	1.2
SOUTH & CENTRAL AMERICA		
Brazil	10.0%	
Argentina	-	
Mexico	2.0	
Chile	10.0	
ASIA		
India	1.0%	
Japan	50.0%	
China	-	
USSU	-	
Thailand	-	
AFRICA		
South Africa	70.0%	

Source: Pioneer Overseas Corporation Study, Harvard Business School, 1982.

market. By 1981 Dekalb market share had fallen to 9% and Pioneer's had risen to 36%. See **figure b** for a comparison of the performance of the main U.S. farm input industries.

The company's earnings (losses) from continuing operations before income tax, for the agricultural seed sector can be seen in **table c.**

TABLE c: Dekalb earnings and losses, seed operations (years ended in Aug.31, in millions of $)

1984	1983	1982	1981	1980	avg.1979-1975
17.3	(9.5)	(9.6)	26.8	29.6	28.6

Operating revenues from worldwide seed operations increased 31% in 1984, compared to a revenue decrease of 15% experienced in 1983. The main explanation of the increased revenues was the increase in domestic seed corn sales. The Argentine seed business was the greatest contributor to the strong performance of the international seed operations. Dekalb entered Argentina in 1959. DP actual best performing crop seed is sorghum. The main area of research is plant breeding, the U.S research effort can be seen in **table d.**

TABLE e Dekalb's international operations location

(sorg=sorghum, sf=sunflower)

country	crop research	wholly-owned	with local partner
Argentina	corn,sorg.,sf.	*	
Australia	corn,sorg,sf.		*
Brazil	corn	*	
Canada	corn	*	
France	corn,sorg,sf		*
Italy	corn	*	*
Mexico	corn		*
Spain	corn		*
Thailand	corn		*

Licensees in: Chile, Colombia, France, Iraq, N.Zealand, Peru, Philippines, Portugal, S.Africa, Thailand, Turkey, Uruguay, Venezuela.

THE CARGILL CORPORATION

The world's largest grain trader, is a privately held corporation based in Minnesota. It is not a major seed company in USA, deriving less than 4% of its farm product sales and less than 1% of its total revenues in the U.S. from seeds. It has less than 2% of the U.S. corn market share.

The Cargill Corp.(CC) sells under three names: Acco Paymaster, PAG and Cargill, it controls Kroeker Seed Company in Canada and the Dorman Seed Company in the U.S.. Seeds are included as an essential part of the total farm service package offered to farmer costumers. CC control of the Seed Division is viewed as a long term strategy to diversify its activities in important areas of food business. According with R.Baldwin, CC retired Head of Research, the research operations were almost nonexistent by the mid 1950's, they have increased gradually to the present large seed division program with approximately a hundred scientists around the world. The growth of CC's U.S. seed operation has been gradual except in 1970 when they purchased PAG and the seed operations were increased by a factor of three. After another decade of gradual growth, in 1980 Acco Paymaster was purchased which again increased the size of the company.

The operations have expanded from corn, to sorghum, sunflower, safflower, soybeans, wheat and rice. The international seed operations start expanding in the early to mid 1960's to Brazil, France, extending Argentina's operations, and more recently they have expanded into Thailand and Phillipines. Besides the research facilities in these countries they are testing varieties of corn, sorghum, safflower and sunflower in Indonesia, Pakistan, India and China. Cargill concentrates all of its research on hybrids, not in open pollinated crops, even in the U.S.

The seed business led all of CC's operations in Brazil, starting in 1962-64 with

subsidiaries in Canada, Mexico, Argentina, U.Kingdom, France and Italy.
NK produces seed of hybrid corn (7% of US market share), hybrid sorghum (world leader producer), wheat (hard red spring accounts for more than 10% of US market share), soybeans (2% of acreage sown with private varieties by 1980), vegetables, cotton, oilseeds and forages.
Sandoz, a pharmaceutical, agrichemical, and food products conglomerate based in Switzerland, acquired NK in 1976, since then NK has lost ground in major seed markets in recent years, see Sandoz financial information in **table g** .
The company has faced an "unplanned development" (from interview with Dr. Romig, NK official) through the years, trying to adapt U.S. products in other areas. In Asia, for example, NK is involved with tropical vegetables like egg plant, melons, canteloupes, squash, peppers; where the polination for hybrid varieties is done by hand due to lower labor costs. The castor oil program is based in India, Thailand and Brazil. The tomato program started in Florida, U.S.A. and has a long term goal of being expanded to Africa, Asia and Latin America. Mexico tropical corn program is one of the present efforts in L.America, representing 15% of the total investment overseas. NK is also marketing soybeans in Argentina, France and Italy . The subsidiaries have independence in research expenditures decisions. The major constraints in overseas activities are reported to be the different business climates within countries, as ell as NK finite stock of resources to invest abroad. Table f shows the last published revenues from NK and subsidiaries before the 1976 merging with Sandoz.

TABLE f :Northrup King 1970-74 total revenues (thousands $)

years:	1970	1971	1972	1973	1974
t.rev:	61,786	71,946	83,711	110,567	153,610

FUNK SEEDS

Funk (F) started in the 1900's as a family seed business selling oats and open pollinated varieties of corn; it was purchased by Corn Products Corporation (CPC) in 1962. F expanded to Italy, France, South Africa, Brazil and Argentina trying to develop a high oil corn variety without too much success. CPC sold F in the early 1970's. Ciba-Geigy (CG), the Swiss based pharmaceutical and chemical firm, with facilities in more than fifty countries, purchased F in 1974, and Stewart Seeds, a Canadian company.

F/CG International has plant breeding programs in Canada, Argentina, Brazil, and more recently in Mexico and Thailand. The major seed activities are in hybrid corn and sorghum, although they work with soybeans and cotton also. In most of the countries that F/CG is operating ,agricultural chemicals entered the market a few years ahead of the seed operations. Funk total sales in 1983 were reported to be approximately $25 million.

AGRIGENETICS, INC.

Ag is the third largest independent seed company in the U.S., and sixth overall in seed sales, following Pioneer, Dekalb, Northrup-King, Funk and Asgrow. Reported sales for 1981 were over $80 million, and over $88 M for 1983. Ag is involved in genetic engineering and microbial products research besides seed breeding and sales. Since the early 1970's, Ag has expanded buying nine seed companies, producing seeds of grasses, vegetables, hybrid corn and sorghum, soybeans, and alfalfa.

