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BIOTECHNOLOGY AND DEVELOPING COUNTRY AGRICULTURE: MAIZE IN THAILAND

by

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RÉSUMÉ

La culture du maïs est relativement récente en Thaïlande : la production a commencé à être commercialisée dans les années 50 ; depuis lors, elle occupe la deuxième place en surface cultivée et figure parmi les quatre principaux produits d'exportation agricole du pays. Le marché du maïs en Thaïlande connait d'importants changements. Sur le plan de l'offre, la production, qui a augmenté par conquête de nouvelles terres, sera diminuée dans l'avenir pour éviter la déforestation ; les terres actuellement en culture seront réduites. Sur le plan de la demande, les exportations, qui absorbaient encore récemment la plus grande partie de la récolte, voient leur avenir remis en question par l'augmentation rapide de la consommation intérieure pour l'alimentation du bétail. L'intensification de l'usage des engrais a permis d'atteindre de hauts rendements avec des variétés courantes de maïs. Cependant, ces engrais sont onéreux (le prix de l'azote représente environ six fois celui du maïs) et l'utilisation des engrais en Thaïlande, où les conditions de culture sont essentiellement pluviales, n'est pas sans risques.

La recherche publique sur le maïs en Thaïlande a fait une remarquable percée, au début des années 70, en réussissant à produire une nouvelle variété auto-fécondée - Suwan 1 - résistante au mildiou du maïs et donnant de meilleurs rendements. Depuis lors, ces variétés améliorées - SW 1 d'abord puis des hybrides - ont été adoptées par un nombre croissant d'agriculteurs. L'amélioration de la production nécessite la mise au point de nouveaux hybrides adaptés aux micro-climats de la Thaïlande. Cet objectif implique la coordination des ressources affectées à la recherche et un développement accru du secteur privé. Les capacités limitées de croissance du marché restent cependant le principal obstacle à l'investissement, tout particulièrement pour les entreprises étrangères de semences, dans la recherche privée en Thaïlande.

SUMMARY

Maize is a relatively new crop in Thailand, but since commercial production began in the 1950s it has become the second most important crop in terms of planted area and one of the country's top four agricultural exports. Major changes are occurring in the maize market in Thailand. On the supply side, increased production through land expansion will be curtailed in the future to prevent further destruction of forest areas and the area under cultivation actually reduced. On the demand side, until recently most maize was exported, but the rapid increase in domestic demand for livestock feed brings the future of exports into question. Higher yields could be achieved with current maize varieties through the increased application of fertilizer. However, not only is fertilizer expensive (the price of nitrogen is about six times the price of maize): there are also risks involved in applying fertilizer in Thailand's mainly rain-fed production conditions.

Public sector maize research in Thailand achieved a major breakthrough in the early 1970s by incorporating downy-mildew resistance, together with higher yields, in a new open-pollinated variety, Suwan 1. Since then improved varieties,

first SW 1 and later hybrids, have been adopted by a growing number of producers. If production targets are to be met, it will be necessary to produce new hybrids for Thailand's particular agro-climatic conditions. This will imply coordination of research resources and an expanded role for the private sector. However, the limited growth potential of the market is a major obstacle to private sector research investment in Thailand, especially for foreign seed companies.

PREFACE

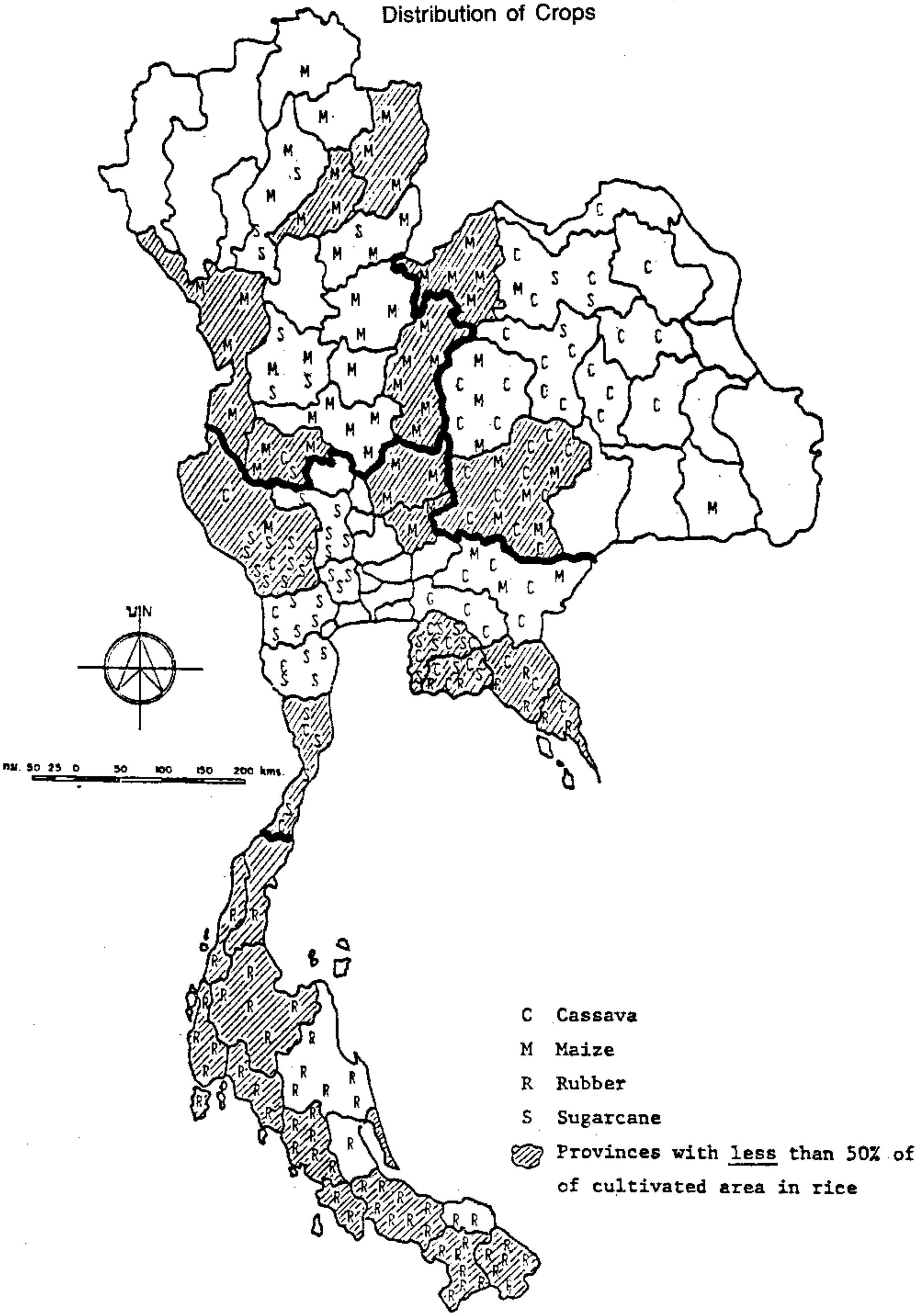
This case study of Thailand has been undertaken as part of a research project on "Biotechnology and Developing Country Agriculture: the Case of Maize", carried out in the context of the Development Centre's research programme on "Changing Comparative Advantages in Food and Agriculture". The project, which assesses the prospects for selected developing countries of incorporating new biotechnologies in maize production and, by implication, enhancing their competitiveness, focuses on the institutional aspects of technological change.

Maize was selected as an eminently suitable subject for examining how new technological developments in industrialised countries "interact" with the situation in developing countries. One of the world's major cereal crops, in many developing countries maize is an important food and/or feed crop for which demand continues to expand, particularly for use as livestock feed. Maize is also a crop on which major biological research effort has been focused. This effort resulted in the innovation of hybridization in the 1930s and shows promise with respect to new biotechnologies.