Ag is focusing its efforts on genetic engineering research. The international seed business include sales of hybrid corn and sorghum in Mexico through a

APPENDIX 2: LIST OF SEED COMPANIES AND ACQUISITIONS.

Table 2.1
U.S. Seed Trade Subsidiaries

The following list is an incomplete listing of parent companies and subsidiaries engaged in the seed industry. Where known, the home country of the parent company, and state and approximate date of acquisition are included in brackets.

Agrigenetics (MN-USA) - a genetic engineering concern
- Agricultural Laboratories (OH)
- Arkansas Valley Seed (CO)
- Colorado Seeds (CO)
- Jacques Seeds (WI-1980)
- Keystone Seeds Co. (CA-1980)
- Seed Research Assoc. (KS-1980)
- Sun Seeds (MN-1979)
- Taylor-Evans (TX-1980)
- VR Seed (IN)
- R.C. Young, (TX)
- McCurdy Seed (IA-1981)
- Growers Seed Assoc. (TX-1981)

American Garden Products (AMFAC) (USA) - sugar concern linked to Gulf & Western
- Henry Field Seed & Nursery (IA-1971)
- Gurney Seeds (SD-1968)
- Western Seed Co. (MT-1971)

Archer-Daniels-Midland (USA) - a major grain company
- Farmer City Grain (IL-1979)

Atlantic-Richfield (USA) - a major petroleum enterprise
- Dessert Seed Co. (CA-1980)

Geo. J. Ball (IL-USA) - a seed concern
- Ball Seed Co. (IL)
- Denholm Seeds (CA)
- Pan-American Seeds (IL)
- Petoseed (CA)

Barenburg Holland B.V. (Netherlands) - Dutch seed company
- Mt. Emily Seeds (USA-1979)

Bayer AG
- Helena Chemical Co. (TN)

Beatrice (USA) - a major food conglomerate
- Dahlgreen Seeds (MN-1972)

Cargill (MN-USA) - a major grain company
- ACCO Seeds (IA-1980)
- Cargill Hybrid Seeds (MN)
- Dorman Seeds
- Kroecker Seeds (1979)
- P-A-G Seeds (MN-1971)

Celanese (USA) - a chemical conglomerate
- Celprill Inc. (1975)
- Joseph Harris Seed Co. (NY-1978)
- Moran Seeds (CA-1974)
- Niagara Farm Seeds (1980)

Central Soya (USA) - food processing enterprise
- O'a Gold Seed Co. (IA-1977)

Ciba-Geigy (Swiss) - a pharmaceutical concern
- Columbiana Farm Seeds (IL-1973)
- Funk Seed Int'l. (IL-1976)
- Louisiana Seed Co. (LA-1979)
- Stewart Seeds (IN-1974)

Claeys Luck (France)
- Neuman Seeds (CA-1980)

DeKalb Ag Research (IL-USA) - seed/petroleum enterprise
- Ramsay Seed (CA-1980)

International Multifoods (USA) - food processing concern
- Baird Inc. (1976)
- Gilderaleeve Seed Co. (IL-1977)
- Lynks Bros. Seed (IA-1976)

International Telephone & Telegraph (USA) - telecommunications conglomerate
- W. Atlee Burpee Seeds (PA-1978)
- O.M. Scott Seeds (OH-1964)

Kleinwanzlebener Saatzucht (KWS) AG - German Seed Conglomerate
- Cokers Pedigreed Seed (SC-1977)

Kent Food (USA)
- Americana Seed Co. (IA-1973)
- L. Wm. Tewles Seed Co. (WI)

Limagrain (France) - cooperative seed company
- Ferry-Morse (CA-1981)

Monsanto
- DeKalb Ag Research Inc. (hybrid wheat program only) (1982)
- Jacob Hartz Seed Co., Inc. (AR-1983)

Occidental Petroleum (USA) - large petro-chemical concern
- East Texas Seed Co. (TX-1973)
- Excel Hybrid Seed (1972)
- Missouri Seed Co.
- Moss Seed Co. (1972)
- Payne Bros. Seed (1973)
- Ring Around Products (AL-1978)
- Stull Seeds (1975)
- West Texas Seed Co. (TX-1975)

Olin Corporation (USA) - chemical enterprise (with Royal Dutch/Shell)
- North American Plant Breeders (NAPB) (KS-1973)

table 2.2

Main International Seed Companies

Rank	Private enterprise	Home state	Parent industry	Total sales (US $ millions)	Seed sales (US $ millions)	Seed firms* Direct	Seed firms* Indirect	Number of crops	Number of var.	Number of states
A	Royal Dutch/Shell	Anglo/Dutch	Petrol	82,291	650	68	3	55	83	76
	Pioneer Hi-Bred	USA	Seed	557	557	27	2	6	55	16
	Sandoz	Switzerland	Chemical	2,946	319	34	—	12	172	13
	Cardo	Sweden	Agro-Ind.	440	285	25	5	18	108	7
	Dekalb-Pfizer	USA	Seed/Chem.	—	187	29	1	8	142	20
	Ciba-Geigy	Switzerland	Chemical	7,061	107	19	7	9	76	14
B	Upjohn	USA	Chemical	1,828	139	10	1	13	52	7
	Cargill	USA	Agro-Ind.	15,000	—	11	—	6	47	5
	Suiker Unie	Netherlands	Agro-Ind.	353	100	15	1	12	72	7
	Svalöf	Sweden	Seed	—	—	7	3	16	82	3
	Clays-Luck**	France	Seed	155	135	5	—	—	—	6
	Kleinwanzelbener Saat.	F.R.Germany	Seed	80	80	26	1	14	125	11
	Cebeco-Handelsraad	Netherlands	Agro-Ind.	—	—	7	—	13	85	7
	Florimond-Desprez	France	Seed	—	—	1	4	10	44	3
	Limagrain	France	Seed	130	130	22	—	8	41	8
	UNCAC	France	Agro-Ind.	—	—	6	—	12	32	2
	De Danske Sukkerfabrikker	Denmark	Agro-Ind.	400	—	10	—	6	43	8

* Direct=a subsidiary.
Indirect=a company of which the senior enterprise has a contractual relationship which may or may not include equity interest.
** There are some indications that a significant share of the Clays Luck equity is now in the hands of public and private French corporations.

(Source:P.R.Mooney, The Law of the Seed:96)

TABLE 2.3 -Continued

MAJOR NON U.S. BASED FIRMS ENGAGED IN SEED PRODUCTION AND/OR DISTRIBUTION[1]

Home Country	Parent Firm/ Seed Subsidiary	Principal Seed Crops Marketed	Major Seed Markets	Net Sales of Parent Firm Million US$	Percentage Seed Sales	Non-Seed Activities of Parent Firm/Observations
France (cont'd)	Limagrain (Cooperative)	hybrid maize	E. & W. Europe N. America, Md. East	...	80+	
	Inode Comm (Fr)					
	Genest S.A. (Fr)	forages, vegetables				
	Hain Angevin (Fr)	corn				
	Halcentre (Fr)	corn				
	Peromin Semences S.A. (Fr)	grasses				
	Dinamilho (Fr)					
	Limagrain do Brasil (Br)	corn				
	Loras Graines (Fr)	grasses, forages				
	Jarrygrain S.G.E.A. (Fr)					
	L. ry-Morse Seed Co. (US)	hybrid corn and sorghum vegetables				
	Tezier Graines	beans, vegetables	W. Europe	...	25	grain production/marketing
	Graines Tezier Maroc (Morrocco)	broad beans, peas				
	Tezier Italia (It)	tomatoes				
Fed.Rep.Germany	Kleinwanzlebener Saatzucht AG (KWS)	sugar beets, grasses hybrid corn	W. Europe, U.S., Can.& S. Am., Md. East	63	80+	feed milling
	Betaseeds (Can/US w. Sandoz)	grain seeds				
	F. von Lochow-Petkus (Fed. Rep. Ger)	cereal seeds				
	Intersaat A.G. (Switz)					
	Indusem (Panama)					
	Jaensch-Peragis Rubenzucht (F.R. Ger)	mangel (fodder beets)				
	KWS Seeds (US)					
	H. Van Waveren Pflanzenzucht (Neth)	vegetables				
	Mc Connell Nurseries (Can)	ornamental tree seeds				
	Ragis K & H Gabil (F.R. Ger)	potatoes				
	Terra-Pflanzenzucht (F.R. Ger)					
	Tohum Islahve Uretma A.S. (Turk)	sugar beets				
Italy	Societa Italiana Per L'Industria Degli Zuccheri (S	sugar beets	S.Europe	150	5	sugar/sugar products

TABLE 2.3 Continued

MAJOR NON-U.S.-BASED FIRMS ENGAGED IN SEED PRODUCTION AND/OR DISTRIBUTION[1]

Home Country	Parent Firm/ Seed Subsidiary	Principal Seed Crops Marketed	Major Seed Markets	Net Sales of Parent Firm Millions US$	Seed Sales	Non-Seed Activities of Parent Firm/Observations
Netherlands (cont'd)						
	Cooperative Vereniging Suiker Unie	sugar beets	W. Europe	300	10	sugar milling/sugar/ sugar products/observations
	D.J. Van der Have (Neth)	grasses				
	Hammerstein International (Neth)	forages				
	J.E. Ohlsens Enke (Den)	vegetables, flowers				
	Ostergards Frøele (Den)					
	Ceres (Fr)	sugar beets				beer, soft drinks and wine/ fast food outlets/grains
New Zealand	Lion Breweries Ltd. Canterbury Seed Co. Ltd.		Pacific Region	256	1	
			W. Europe, N. America	n/a	10	investments
Sweden	Cardo Group					
	Hillesholeg Fro A.B. (Swe)	sugar beets				
	W. Wulbull A.B. (Swe)	cereals, flowers				
	Dippe Gebruder Saatzucht (F.R. Ger)	sugar beets				
	International Forest Seeds (US)	forest seeds				
	Graines France Suedoise S.A. (Fr)					
	Hilin Masters Group (UK)	grasses, cereals				
	B.V. Hollandsche Z. Zaat (Neth)					
	Kemanobel		W. Europe	n/a	25	chemicals/plastics/ consumer goods
	Barnagen (Swe)					
	Claber S.p.A. (It)					
	Dom Samen Fehlemann K.G. (Austria)					
	Dom Samen Ges mbH (F.R. Ger)	vegetables				
	Dom Sementi (It)					
	Graines d'Alsace S.A.R.L. (Fr)	small grains				
	R & G Cuthbert (UK)					
Spain	Compañia de Industrias Agrícolas S.A.	sugarbeets	S. Europe	179[a]	5	sugar and sugar products beet pulp/ yeast products/ alcohol

TABLE 2.3-Continued

MAJOR NON-U.S.-BASED FIRMS ENGAGED IN SEED PRODUCTION AND/OR DISTRIBUTION[1]

Home Country	Parent Firm/ Seed Subsidiaries	Principal Seed Crops Marketed	Major Seed Markets	Net Sales of Parent Firm Millions US$	Seed Sales	Non-Seed Activities of Parent Firm/Observations
United Kingdom	Dalgety	vegetables, cereals pulses, grasses	W. Europe, Austr.	4,100	<1	holding co./general agents/ wholesalers
	Dekalb Shand Pty. (50% w. Dekalb-Aust.)	hybrid corn				
	Dalgety & New Zealand Loan Ltd. (NZ)	grasses				
	Rank-Hovis-McDougall (RHM)		W. Europe	3,300	5	manufacturing/food products
	British Hybrid Cereals (UK)	cereals				
	Byford Group (UK)					
	Christopher Hill Group (UK)					
	RHM Agriculture (Caledonia) Ltd. (UK)					
	RHM Agriculture (Dalbeattie) Ltd. (UK)					
	RHM Agriculture (Mid Calder) Ltd. (UK)					
	Curtis Hoody Ltd. (UK)					
	Simmons Watts Ltd. (UK)					
	Whittons & Curtis Ltd. (UK)					
	Brooks Hasler (UK)					
	RHM Agriculture (Northwest) Ltd. (UK)					
	Radnorshire Co. Ltd. (UK)	wheat				
	Griffiths & Hartland Ltd. (UK)					
	R. Townsend & Co. (UK)					
	Rawlings, James & Phillips Ltd. (UK)					
	Fulford Trumps & Co. Ltd. (UK)					
	John Irwin Ltd. (UK)					
	RHM Arable Services Ltd. (UK)					
	RHM Agricultural Industries Ltd. (UK)	grasses, cereals				
	Guinesses (UK)					
	J.Bibby and Sons Ltd.			300+	10	poultry, turkey and meat products/animal feeds/ farm products/edible oils.
	Twyford Seeds Ltd.					