Suthad Setboonsarng has contributed this case study of Thailand, one of the few developing country exporters of maize. It traces production and consumption trends, examines Thailand's maize research, technology development and diffusion system and discusses the technological problems to be confronted in keeping pace with rapidly-increasing domestic demand. In addition to the case of Thailand, the project includes case studies of Brazil, Indonesia and Mexico. It also analyses trends in research on the emerging maize biotechnologies, and in the supply, demand and trade of maize internationally. The country studies, together with the analysis of technology trends (entitled "Emerging Maize Biotechnologies and their Potential Impact") are all being published in this Technical Papers series. The conclusions and policy implications to be drawn from the project will be published by the OECD in a separate volume by Carliene Brenner.

Louis Emmerij
President of the OECD Development Centre
May 1990

THAILAND
Distribution of Crops



I. INTRODUCTION AND BACKGROUND

Maize is a relatively new crop in Thailand. Commercial production began only in the early 1950s. Almost all production then was exported for use as animal feed. The increase in production and exports has made it one of Thailand's major crops over the past two decades. Since the mid-1970s, rapid expansion of the poultry and compound feed industry has driven up domestic demand. If demand continues to expand, Thailand will be importing maize in the 1990s.

In the past, the apparent source of growth was expansion of land area. But the road system, maize research and cheap fuel also contributed significantly. The land frontier has been exhausted and the government is planning to control maize production in high slope areas to prevent soil erosion. Future expansion of maize production will depend mainly on increasing productivity of the land. There is immense interest in the potential of maize technology in Thailand.

This paper aims to describe the maize research system in Thailand and explore its potential for meeting future production requirements. The possibilities of and obstacles to applying biotechnology to maize research in Thailand are also discussed.

Before considering maize research, agro-ecological conditions, maize production and its utilization are described.

A. Agro-ecological Conditions and Maize Cultivation

1. Regional characteristics

Thailand's 51 million hectares can be divided into four main regions: North, Northeast, Central and South (Map and Table 1.1).

Table 1.1
Land Utilization and Farm Holding Land by Region
1985

	Total Land		Farm Holding Land	
	(Million ha)	(Per cent)	(Million ha)	(Per cent)
Northeast	16.89	32.91	8.86	43.05
North	16.96	33.06	4.67	22.68
Central	10.39	20.25	4.64	22.54
South	7.07	13.78	2.41	11.73
Total	51.31	100.00	20.58	100.00

Source: Agricultural Statistics of Thailand, Crop Year, 1986/1987.

a) North

This accounts for about 17 million hectares or one-third of the total land area. It consists of several mountain ranges that run north-south and are the source of many rivers, including the four (Ping, Wang, Yon and Nan) that merge to form the Chao Phya River and run down through the Central Plain into the Gulf of Thailand. Because of the mountains, only about a quarter of the total land area (about 4.7 million hectares) is farmland.

This region can be further divided into two sub-regions: the upper and lower North. The upper Northern valleys are well irrigated and grow rice, soybeans, tobacco, fruit and vegetables. The lower part of the region is rain-fed upland where maize, rice and soybeans are grown. This is the largest maize-growing area and about 46 per cent of the total maize area (or 0.9 million hectares) is in this sub-region.

b) Northeast

This region is about the same size as the North (16.9 million hectares). It is a sandstone plateau sloping down the mountains in the south and west towards the Mekong River. These mountains block the southwesterly monsoon rains, making the region rather dry. This dryness is aggravated by sandy soil which cannot hold rain water.

Although the land is not rich and does not have adequate water, its farmland area is almost twice the size of the North (about 8.8 million hectares). It is the biggest region in terms of farmland (about 43 per cent of the total).

This region produces mainly field crops, especially cassava, maize and sorghum. Glutinous rice is also grown for subsistence consumption. Maize is a small crop here, accounting for only 0.52 million hectares (about 6 per cent of the total farm area).

c) Central

This accounts for 10 million hectares (20 per cent of the land area). Chao Phya river delta, one of Asia's major river deltas, is here. Apart from being irrigated by monsoon rain and the river system, the region gets the most irrigation investment from the government. Although its land area is small, almost half of it is farmland. About 23 per cent of the country's farmland is in this region.

It can be further divided into three sub-regions: the East, West and Central Plain proper. The eastern part consists of hilly and coastal areas, while the west is mountainous and less suitable for agriculture. The Central Plain proper is the country's best farmland, with rich deltaic soil and well-regulated water supply.

Rice is the region's main product but it also produces fruit, vegetables, livestock and fish (aquaculture). The upland fringe area produces sugarcane, maize and cassava. About 0.54 million hectares of maize (27 per cent of total maize area) comes from the Central region.

d) South

This is a peninsular strip, divided by a mountain range stretching from the Myanmar (Burmese) border in the north to the Malaysian in the south. There is little flat land.

The equatorial climate makes the region suitable for tree crops. It produces rubber, fruit, coconut, oil palm and also fish. Only a very little maize is grown.

2. Agro-ecological conditions for maize

Rainfall and soil conditions are two major determinants of agro-ecological conditions.

a) Rainfall

Its distribution is the major factor in Thai maize production because most maize is grown in rain-fed conditions.

The rainy season in Thailand usually begins in mid-May, when the southwesterly monsoon brings rain from the Indian Ocean, and lasts until mid-October. The east coast of the southern region has additional rainfall from the northeasterly monsoon from November to February.

Rainfall is highest in the South (total about 2,316-2,404 mm.) and lowest in the North (1,225 mm.). Although rainfall in the Northeast (1,132-1,443 mm.) is slightly higher than the North, its sandy soil cannot retain the water for further use. Rainfall in the Central region is about 1,487 mm.

Maize does not like too much water. The South's high rainfall makes it unsuitable for maize, which can be grown in all other regions. It is usually grown at the beginning of the rainy season and harvested after about 100 days. This leaves time to plant the second crop which can be either mungbean, soybean, sorghum or maize. Although this practice increases productivity of land, maize harvested during the rainy season is wet and difficult to dry because of high humidity and becomes susceptible to aflatoxin.

b) Soil conditions

Maize can be grown in a vast range of soil conditions, but it prefers well drained loam to clay loam soils, with the pH. from 6.0-7.0 and good organic material.

A large area meets this criteria but maize cannot be grown without good rainfall. A more detailed description of the agro-ecological zone is in the Appendix.

B. Maize Production in Thai Agriculture

1. Historical development

Maize was originally planted by small subsistence farmers for direct consumption. Its use as animal feed was started in 1932 by Prince Sithiporn, then director-general of the Department of Agriculture[1]. Maize production became significant after World War II. The firms importing maize from Japan induced Thai farmers to grow the flint maize variety from Latin America. These importers bought most of the production. The profit from growing maize persuaded farmers to expand its cultivation by clearing forest in the lower North region. This expansion was helped by the World Health Organization (WHO)'s eradication of malaria in Thailand. Maize expansion was so rapid that one observer predicted Thailand would become a major world maize exporter (Silcock, 1970).

The growth of the area planted was indeed striking. From about 23,000 hectares in 1947, it went up to 204,000 in 1958-1960 and one million in 1971 (Table 1.2). The expansion tapered off in the 1970s when additional land became less accessible. In the 1980s, there was almost no growth in planted area.

Table 1.2
Average Planted Area, Output and Yield of Maize
1937-1986

Year	Planted Area (OOO ha)	Output (OOO tons)	Yield (tons/ha)
1937-1946	10.72	8.20	0.7649
1947-1952	33.73	28.92	0.8358
1953-1965	240.66	427.52	1.5946
1966-1974	901.32	1,752.38	1.9380
1975	1,312.00	2,863.20	2.1823
1976	1,284.64	2,675.20	2.0825
1977	1,205.44	1,677.00	1.3912
1978	1,385.76	2,791.00	2.0141
1979	1,524.64	2,863.00	1.8778
1980	1,433.60	2,998.00	2.0912
1981	1,567.36	3,449.00	2.2005
1982	1,679.04	3,002.00	1.7879
1983	1,688.32	3,552.00	2.1039
1984	1,816.80	4,226.00	2.3261
1985	1,980.32	4,934.00	2.4915
1986	1,951.04	4,309.00	2.2086

Maize production grew about 14 per cent a year during the 1970s and slowed to 7 per cent during the 1980s (Figure 1.1). The apparent source of growth was land expansion. But maize research was important too. Maize yields reached 1 ton/ha in 1951, 2 tons in 1962, 2.4 in 1970 and then declined slightly, rising to 2.5 in 1985 (Figure 1.2). Research is important in spreading maize to many areas by increasing its adaptability.

2. Regional production

The "corn belt" of Thailand is in the lower Northern region (Table 1.3). Although maize production began in the Northeast, it spread rapidly to the East-West sub-region of the Central Plain and the lower North regions. During 1961-1965, these two regions accounted for 368,000 hectares of the total 436,000 hectares planted to maize (84 per cent of total planted area) and produced 709,000 tons (87 per cent of total output). The Northeast had about 10 per cent of the maize area and 8 per cent of the planted area and output. The upper North and South had only 6,000 hectares planted to maize.

Table 1.3
Maize Production, Planted Area and Yield by Region

Year	Northeast	Upper North	Lower North	Central Plain	East-West	South	Total
			Average Output (tons)				
1961-1965	65,144.46	10,083.60	331,597.65	18,487.40	377,517.22	9,465.54	815,595.90
1966-1970	153,273.26	36,185.92	582,546.30	19,433.56	573,182.36	25,060.77	1,389,692.19
1971-1975	486,032.46	77,355.78	1,033,789.56	12,392.64	615,663.18		2,225,233.62
1976-1980	619,899.98	127,505.54	1,262,721.42	13,685.94	552,629.36	13,622.36	2,590,064.60
1981-1987	973,777.71	237,711.00	1,537,097.86	23,940.86	975,568.29	5,294.33	3,753,390.05
			Average Planted Area (ha)				
Year	Northeast	Upper North	Lower North	Central Plain	East-West	South	Total
1961-1965	44,830.46	6,356.42	181,779.26	10,502.69	186,417.60	6,335.30	436,221.73
1966-1970	90,166.91	20,106.94	321,476.54	10,513.95	280,568.06	15,917.25	738,749.70
1971-1975	245,406.70	34,212.45	512,548.74	6,909.15	313,865.63		1,112,944.67
1976-1980	358,349.66	70,334.85	624,669.57	11,706.14	286,066.18	7,719.07	1,358,845.47
1981-1987	484,578.79	115,574.40	722,960.09	14,428.34	437,161.92	3,478.61	1,778,182.16
			Average Yield (tons/ha)				
Year	Northeast	Upper North	Lower North	Central Plain	East-West	South	Total
1961-1965	1.52	1.59	1.82	1.76	2.03	1.49	1.87
1966-1970	1.70	1.80	1.81	1.85	2.04	1.57	1.88
1971-1975	1.98	2.26	2.02	1.79	1.96	ERR	2.00
1976-1980	1.73	1.81	2.02	1.17	1.93	1.76	1.91
1981-1987	2.01	2.06	2.13	1.66	2.23	1.52	2.11

Source: Compiled and adjusted from the Agricultural Statistics of Thailand, by the Agricultural and Rural Development Program, Thailand Development Research Institute, 1989.

Figure 1.1:

Output and planted area of maize

1947-1986

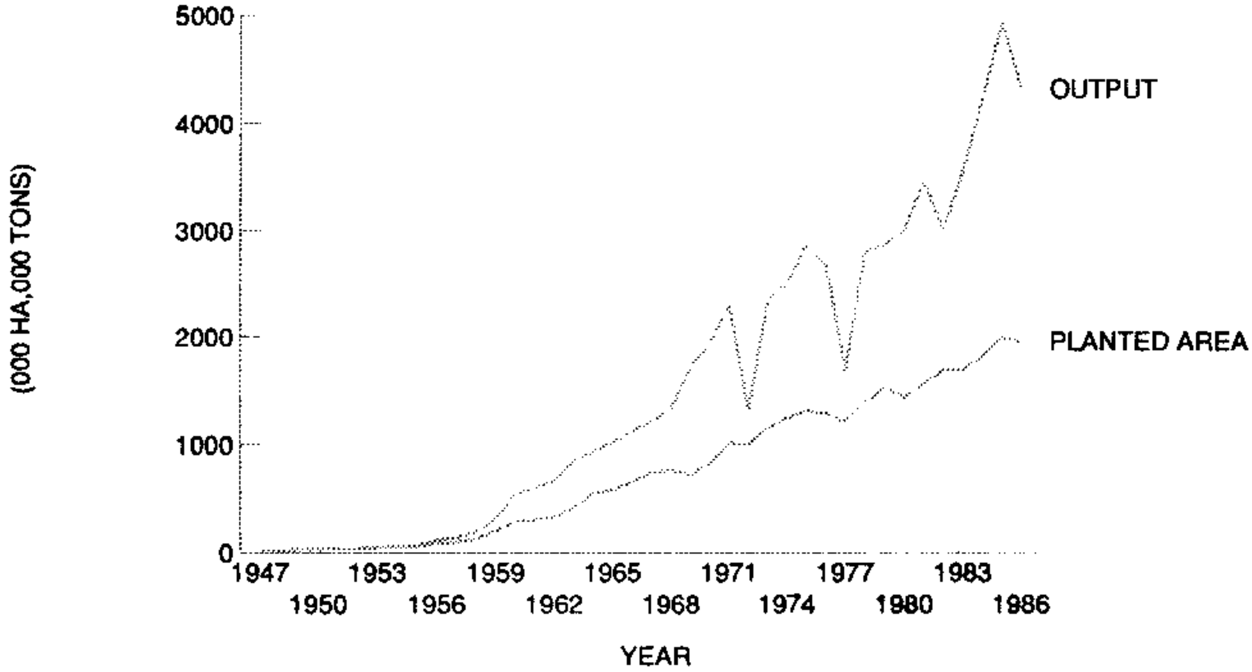
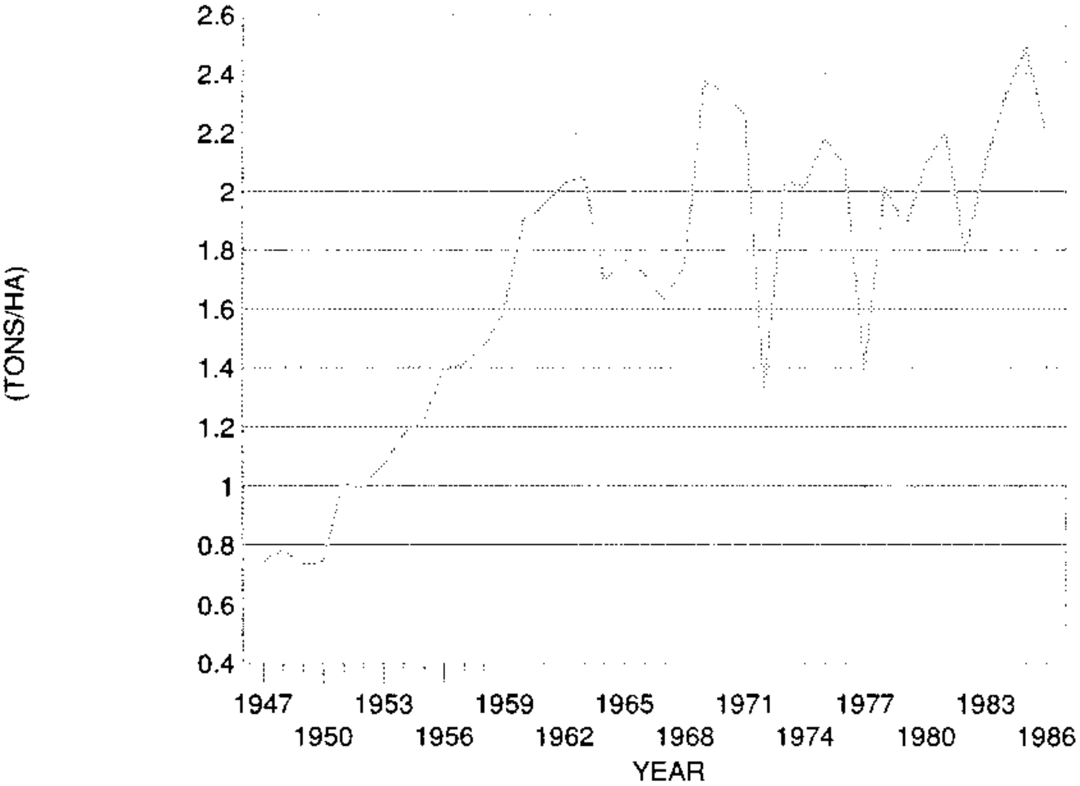