TABLE 2.4

MAJOR U.S.-BASED FIRMS ENGAGED IN SEED PRODUCTION AND/OR DISTRIBUTION

Parent Firm/U.S. Seed Subsidiaries	Principal Seed Crops Marketed	Net Sales of Parent Firm, 1981 (million US $)	Seed Sales as Percentage of Total	Principal non-seed activities of Parent Firm	Observations
MAJOR INDEPENDENT SEED COMPANIES					
Agrigenetics Inc.		80	80+	genetic engineering and microbial research	recent entry through acquisition of several regional seed companie
Arkansas Valley Seeds	grasses				
Keystone Seeds	vegetables				
McCurdy Seed Co.	hybrid corn and sorghum				
R.H. Young seeds	hybrid sorghum				
Sunseeds	vegetable				
Taylor-Evans Seed Co.	hybrid corn and sorghum				
Colorado Seeds	cereals and alfalfa				
V.N. Seeds	soybean, sorghum, farm seeds				
Jacques Seeds	hybrid corn sorghum, soybeans, alfalfa				
DEKALB AgResearch, Inc.		546	39	oil and gas exploration/ livestock marketing and brokerage	earnings from natural resources more than doubled those of seed in 1981
(10 non-U.S. Seed Subsidiaries and Associates	hybrid corn and sorghum sunflowers, alfalfa				
Pioneer Hi-Bred International (10 Int'l Seed Subsidiaries)	hybrid corn and sorghum soybeans, forages, cotton	478	94	electronic data systems	leader in hybrid corn market with 33 percent share

A. Independent companies with annual seed sales in excess of US$ 50 million

Source: Goodman et. al, 1982.

TABLE 2.4 Continued

MAJOR U.S.-BASED FIRMS ENGAGED IN SEED PRODUCTION AND/OR DISTRIBUTION

arent Firm/U.S. Seed Subsidiaries	Principal Seed Crops Marketed	Net Sales of Parent Firm, 1981 (million US $)	Seed Sales as Percentage of Total	Principal non-seed activities of Parent Firm	Observations
elanese		3,146	<1	Textiles/chemicals/fibers/ plastic consumer goods	
Celpril, Inc.					
Joseph Harris Seed Co.	vegetables, grasses				
Moran Seeds	vegetables				
Nugrain					
entral Soya		1,744	<1	Grain merchandising/ oilseeds processing/ poultry/animal feeds	
O's Gold Seed Co.	hybrid corn and sorghum grasses				
ontinental Grain Co.		10,000[c]	<1	grain trading & brokerage/ animal feeds/poultry processing/baking	World's second largest grain trader
Hannas, Hanson and Hanger (Can)					
Pacific seeds (Austria)[g]					
Golden Acres (Austria)[g]					
iamond Shamrock Int'l		3,143	<1	Chemicals/oil and gas products/nutrition and health products	
Golden Acres Hybrid Seed Co.	Hybrid corn				

TABLE 2.4-Continued

MAJOR U.S.-BASED FIRMS ENGAGED IN SEED PRODUCTION AND/OR DISTRIBUTION

Parent Firm/U.S. Seed Subsidiaries	Principal Seed Crops Marketed	Net Sales of Parent Firm, 1981 (million US$)	Seed Sales as Percentage of Total	Principal non-seed activities of Parent Firm	Observations
Occidental Petroleum		12,500	<1	crude oil production/chemicals/coal & phosphate mining	
Ring-Around Products	hybrid corn & sorghum grasses, soybeans				
Excell Hybrid Seeds	hybrid cereals				
Missouri Seed Co.	wheat				
Horn Seed Co.					
Payne Bros. Seed Co.					
Stull Seeds					
East Texas Seed Co.					
West Texas Seed Co.					
Olin Corp.		1,800[a]	5	chemicals/metals/cellophane/sports equipment/homebuilding	
Rudy Patrick Seed Co.					
Olin Plant Breeders	cereals, barley				
Agripro	soybeans				
H.P. Hybrid					
Midwest Seed Growers					
North American Plant Breeders[9]	grasses, vegetables				
Tekseed Hybrid Co.[9]	hybrid corn & sorghum				
Pfizer Inc.		2,740	<1	pharmaceuticals/consumer products	
Pfizer Genetics	cereals				
Clemens Seed Farm					
Jordan Wholesale Co.					
Rojan Seed Co.	hybrid corn				
Warwick Seeds (Canada)	hybrid corn				

APPENDIX 3: GENERAL DATA

Table: 3.1 . Index Numbers (1977=100) of Prices Paid by Farmers, 1970-1983.

	All inputs	Seeds	Feed	Fertilizer	Chemicals	Mach.
1970	54	43	54	48	62	49
1972	61	52	57	52	65	54
1974	83	82	104	92	76	68
1976	97	92	103	102	111	91
1978	108	105	98	100	94	109
1980	138	118	123	134	102	136
1983	153	141	134	137	125	174

Source: USDA Statistics 1984.

Appendix Table 3.3. Plant Breeding and Research Expenditures at Public Plant Breeding Institutions 1970-79.

	Plant Breeding & Genetic Research Expenditure ($M)	Total Expenditures on Research ($M)	% PB & G Res. Exp. of Total	Source of Plant Breeding & Genetic Research		USDA as % of Total P.B.&G. Exp.
				USDA ($M)	State ($M)	
1970	32.2	281.8	11.63	12.9	19.3	40
1971	34.1	299.8	11.37	13.4	20.6	39
1972	36.3	356.0	10.20	13.7	22.4	38
1973	40.3	384.6	10.48	15.1	25.1	37
1974	43.9	423.9	10.36	15.6	28.2	36
1975	49.1	482.2	10.18	17.4	31.6	35
1976	57.6	517.0	11.14	19.9	37.3	35
1977	63.7	594.2	10.72	22.1	41.1	35
1978	70.9	648.9	10.93	23.9	46.4	34
1979	79.8			26.3	52.5	33

Source: Butler and Marion.

Table: 3.5. Percent of Total Soybean Acreage Harvested Planted by Major Private and Public Breeders, 1980.

Major Private Breeders	Percent
Northrup King	2.0
Asgrow	1.8
Pioneer	1.4
North American Plant Breeders	1.4
Ring Around Products	1.0
Total Major Private	7.6
Major Public Breeders	**Percent**
Univ. of Illinois	20.5
Mississippi State	16.6
Iowa State	8.4
Others Public	24.7
Total Major Public	70.2

Source: Butler and Marion, 1983.