Figure 1.2: Maize yield, 1947-1986



This pattern changed slightly in 1971-1975 when production expanded rapidly in the Northeast, mainly because of the new Friendship Highway[2], which facilitated transport of maize and other crops to the port in Bangkok. Production in the South fell drastically during this period because of expansion of oil palm cultivation, which began around 1972. The substitution was not in the maize area but oil palm cultivation absorbed the limited labor supply. The average planted area and production in the Central region fell partly because of the 1972 drought and partly because of increased production of sugarcane.

Since the mid-1970s, expansion of the livestock sector has boosted domestic demand for maize. The production area in each region increased to cater for poultry production there. This was more evenly-spread production expansion. But in the lower North, it started to taper off because of cultivation of soybean, a much-needed source of protein for animal feed (Figure 1.3).

3. Farm sizes

Maize farmers are small-scale farmers. Table 1.4 shows their average farm size was 2.9 hectares in 1978 and 2.67 in 1983.

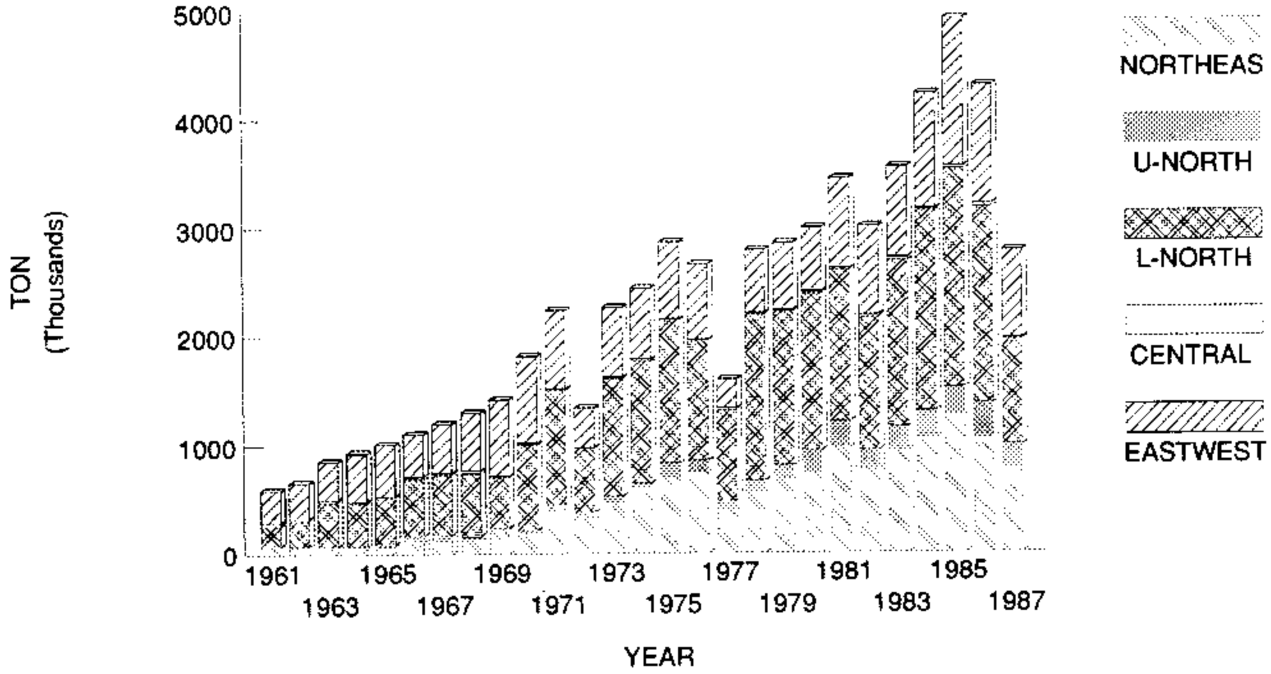
Table 1.4
Number of Holdings and Planted Area of Maize by Region

	All Sizes		Under 9.0 ha		0.9 - 1.6 ha		1.6 - 5.5 ha		Over 5.5 ha	
	1978	1983	1978	1983	1978	1983	1978	1983	1978	1983
Whole Kingdom										
No. of holdings	380,170	532,296	27,714	40,934	32,206	50,027	223,500	318,417	96,750	122,915
Planted Area (ha)	1,104,384	1,422,216	13,037	18,078	21,467	32,245	460,467	644,348	609,412	727,545
North										
No. of holdings	229,774	325,587	20,570	31,428	23,450	37,848	134,222	190,556	51,532	65,755
Planted Area (ha)	560,596	739,102	9,266	13,079	14,603	23,225	252,925	353,947	283,801	348,850
Northeast										
No. of holdings	84,956	130,564	4,508	5,811	6,478	9,347	53,260	85,469	20,710	29,937
Planted Area (ha)	254,702	393,116	2,411	2,900	5,005	6,595	114,604	186,023	132,682	196,598
Central										
No. of holdings	62,150	73,163	2,366	3,628	1,961	2,386	33,968	40,596	23,855	26,553
Planted Area (ha)	286,840	285,287	1,284	2,059	1,745	2,271	91,640	103,563	192,171	180,393
South										
No. of holdings	3,290	2,982	270	67	317	446	2,050	1,796	653	673
Planted Area (ha)	2,246	1,713	76	40	114	154	1,298	815	758	704

Source: Agricultural Census Report, 1978, NSO, Thailand; Intercensal Survey of Agriculture, 1983, NSO, Thailand.

Figure 1.3: Maize output by region

1961-1987



The average farm size in the overall Central region is largest among the four regions. In the Northeast, it is slightly smaller and in the South the smallest. Farm size decreases slightly overall between 1978 and 1983. The most common farm size in all regions is between 1.6-6.4 hectares.

4. Crop mix

In the major production area in the lower North, maize is the chief crop grown at the beginning of the rainy season. It is then followed by mungbean or soybean. In the Northeast, maize is usually the only crop. In the Central region, maize is grown as a second crop after rice in the upper Central region. There is little maize grown in the irrigated area because its return is not as attractive as rice.

Maize accounted for 25 per cent of the planted area in the lower North, 19 per cent in the Northeast and East-West, 14 per cent in the upper North and 1 per cent in the Central region during 1983-1987. Production in the South is negligible (Figure 1.4).