Table: 3.7

U.S. Seed Trade, 1965-1984
Quantity (MT) and Value ($1000) exported (X) and imported (M) by type of seed

Kind of Seed		1965		1970		1975		1980		1984	
		Q	TV	Q	TV	Q	TV	Q	TV	Q	TV
Grain	X	3,476	2,376	78,775	17,598	72,707	36,624	80,260	58,507	217,642	146,718
	M	-	-	40,398	3,281	20,123	13,553	7,870	6,427	48,246	30,385
Forage	X	14,429	10,687	32,636	21,870	36,023	43,839	48,795	74,866	92,614	73,144
	M	23,667	10,542	26,954	11,687	20,221	16,275	21,478	18,178	18,400	17,555
Vegetables	X	-	-	3,359	10,481	4,702	27,536	38,411	81,277	17,110	99,499
	M	65,946	3,957	51,681	6,717	27,473	11,824	35,346	25,073	12,508	34,827
Other	X	-	-	4,765	3,710	4,899	8,218	32,295	30,453	35,226	46,280
	M	113	1,052	719	1,503	425	4,189	2,901	8,579	18,364	21,773
Total	X	22,905	13,063	119,535	53,659	118,331	116,217	199,762	235,103	362,592	365,641
	M	89,726	15,551	119,752	23,188	68,242	45,841	67,595	58,257	97,518	104,540

Source: USDA/FATUS Fiscal years statistical reports

Table: 3.8a

U.S. Seeds Exports by Type of Seed, 1950-1984.
(Quantity: MT; Value: $1000)

Fiscal Year		Forage	Vegetables	Grain	Others	Total
Avg. 1950-1954	(Q)	10,488	1,670	17,131	84.4	26,273
	(TV)	6,557	2,466	1,790	394	11,207
Avg. 1955-1959	(Q)	18,597	1,987	16,008	108	36,701
	(TV)	10,432	3,345	3,012	571	17,360
1960	(Q)	28,630	2,107	16,461	148	47,341
	(TV)	12,750	4,244	2,815	728	20,537
Avg. 1960-1964	(Q)	26,928	2,675	17,131	151	46,886
	(TV)	13,571	5,302	3,299	781	22,953
1965	(Q)	28,734	2,865	14,845	2,963	49,408
	(TV)	15,569	6,094	3,531	2,557	27,856
1970	(Q)	32,432	4,882	51,360	17,626	106,301
	(TV)	21,814	11,666	13,669	6,814	53,963
1975	(Q)	36,033	6,359	37,429	19,965	99,787
	(TV)	43,838	30,045	22,246	16,886	113,116
1980	(Q)	48,795	38,411	80,260	32,295	199,762
	(TV)	74,866	81,277	58,507	20,453	235,102
1984	(Q)	92,614	17,110	217,642	35,226	362,592
	(TV)	73,144	99,499	146,718	46,280	365,641

Source: USDA Foreign Agricultural Reports

Table: 3.10

U.S. Corn Seed* Exports, 1950-1983
(Quantity: MT . Value: $1000 (a). WQ & WV is Change in Quantity and Value in percentage)

Period	Q	V	WQ	WV
1950 - 1954	6066	1292		
1955 - 1959	10703	2546	43	49
1960 - 1964	6847	1861	-56	-37
1965 - 1969	13572	3222	50	42
1970 - 1974	18540	4931	27	35
1975 - 1979	13727	11029	-35	55
1980 - 1983	15389	19460	11	57

Source: USDA/Foreign Agricultural Circulars

* except sweet corn

(a) deflated by CPI (1967=100)

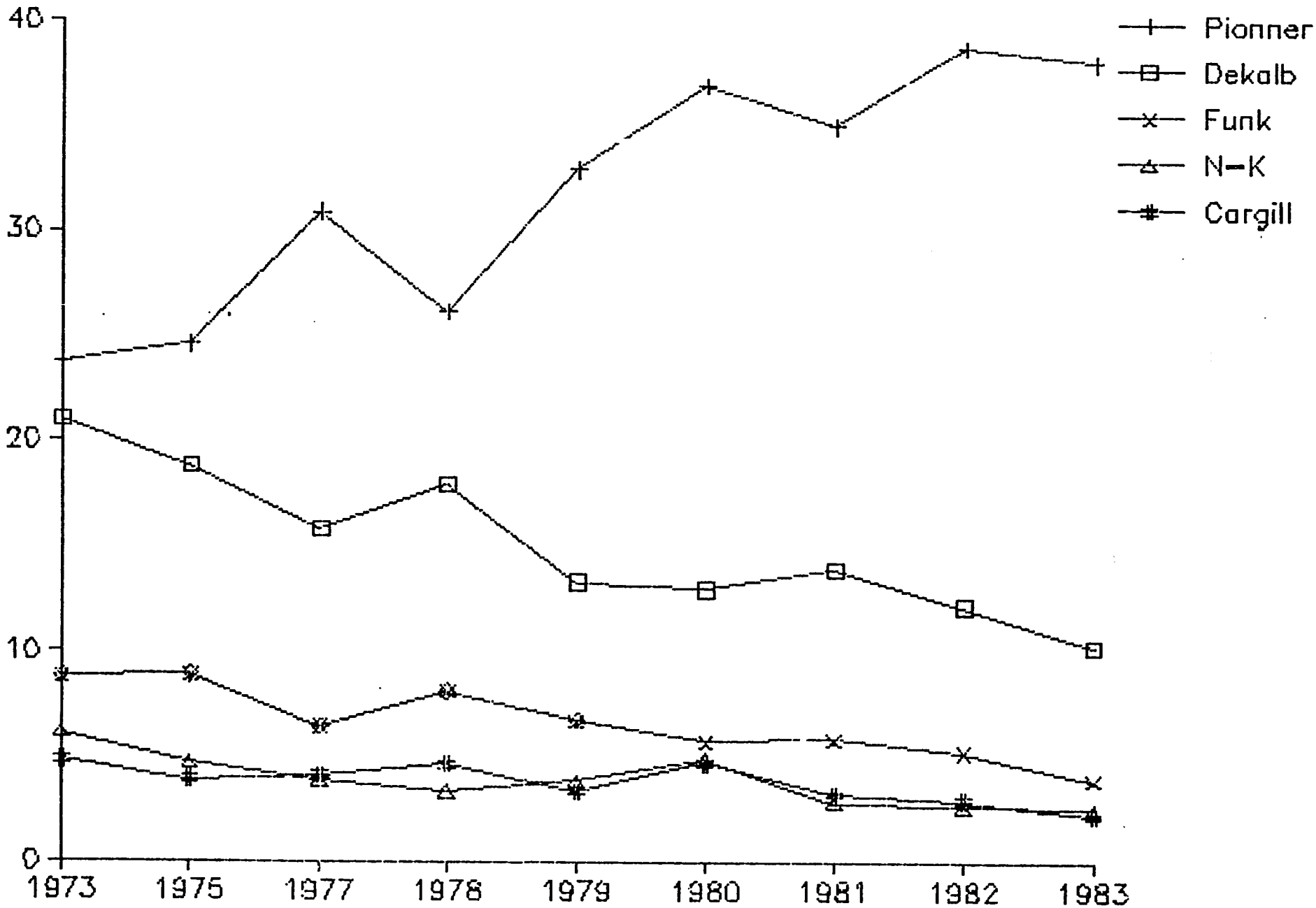

FIGURE 3.11. U.S. CORN MARKET SHARE, IN PERCENTAGE.

Table: 3.13

World Rice Production, 1960-1983

		1960	1965	1970	1975	1980	1983
WORLD	P	239.5	254.2	306.8	348.6	399.8	449.8
	A	119.5	125.5	135.5	141.1	145.4	144.5
	Y	20.0	20.3	22.6	24.5	27.5	31.1
EUROPE	P	1.4	1.3	1.9	1.9	1.8	1.7
	A	0.3	0.3	0.4	0.4	0.4	0.3
	Y	41.1	40.6	48.4	51.2	48.9	50.8
N&C AMERICA	P	3.5	4.5	5.4	7.7	8.7	7.0
	A	1.3	1.3	1.5	2.0	2.1	1.6
	Y	27.4	33.7	36.6	39.4	40.3	42.4
S. AMERICA	P	7.0	9.8	10.5	11.7	14.4	12.4
	A	3.9	5.6	5.6	6.4	7.5	6.3
	Y	18.1	17.6	18.7	18.1	19.2	19.5
ASIA	P	137.8	143.4	180.1	317.0	362.9	417.1
	A	79.4	83.8	90.6	128.2	129.6	130.5
	Y	17.3	17.1	19.9	24.7	28.0	32.0
AFRICA	P	4.5	5.4	7.5	7.8	8.4	8.5
	A	2.9	3.1	3.9	4.5	4.9	4.9
	Y	15.5	17.2	19.4	17.4	17.1	17.4
OCEANIA	P	0.1	0.2	0.3	0.4	0.6	0.5
	A	-	-	-	0.1	0.1	0.1
	Y	35.0	48.9	53.3	47.5	48.1	57.7

P: Million Tons
A: Million Ha
Y: 100kg/Ha

Source: FAO Production Yearbooks

Table: 3.15

World Sorghum Production, 1960-1983

		1960	1965	1970	1975	1980	1983
	P	26.3	29.8	44.2	52.1	58.4	62.5
WORLD	A	26.7	30.6	37.8	43.8	46.7	46.5
	Y	9.9	9.7	11.7	11.9	12.5	13.4
	P	0.05	0.19	0.39	0.5	0.6	0.5
EUROPE	A	0.04	0.08	0.13	0.2	0.2	0.2
	Y	12.5	24.4	30.8	33.3	36.5	32.9
	P	14.7	12.5	20.4	22.8	20.1	19.2
N&C AMERICA	A	6.3	4.8	6.8	7.9	7.1	6.3
	Y	23.3	25.8	29.9	28.7	28.2	30.2
	P	0.32	1.8	4.3	6.1	4.3	9.5
S. AMERICA	A	0.36	1.4	2.2	2.4	2.0	3.1
	Y	8.6	12.9	19.5	24.8	20.9	30.0
	P	8.4	10.3	10.5	11.9	22.2	23.2
ASIA	A	17.4	18.8	19.5	18.9	22.1	20.9
	Y	4.8	5.5	5.4	6.3	10.0	11.1
	P	2.5	4.7	8.0	9.8	10.3	9.0
AFRICA	A	2.4	5.3	8.8	13.7	14.6	15.0
	Y	10.4	8.9	9.2	7.1	0.7	5.9
	P	0.2	0.2	0.6	0.9	0.8	1.0
OCEANIA	A	0.1	0.1	0.4	0.5	0.5	0.7
	Y	19.8	13.9	14.4	17.6	14.1	14.2

A: Million Ha
Y: 100kg/Ha
P: Million Tons

Source: FAO Production Yearbooks

Table: 3.17. Value of U.S. Seed Exports to Selected Countries, 1980-1984 ($1000)

	1980	1984
Canada	34,234	29,907
Mexico	31,688	59,648
Argentina	10,101	4,478
Colombia	3,013	4,277
Venezuela	8,892	6,127
Chile	1,301	3,350
Brazil	5,536	4,885
U. Kingdom	10,231	9,479
Netherlands	16,966	13,507
France	10,182	14,680
W. Germany	7,459	6,369
Italy	20,732	24,786
Greece	3,937	4,496
Sweden	1,289	4,366
Spain	6,522	748
S. Arabia	2,278	12,492
Japan	23,393	41,902
E&SE Asia	2,464	8,499
S. Korea	159	4,776
Australia	7,462	6,075
Egypt	974	4,374
S. Africa	1,954	4,904

Source: U.S.D.A.

TABLE 3.19.

SMPL 1 - 27

Series	Mean	S.D.	Maximum	Minimum
YIELD	3.7296296	2.2830167	8.8999990	1.0000000
SEED	1051.8519	2647.7839	11397.000	1.0000000
FERT	1220.0000	1080.1257	3486.0000	27.000000
RPC	42.237037	23.717539	123.00000	16.000000
SCOMP	9.4814815	17.376755	66.000000	1.0000000
ED	55.962963	22.072401	93.000000	16.000000
NPUBH	0.0281723	0.0339781	0.1529412	7.299D-04