C. Utilization and Trends

1. Present structure of utilization

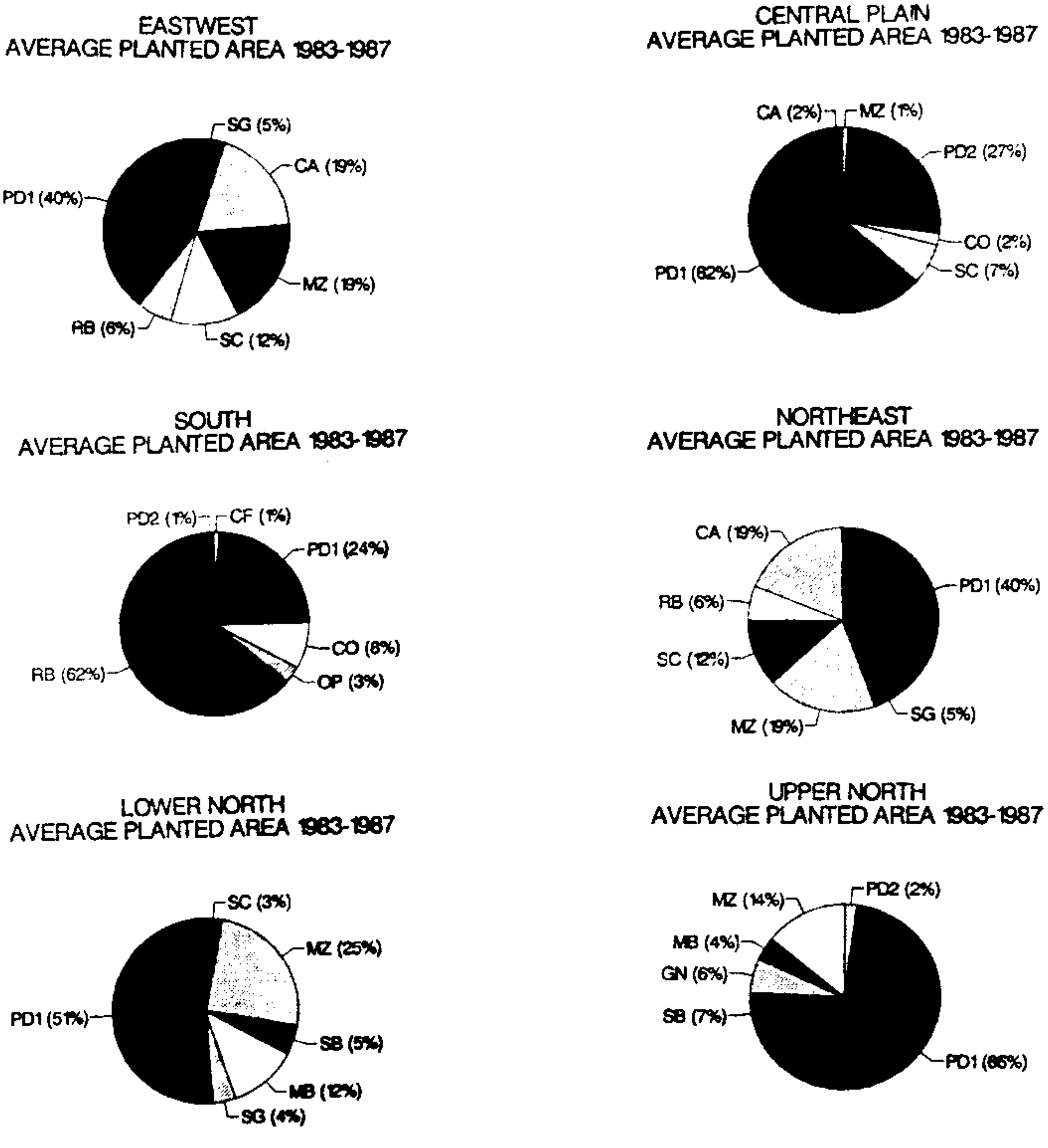
Maize production is largely for export, domestic animal feed, direct human consumption and seed.

The major demand is for exports. In the 1960s, over 95 per cent was exported. Between 1981-1986, the export share fell to about 75 per cent because of increased domestic demand from the poultry industry.

The chief maize export markets in the past were Japan and Taiwan, but shipments fell to near zero during the 1980s even though Thailand had the advantage of low production costs and of being close by. The customer complaint was poor quality. Aflatoxin was cited as the major problem, but another reason was that the two countries were subject to commercial pressure from the United States[3]. Thailand's major export markets now became neighboring countries, especially Malaysia, and the Middle East.

The domestic animal feed industry is expanding rapidly. The modern compound feed industry dominates the traditional feed industry. "Backyard" livestock activities are giving way to more efficient livestock production methods. The derived demand for animal feed thus increases with demand for meat. Table 1.5 shows the share of domestic demand in total production rose from 7 per cent in 1980 to 32 per cent in 1985. Domestic demand for 1986 was low because the Animal Feed Association estimated that the demand was 1.2 million tons in 1986. There is a problem in using "domestic disappearance" in calculating demand because stock is not taken into consideration. But domestic demand is still expanding rapidly.

Figure 1.4



PD1 Main season paddy crop
CA Cassava
MZ Maize

SC Sugarcane
RB Rubber
SG Sorghum

Table 1.5
Production, Export and Domestic Consumption of Maize, 1981-1986

Year	Production (000 tons)	Yield (ton/ha)	Export (000 tons)	Percentage	Domestic Consumption (000 tons)	Percentage
1981	3,449	2.20	3,210	93	239	7
1982	3,002	1.79	2,158	72	844	28
1983	3,552	2.10	2,873	81	679	19
1984	4,226	2.33	3,063	72	1,163	28
1985	4,934	2.49	3,349	68	1,585	32
1986	4,309	2.21	3,383	79	925	21

Source: Office of Agricultural Economics, Agricultural Statistics of Thailand, various issues.

Expansion of the livestock industry since the mid-1970s has increased domestic demand for maize. Domestic demand for feed was almost 2 million tons in 1988. The demand for poultry feed was the most important source (Table 1.6). At this rate of increase, Thailand will have to import maize in the 1990s.

Table 1.6
Derived Demand for Major Feed Ingredients 1988
(Tons)

Animal	Feed Use	Fishmeal	Soy-Meal	Maize	Rice Bran
Chicken	1,280,000	128,000	192,000	806,400	25,600
Layer	720,000	50,4000	72,000	396,000	93,600
Parent Stock	180,000	9,000	27,000	113,400	3,600
Small Layer	22,500	1,575	2,250	12,375	2,250
Pig	1,500,000	135,000	60,000	150,000	690,000
Others	1,019,625	94,487	45,367	32,531	231,728
Total	4,722,125	418,462	398,617	1,510,706	1,046,778

Source : Setboonsamg *et al.*, 1989.

Maize is also directly consumed in Thailand, usually as a dessert or snack. But the quantity of consumption is limited. Glutinous maize and sweet corn are used for this but consumption is limited. Total cultivation of these two maize varieties was about 30,000 ha. in 1987.

A new and expanding use of maize is baby corn. The young ear of maize that is harvested before pollination has become an export item. Canned baby corn exports were as much as 230 million baht (about US$9.5 million) in 1986 (Table 1.7).

Table 1.7
Export of Canned Baby corn

Year	Quantity (tons)	Percentage Change	Value (000 baht)	Percentage Change
1980	916	-	21,378	-
1981	1,229	34.17	28,898	35.18
1982	1,521	23.76	36,647	26.82
1983	4,014	163.91	89,589	144.46
1984	4,482	11.66	101,131	12.88
1985	6,281	40.14	141,469	39.89
1986	11,317	80.18	230,629	63.02
1987	17,219	52.15	334,861	45.19
Growth Rate	42.86		40.26	

Source : Agricultural Statistics of Thailand, Office of Agricultural Economics.

One factor stimulating growth of baby corn is the government subsidy to expand the dairy industry, which increases demand for dairy cattle feed. The by-product of baby corn is the outer layer of the ear and the stalk itself. Small dairy farms are growing up around the baby corn area in the lower Northern region.

Seed demand is another source of demand for maize output. At the seed rate of 20 kg/ha and the cultivated area of 2 million ha., the amount of seed required is about 40,000 tons.

2. Future trends

With the increase in demand for meat, maize use in the animal feed industry will probably continue to expand. It is difficult to predict because of uncertainty in the international component of demand for poultry and shrimp exports. However, growth of domestic demand (now more than 80 per cent of total production of poultry meat) is at least 8 per cent a year (Setboonsarng *et al.*, 1988). Within three years, domestic consumption will reach the current level of production. There will be a sharp increase in demand for maize from the animal feed industry and some increased demand from direct consumption.

Demand for seed use will fall because of the attempt to reduce cultivation area. However, in terms of value of the seed market, there will be a big expansion because of the need to increase productivity of the existing cultivated area.

II. DEVELOPMENT OF MAIZE TECHNOLOGY

Modern science is improving production and utilization of maize. Most important is improvement of maize variety. Research on soil, entomology, plant pathology and physiology and agricultural engineering have also contributed to better use of inputs (land, labor and capital) and increased output.

Research on maize variety and chemistry have enhanced use of maize for human consumption, animal feed and industrial use.

A. Development of Maize Varieties

This has been in four stages:

1. Before World War II

Maize is thought to have been introduced to Thailand in 1680. Between 1939 and 1946, two varieties - Mexican June and Nicholson's Yellow Dent - were brought from the United States to be planted as animal feed. However, cultivation of maize for commercial purposes during that period was minimal.

2. Period of Guatemala Variety (1953-1975)

After World War II, Japanese maize importers introduced flint maize from Central America to Thai growers. In 1950, the Thai-USOM (United States Operations Mission) Crop Development Project was established. In 1953, H. Ream, the project's adviser, brought the Guatemala variety from Indonesia[4]. Guatemala was found to perform well in the Thai environment. It was then introduced to Thai maize growers in Lopburi in the mid-1950s. Its obvious superiority over the local variety made it spread quickly to other maize areas[5]. The planted area of maize also increased rapidly (from 48,000 hectares in 1953 to about 200,000 hectares in 1959, an average increase of almost 70 per cent a year).

The increase in planted area and the importance of the foreign exchange it earned induced the government to try to improve yield and quality. The effort to improve maize varieties began in 1959 with the joint venture of the Department of Agriculture in the Ministry of Agriculture and Cooperatives, Kasetsart University and the Rockefeller Foundation. Most of the work was done by the Department of Agriculture, which had both research stations and scientists.

Given the capacity of research stations, equipment and scientists at that time, a controlled mass-selection method was chosen to improve the yield of the Guatemala variety. This produced PB varieties (PB stands for Phra Bhudhabaht, the name of the Agriculture Department's research station) that were released between 1965 and 1975. By 1974, about 80-90 per cent of the planted area in maize was under the PB series (Jiyahnon, 1979).

By 1970, the downy mildew problem was so severe that research was shifted from yield increase to downy mildew resistance (DMR). The effort to introduce DMR into Thai Composite #1 began in 1971. It was found that Philippines DMR 1 and 5 could provide the source for DMR and was also adaptable to Thailand, so they were crossed with Thai Composite #1 (S) C_1. In 1972, DMR was introduced into Thai Composite #1. Its improvement in 1973 produced Thai Composite #1 DMR. Using S_1 recurrent selection, the Thai Composite DMR (S) C_2 was developed. This was released in 1974 as Suwan 1 (SW 1).

SW 1 was a big success because apart from resistance to downy mildew, it had high yield in most cultivated areas. It has been introduced in more than 20 countries. Public and private sectors used it as genetic material for both open-pollinated and hybrid varieties. Research on SW 1 continued and through recurrent selection, it kept improving itself. Yields increased with each new vintage (Table 2.1) and it was important in developing the maize seed industry in Thailand.

Table 2.1
Mean Yield of Suwan 1 Cycle 0-9
Tested at Farm Suwan
1975-1985

Suwan		Height Plant	Ear (cm)	Yield (ton/ha)	Leaf Area (cm^2-pl)	HI
SW 1-	CO	237	135	8	7220	0.47
	C1	236	135	8.524	2023	0.51
	C2	233	151	8.453	6856	0.47
	C3	231	134	8.282	7497	0.5
	C4	234	130	8.222	6609	0.48
	C5	239	134	9.137	7010	0.48
	C6	241	141	9.066	7229	0.46
	C7	231	134	9.583	7976	0.52
	C8	233	130	9.409	7419	0.46
	C9	237	130	9.416	7508	0.49

Source : Sriwatanapongse (undated).

Research at Farm Suwan was also done to improve the protein and oil content of maize. In 1973, research had a new target: improvement of protein content. Thai Opaque-2 Composite #3 was found that year. Though intensive screening continued for DMR, researchers at Farm Suwan found and released Thai-Opaque-1 Composite #4 and #5 in 1976. These varieties were not very successful because high protein maize had lower yield and did not fetch a good price. Breeding for high oil maize suffered the same fate.

4. Period of hybrid maize

Research on hybrid maize started as early as 1960. Hybrid varieties from the United States and the Philippines were tested by both the Department of Agriculture and Kasetsart University. Yields were not satisfactory because they came from a narrow genetic pool. In the early 1970s, research on hybrid was overshadowed by DMR research. After discovery of Suwan 1, hybrid research re-emerged.

In 1977, the team at Kasetsart University started developing the inbred line from Thai Composite #1 DMR (S) C_4[11]. In 1980, 13 inbred lines were selected. The high yield variety from the single-cross of these inbred lines was Suwan 2301. In 1981, Suwan 2301 yielded 13 per cent more than Suwan 1. In 1982, the regional variety test showed this had risen to 17 per cent and another hybrid maize, Suwan 2602, a three-way cross hybrid, was released.

Besides government efforts to develop and promote high-yield maize, private firms - local and international - were producing and marketing both Suwan 1 and hybrid maize in Thailand. The share of private companies in producing and distributing improved maize seed grew quickly. Hybrid seed sales rose from about 500 tons in 1983 to 2,000 tons in 1986 and 3,000-8,000 tons in 1989.

Private firms and hybrid seed will probably play a more important role in increasing maize production in the future. Suwantharadol (1989) reported the forecast of 7 major seed companies that by 1999 hybrid may have as much as 62 per cent of the total seed market or as little as 25 per cent. The pessimistic forecast stemmed from the unusual performance of open-pollinated research, especially Suwan 1. The optimistic prediction believed the Suwan series would come to an end soon and hybrid would take over the market.

5. Maize quality period (moisture and aflatoxin)

A more important quality issue arose when maize left the field. During the 1970s, a major problem with maize exports was moisture content. This was unfortunate because maize was commonly grown at the beginning of the rainy season and harvested before it ended. The maize could have up to 25 per cent moisture. With high humidity, it took time to dry. The problem was solved by a cheap moisture measurement device introduced by private companies in the mid-1970s. With it, the local maize trader could assess the percentage of moisture and give the farmer a suitable price. The difference in price was enough to encourage the farmer to dry his maize.

Research is currently dominated by the aflatoxin problem[12]. From 1981, maize exports to Japan had high aflatoxin. This forced Thai exporters to sell maize to other markets at a lower price. The research on aflatoxin, started in 1981, **involved:**

- a survey of A. flavus (the fungus responsible for aflatoxin) in different regions and marketing levels (farmer's field, grain elevator warehouse and exporter warehouse).

- research on a cheaper way of detecting aflatoxin.

- development of a maize variety less susceptible to A. flavus.

- shifting cropping time.

- post-harvest practice: chemical treatment before storage, proper storage practice and research on a more efficient dryer.

B. Maize Varieties for Direct Consumption

For direct consumption of maize, three kinds have been developed: waxy corn (glutinous corn), sweet corn and baby corn.

1. Waxy corn (Zea mays variety, ceratina Kulesh)

There is no record of when waxy maize was introduced to Thailand. In 1968, the Department of Agriculture brought Philippines Glutinous Syn #20 from the Philippines. Using mass selection, a better-performing variety was determined and distributed to farmers in 1976. No other improved variety of waxy corn has been released since. This variety was also used by baby corn growers. The research team at the University did not pay attention to waxy corn because of its limited planted area.

2. Sweet maize (Zea mays variety, saccharata sturt)

Sweet maize was brought to Thailand in 1974 by Professor James A. Brewbaker, of the University of Hawaii. Known as Hawaiian Sugar, it was evaluated and selected at the National Corn and Sorghum Research Center at Farm Suwan. Several varieties of sweet maize were released to the farmer.

Super Sweet was brought to Thailand in 1968 from the University of Illinois. It was tested and developed at several research stations of the Department of Agriculture. In 1979, Pak Chong Super Sweet was discovered and distributed.