	Covariance	Correlation
YIELD, YIELD	5.0191216	1.0000000
YIELD, SEED	855.38956	0.1469477
YIELD, FERT	1513.1556	0.6372218
YIELD, RPC	14.201123	0.2723544
YIELD, SCOMP	0.7820303	0.0204709
YIELD, ED	33.841836	0.6974060
YIELD, NPUBH	0.0249789	0.3343917
SEED, SEED	6751101.7	1.0000000
SEED, FERT	-59068.315	-0.0214481
SEED, RPC	28327.226	0.4684274
SEED, SCOMP	11188.257	0.2525234
SEED, ED	11091.791	0.1970879
SEED, NPUBH	8.9250431	0.1030194
FERT, FERT	1123461.7	1.0000000
FERT, RPC	2955.5073	0.1198060
FERT, SCOMP	-463.66667	-0.0256539
FERT, ED	7157.4815	0.3117645
FERT, NPUBH	15.158418	0.4289144
RPC, RPC	541.68752	1.0000000
RPC, SCOMP	-60.669681	-0.1528706
RPC, ED	69.671739	0.1382063
RPC, NPUBH	0.2413627	0.3110223
SCOMP, SCOMP	290.76818	1.0000000
SCOMP, ED	54.054870	0.1463548
SCOMP, NPUBH	-0.0994101	-0.1748448
ED, ED	469.14678	1.0000000
ED, NPUBH	0.0956136	0.1323918
NPUBH, NPUBH	0.0011118	1.0000000

TABLE 3.20.

obs	LANDQ	RAIN	SCOMP	RPC	NPM
1	101.0000	58.10000	30.00000	20.80000	68.00000
2	92.00000	36.90000	28.00000	53.90000	193.0000
3	108.0000	24.70000	1.000000	46.00000	330.0000
4	94.00000	25.10000	7.000000	49.00000	0.000000
5	62.00000	36.20000	60.00000	16.00000	160.0000
6	96.00000	33.10000	66.00000	33.40000	167.0000
7	64.00000	25.60000	2.000000	28.30000	161.0000
8	104.0000	23.90000	1.000000	51.50000	269.0000
9	115.0000	28.60000	14.00000	123.0000	497.0000
10	176.0000	48.60000	17.00000	36.40000	224.0000
11	100.0000	37.20000	7.000000	25.40000	139.0000
12	160.0000	95.80000	2.000000	35.00000	14.00000
13	172.0000	8.200000	2.000000	46.80000	0.000000
14	183.0000	61.00000	2.000000	23.60000	4.000000
15	171.0000	89.00000	5.000000	24.80000	52.00000
16	111.0000	22.50000	1.000000	27.00000	251.0000
17	204.0000	48.40000	1.000000	36.00000	0.000000
18	92.00000	18.90000	1.000000	36.50000	53.00000
19	98.00000	25.90000	1.000000	70.50000	4.000000
20	83.00000	41.40000	1.000000	30.90000	0.000000
21	136.0000	75.50000	1.000000	18.00000	36.00000
22	170.0000	9.200000	1.000000	42.40000	56.00000
23	81.00000	161.4000	1.000000	33.40000	70.00000
24	98.00000	23.90000	1.000000	43.30000	107.0000
25	95.00000	24.30000	1.000000	72.50000	52.00000
26	102.0000	32.10000	1.000000	26.00000	22.00000
27	88.00000	44.20000	1.000000	90.00000	19.00000

LandQ is land quality index
Rain is annual average precipitation, inches/year, in agricultural areas
SComp are the five major companies doing research in each country
Rpc is real price of corn measured in kgs of nitrogenous fertilizer (urea in most of the countries) that could be purchased with 100 kgs of corn equivalents, average 1977-1980.
Npm is number of maize publications in the period 1948-1968.

TABLE 3.21.

REGRESSION # 1

SMPL 1 - 27
OLSQ // Dependent Variable is LYIELD
27 Observations

	COEFFICIENT	STANDARD ERROR	T-STATISTIC
C	-1.4287781	1.0078773	-1.4176110
LSEEDH	0.0879664	0.0295168	2.9802193
LFERT	0.1473359	0.0797011	1.8486061
LSCOMP	0.0065318	0.0593824	0.1099950
LED	0.4910656	0.2062062	2.3814295
LNPUBH	0.0252848	0.0596951	0.4235660

R-squared	0.727537	Mean of dependent var	1.112275
Adjusted R-squared	0.662664	S.D. of dependent var	0.674076
S.E. of regression	0.391507	Sum of squared resid	3.218835
Durbin-Watson stat	2.325946	F-statistic	11.21491
Log likelihood	-9.59930		

T values are: 1.721 (P=0.01)
2.080 (P=0.05)
2.518 (P=0.10)

REGRESSION # 2

SMPL 1 - 27
OLSQ // Dependent Variable is LYIELD
27 Observations

	COEFFICIENT	STANDARD ERROR	T-STATISTIC
C	-1.8486675	1.2557101	-1.4722088
LSEEDH	0.0862272	0.0348903	2.4713788
LFERT	0.2103810	0.0890579	2.3620302
LSCOMP	0.0525006	0.0645867	0.8128698
LLR	0.4814693	0.2496378	1.9286718
LGRADH	0.0571042	0.0606977	0.9407964

R-squared	0.718811	Mean of dependent var	1.112275
Adjusted R-squared	0.651861	S.D. of dependent var	0.674076
S.E. of regression	0.397727	Sum of squared resid	3.321916
Durbin-Watson stat	2.086503	F-statistic	10.73658
Log likelihood	-10.02485		

TABLE 3.21.

REGRESSION # 3

SMPL 1 - 27
OLSQ // Dependent Variable is LYIELD
27 Observations

	COEFFICIENT	STANDARD ERROR	T-STATISTIC
C	-0.5798046	1.0143745	-0.5715883
LSEEDH	0.0833979	0.0264132	3.1574351
LFERT	0.0736861	0.0784124	0.9397256
LED	0.3255259	0.2034050	1.6003833
DUMMY	0.3926571	0.2080662	1.8871738

R-squared	0.763487	Mean of dependent var	1.112275
Adjusted R-squared	0.720485	S.D. of dependent var	0.674076
S.E. of regression	0.356378	Sum of squared resid	2.794118
Durbin-Watson stat	2.346614	F-statistic	17.75458
Log likelihood	-7.689019		

values are: 1.717 (P=0.01), 2.074 (P=0.05), 2.508 (P=0.10)

REGRESSION # 4

OLSQ // Dependent Variable is LYIELD
27 Observations

	COEFFICIENT	STANDARD ERROR	T-STATISTIC
C	1.1512380	0.1473028	7.8154504
LSEEDH	0.1022674	0.0245601	4.1639724
DUMMY	0.6047231	0.1666636	3.6284066

R-squared	0.731151	Mean of dependent var	1.11227[illegible]
Adjusted R-squared	0.708747	S.D. of dependent var	0.67407[illegible]
S.E. of regression	0.363784	Sum of squared resid	3.17613[illegible]
Durbin-Watson stat	2.090347	F-statistic	32.6347[illegible]
Log likelihood	-9.41901		