3. Baby corn

Baby corn is the young ear of maize harvested before it is fertilized. Each plant can give many ears. In the past, baby corn was not popular. The varieties used were sweet corn and super sweet and the local "candle maize." However, since the invasion of downy mildew in the late 1960s and early 1970s, farmers shifted quickly to Suwans and Thai DMR #6 which were resistant to downy mildew. This change from expensive sweet maize seed to using grain as seed reduced costs by 200-300 baht/ha. With higher profits, baby corn became more popular. While the higher quality output was selected for export (canning industry), the non-standard ears found a growing domestic market.

After the release of Suwan, most farmers switched to Suwan 1 or 2 to produce baby corn. There was no specific variety for baby corn until 1986, when the Department of Agriculture developed Rangsit 1, which gave better yield and was also downy mildew resistant.

Feed use received more research attention than did use for direct consumption. This was understandable because the area devoted to human consumption maize was much smaller. However, human consumption has grown as income and population increase. Although there is an overspill of benefits from research in animal feed maize to maize for direct human consumption, the latter may need more direct research in the future.

C. Other Research

1. Entomology

In 1961, the locust Patanga Succincta L., one of the insects most damaging to maize, was found in Thailand. The initial effort to control it was to spray on sight. However, with research on its life cycle, a more effective timing and an integrated pest management system was implemented. In 1975, the patanga problem was under control in the lower North. In 1977, it was controlled in the Northeast. There have been limited patanga problems in these areas since then.

Guenee (Ostrinia furnacalis) was also an important insect problem in Thailand. By drilling holes in the stalk, it weakened it and also reduced the yield of maize up to 40 per cent. The problem has not been completely solved.

2. Machinery and equipment

Equipment used in the processing and grading of maize includes: shelling machine, moisture measurement equipment and drying facility. The shelling machine commonly used was adapted from an imported model around 1960. These machines, usually owned by the middlemen who provide the service as part of overall purchasing transactions, are well suited to the hard shell of flint maize grown in Thailand.

The moisture measurement equipment, used to grade the quality of maize purchased from the farmer, became popular in the mid-1970s. Equipment that can give a precise level of moisture is still quite expensive. The popular version used is relatively simple and gives only rough measurement. This equipment is usually owned by local grain middlemen.

During the past few years, since aflatoxin has become a big problem in maize quality, demand for equipment to measure the level of aflatoxin has grown. As the existing model of aflatoxin measurement equipment is still expensive, only exporters possess the equipment.

The aflatoxin problem also induced demand for drying facilities. A small drying facility developed and sold by some private companies proved unpopular because it was not cost effective. However, there has been an increase in the number of medium size drying silos in the major maize growing area. These facilities have increased with the number of animal feed companies in the area.

3. Research on other uses of maize

Many by-products of maize have been studied. Research on maize oil production in Thailand has been contemplated. There is no technical constraint to setting up a plant in Thailand and the machinery can be made by Thai engineers. However, it is not commercially viable because corn starch, the main product of this process, cannot compete with cheap cassava starch in Thailand.

Production of high-fructose-corn-syrup (HFCS) was also contemplated in Thailand. The main constraint was the relatively high price of maize in Thailand, dictated by demand from the animal feed industry. The cost of HFCS would be too high to compete with sugar even though the domestic price of sugar is higher than the world price.

So technology in maize production in Thailand has been rather well organized and advanced, especially in maize variety development. The catalyst was the Rockefeller Foundation. Research into maize responded quickly to the production problem in each time period. The emphasis of research was on the production side. Less attention was given to improving utilization of maize.

III. TECHNOLOGICAL CAPABILITY

The technological capability of a research program depends mainly on:

- scientists,
- laboratories and equipment,
- genetic material.

A. Structure and Organization of Agricultural Research

Most agricultural research is done in the public sector. Three kinds of organization are involved: universities, other government agencies and international agencies.

1. Universities

These perform two functions: training and conducting basic research. The system emphasizes training. Research is secondary. The foremost university in agriculture is Kasetsart University in Bangkok. Agricultural research is also done by four regional universities: Chiang Mai University (CMU) and Mae-Jo Agricultural University in the North, Khon Khen University (KKU) in the Northeast and Prince of Sonkhla University (SU) in the South.

From the number of students enrolled in the degree program (Table 3.1), it is clear the university system in Thailand is geared towards training to master's degree level. The master degree program is quite large in agriculture. Graduates are expected to join the Ministry of Agriculture and Cooperatives (MOAC). Some of the better students are retained as lecturers. These are usually sent abroad for further training with a scholarship.

The PhD program in Thailand is not big in agriculture. Without a strong Phd program, it is difficult to build up sufficient critical mass to carry out basic research in any of these areas. Medical research has a stronger program.

Table 3.1
Degree Programs Related to Biotechnology and Genetics Engineering

BACHELOR DEGREE

Area	University/Institute							Total
	CU	KU	MU	KMITT	KKU	CMU	SU	
Agriculture	-	338	-	-	170	137	85	730
Biochemistry	16	-	-	-	-	-	-	16
Chemical Engineering	26	-	-	39	-	-	12	77
Chemical Technology	49	-	-	-	-	-	-	49
Biotechnology	-	12	22	-	-	-	-	34
Food Technology	34	-	-	-	-	-	-	34
Food Science	-	31	-	-	-	36	-	67
Genetics	7	-	-	-	-	-	-	7
Medicine	137	-	416	-	70	114	75	812
Microbiology	22	-	-	10	-	-	-	32
Sanitary Engineering	17	-	-	-	-	-	-	17
Environmental Engineering	-	-	-	-	6	16	-	22
Fisheries Science	-	65	-	-	-	-	14	79
Marine Science	3	-	-	-	-	-	-	3
Veterinary Science	44	51	-	-	-	-	-	95
TOTAL	355	497	438	49	246	303	186	2074

MASTER DEGREE

Classification	University/Institute							Total
	CU	KU	MU	KMITT	KKU	CMU	SU	
Agriculture	-	184	-	-	13	3	-	200
Biochemistry	3	-	16	-	-	-	-	19
Biomedical Instrumentation	-	-	6	-	-	-	-	6
Chemical Engineering	11	-	-	6	-	-	-	17
Chemical Techonology	-	-	-	-	-	-	-	-
Biotechnology	5	-	-	5	-	-	-	10
Fisheries & Aquaculture	-	9	-	-	-	-	-	9
Food Technology	9	-	-	-	-	-	-	9
Food Science	-	5	-	-	-	-	-	5
Food Chemistry	-	-	-	-	-	-	-	-
Genetics	3	4	-	-	-	-	-	7
Marine Biology	10	-	-	-	-	-	-	10
Medicine	16	-	57	-	14	3	-	90
Microbiology	3	12	2	-	-	-	-	27
Sanitary Engineering	17	-	-	-	-	-	-	17
Tropical Medicine	-	-	27	-	-	-	-	27
TOTAL	77	214	118	11	27	6	-	453

Table 3.1 (continued)

DOCTORATE

Classification	University/Institute							Total
	CU[1]	KU[1]	MU[2]	KMITT	KKU	CMU	SU	
Agriculture	-	3	-	-	-	-	-	3
Biochemistry	-	-	22	-	-	-	-	22
Microbiology	-	-	22	-	-	-	-	22
Tropical Medicine	-	-	1	-	-	-	-	1
TOTAL	-	3	45	-	-	-	-	48

1. Estimated number of graduates.
2. Total number of graduates since establishment of program (1970).

CU - Chulalongkorn University
MU - Mahidol University
KU - Kasetsart University
KMITT - King Mongkut's Institute of Technology; Thonburi
KKU - Khon Kaen University
SU - Prince of Songkhla University
CMU - Chiang Mai University

Source: Capability Development for Biotechnology-based Industries; Science and Technology Development Program, TDRI, March 1989.