T values are: 1.711 (P=0.01), 2.064 (P=0.05), 2.492 (P=0.10)

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Residual Plot - REGRESSION # 5

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Residual Plot
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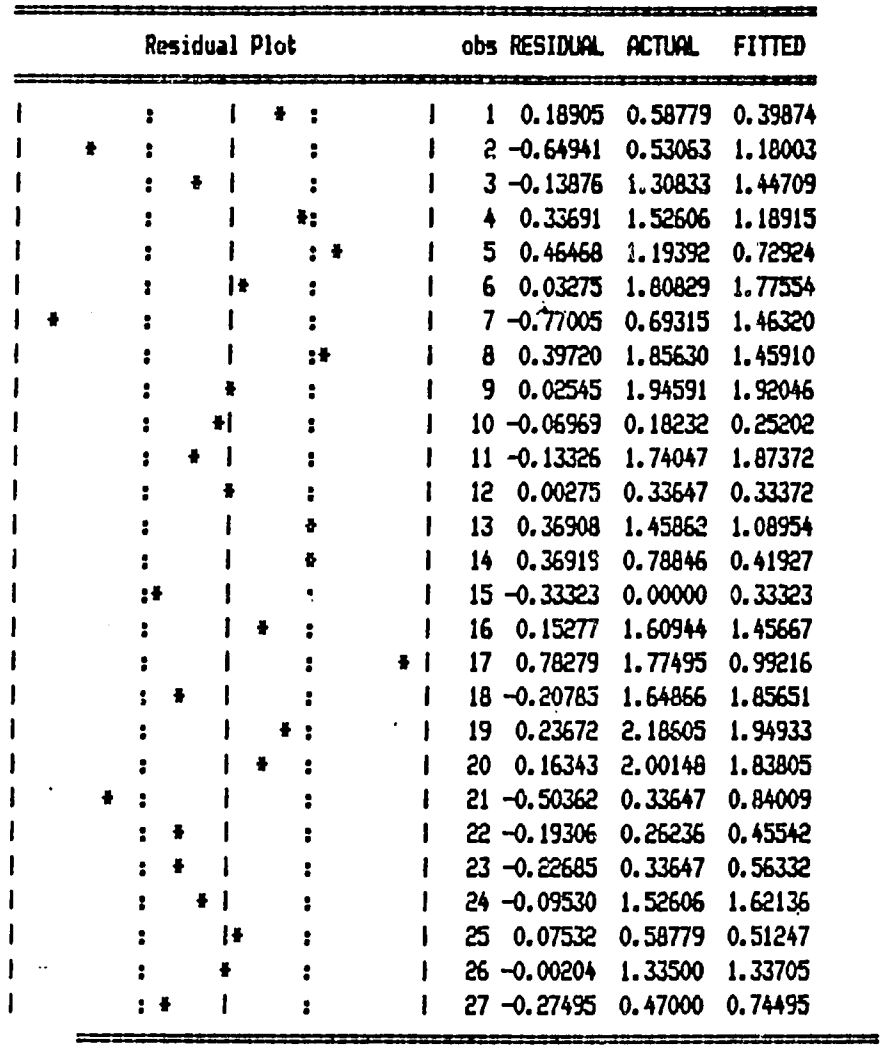

obs	RESIDUAL	ACTUAL	FITTED
1	0.18905	0.58779	0.39874
2	-0.64941	0.53063	1.18003
3	-0.13876	1.30833	1.44709
4	0.33691	1.52606	1.18915
5	0.46468	1.19392	0.72924
6	0.03275	1.80829	1.77554
7	-0.77005	0.69315	1.46320
8	0.39720	1.85630	1.45910
9	0.02545	1.94591	1.92046
10	-0.06969	0.18232	0.25202
11	-0.13326	1.74047	1.87372
12	0.00275	0.33647	0.33372
13	0.36908	1.45862	1.08954
14	0.36919	0.78846	0.41927
15	-0.33323	0.00000	0.33323
16	0.15277	1.60944	1.45667
17	0.78279	1.77495	0.99216
18	-0.20785	1.64866	1.85651
19	0.23672	2.18605	1.94933
20	0.16343	2.00148	1.83805
21	-0.50362	0.33647	0.84009
22	-0.19306	0.26236	0.45542
23	-0.22685	0.33647	0.56332
24	-0.09530	1.52606	1.62136
25	0.07532	0.58779	0.51247
26	-0.00204	1.33500	1.33705
27	-0.27495	0.47000	0.74495

TABLE 3.23

obs	Y69/71	A69/71	Y59/61	A59/61
1	5.160000	23749.00	3.550000	27274.00
2	2.640000	10521.00	2.480000	9138.000
3	1.360000	10021.00	1.300000	6783.000
4	1.220000	7412.000	0.900000	6088.000
5	2.320000	3170.000	1.610000	3518.000
6	2.760000	3617.000	1.630000	11033.00
7	3.090000	2391.000	2.260000	2553.000
8	2.250000	3880.000	1.790000	2639.000
9	5.150000	1436.000	2.840000	847.0000
10	1.260000	5290.000	1.230000	3707.000
11	3.570000	1272.000	2.380000	1366.000
12	4.660000	986.0000	3.250000	1193.000
13	1.050000	5794.000	0.920000	4387.000
14	5.080000	490.0000	4.050000	189.0000
15	0.960000	2667.000	0.920000	2483.000
16	3.740000	634.0000	2.820000	678.0000
17	2.570000	771.0000	1.790000	267.0000
18	0.810000	2356.000	0.600000	1968.000
19	3.910000	623.0000	2.200000	668.0000
20	3.610000	413.0000	2.460000	550.0000
21	3.430000	526.0000	2.380000	427.0000
22	3.070000	162.0000	1.380000	194.0000
23	5.550000	122.0000	3.550000	52.00000
24	1.120000	671.0000	0.770000	640.0000
25	1.090000	640.0000	0.980000	485.0000
26	1.250000	684.0000	1.120000	692.0000
27	4.020000	127.0000	2.780000	185.0000
28	1.690000	373.0000	1.410000	251.0000
29	3.110000	70.00000	1.990000	74.00000
30	1.150000	606.0000	1.130000	356.0000

Y69/71 = Yield in mt/ha average 1969/1971
Y59/61 = Yield in mt/ha average 1959/1961

A69/71 = Area in 1000 HA average 1969/1971
A59/61 = Area in 1000 HA average 1959/1961

Obs. are 30 selected countries, see Section B.

Source: FAO Production Yearbooks.