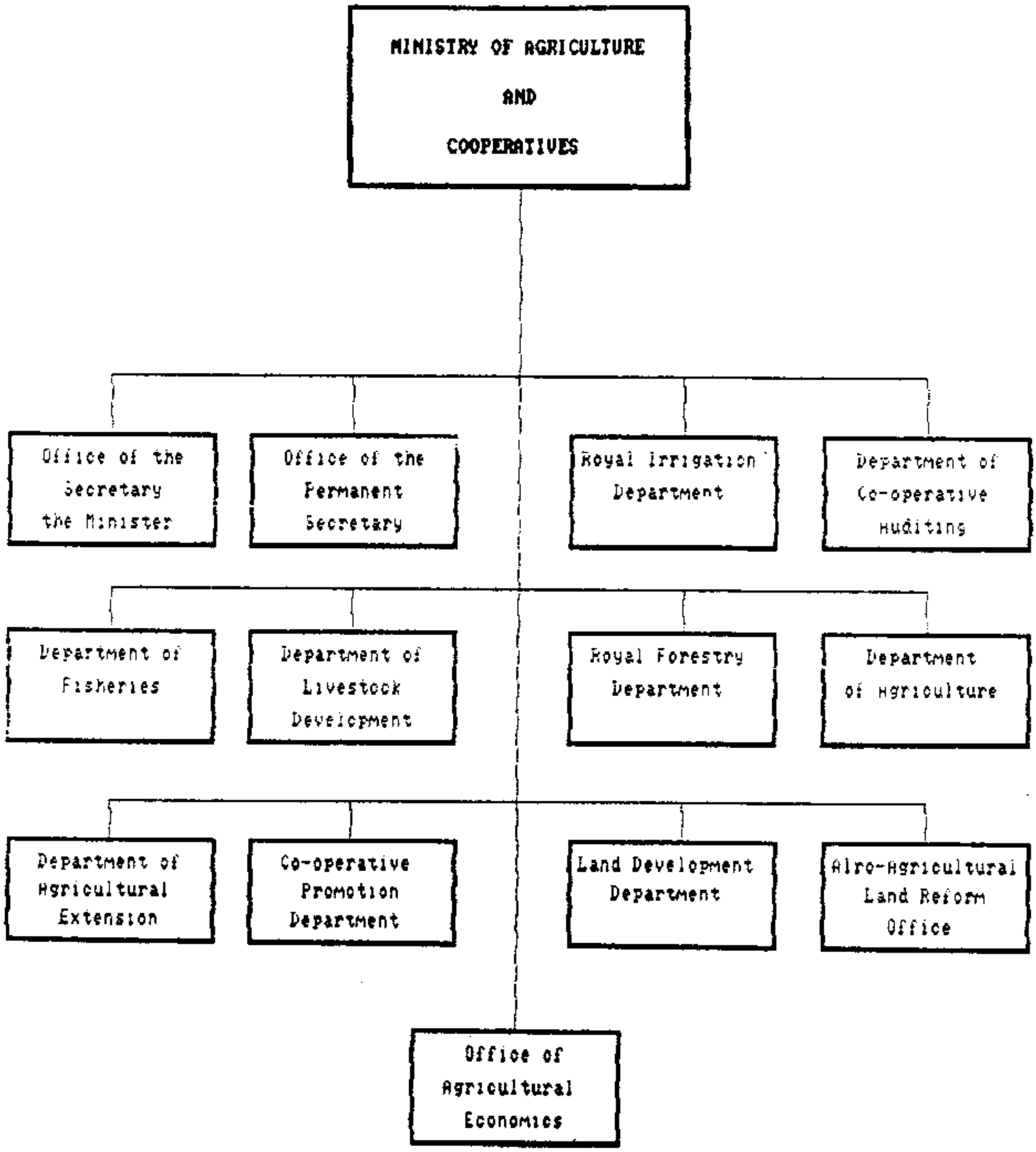
2. Government agencies

The main public agency conducting applied research in agriculture is the MOAC. Specialized applied research is the responsibility of the Ministry of Science, Technology and Energy (MOSTE). This ministry was established in early 1980 to coordinate and carry out the country's science and technology plan.

Within the MOAC, five departments conduct and disseminate research: Agriculture (crop related research), Fisheries, Livestock, Forestry and Agricultural Extension (Figure 3.1). Within the Department of Agriculture (DOA), research is divided between 12 research institutes and discipline divisions. Maize research comes under the Field Crop Research Institute. The research emphasis in the DOA is on application at farm level. To support this objective, under each institute there are regional research centers and under each regional center a few research stations.

Research on biotechnology and genetic engineering is coordinated by the Center for Biotechnology and Genetic Engineering of the MOSTE. The Center was established in 1983 as part of the UNIDO center for biotechnological research in the region. However, this aim changed in 1986 to focus on Thailand. One of the 12 subject areas of the Center is agriculture. Some of the agriculture-related projects it funds are: biological nitrogen fixation research, disease resistant papaya, hybrid rice and marker-gene in rice.

Figure 3.1


MINISTRY OF AGRICULTURE AND COOPERATIVES
Office of the Secretary the Minister
Office of the Permanent Secretary
Royal Irrigation Department
Department of Co-operative Auditing
Department of Fisheries
Department of Livestock Development
Royal Forestry Department
Department of Agriculture
Department of Agricultural Extension
Co-operative Promotion Department
Land Development Department
Alro-Agricultural Land Reform Office
Office of Agricultural Economics

3. International research agencies

International agencies have significantly shaped agricultural research in Thailand. At least three types of international research agencies are involved in Thai agricultural research: international agricultural research institutions (IRRI, CIMMYT, ICRISAT, ACIAR, CIAT), foundations (Rockefeller, Ford) and aid agencies (USAID, CIDA, JICA).

The most important contribution from international agricultural research centers is germplasm. Access to the international pool of genetic material has enhanced maize research in Thailand. These international research centers also provide training and experts to advise on research.

The foundations stress institution building and human resource training, give scholarships and otherwise strongly influence research.

4. Manpower and budget from selected research institutes

In the 20 major research institutes, there were 307 PhDs and 689 MS researchers in 1987. The research budget was 1,222 million baht, of which 374 million came from abroad (Table 3.2). For these resources, FAO/UNDP choose Thailand as the regional biotechology center in 1982. The Institute for Biotechnology and Genetic Engineering was set up in 1983.

Table 3.2
Personnel, Budget and Research Areas of Selected Institutes Doing Research in Biotechnology

Institute	Personnel Ph.D	MS	Budget Government	Foreign	Major Research Areas
Center for Biotechnology	27	10	5.3	0.6	Applied microbiology, medical biotechnology.
Center for Molecular Genetics & Genetic Engineering	17	7	2.1	4.8	Medical biotechnology, genetic engineering, enzyme technology, mosquito control agents, diagnostic enzymes.
Institute of Food Research Development	1	20	10	-	Food technology, food & Product biotechnology, food processing, fermentation technology, enzyme technology, applied microbiology.
Central Laboratory & Green House	70	50	5.5	-	Seed improvement, fermentation industry.
Institute of Biotechnology Engineering	16	2	2	50	Process engineering, & Genetic biochemistry, microbiology, genetic engineering, plant tissue culture.
Marine Biotechnology Lab.	11	7	na	na	Marine science & marine ecology.
Biochemical Engineering & Pilot Plan R&D Unit	8	8	1.4	-	Process development for yeast, spirulina, industrial alcohol & industrial biogas.
Institute for Science & Technology R&D	56	39	11	-	Plant tissue culture, improvement of animal breeding, post harvest technology, fermentation technology, enzyme technology, food technology, natural pharmaceutical products.
Research Institute for Health Science	3	11	7	6	Nutrition, fertility control, infectious diseases.
Maejo Institute of Agricultural Technology	5	40	0.55	2.9	Plant technology, animal technology.
Pharmaceutical & Natural Products Research Dept.	1	15	3.21	1.35	Pharmaceutical & natural products.
Food Industry Department	1	16	1.99	0.86	Food technology, process development in small industries.
Bangkok Microbiological Resource Center		2	0.2	0.1	Microbial technology, fermentation technology, culture collection, training & research.

Table 3.2 (continued)

Rhizobium Research Center	1	6	3.5	-	Mycrorhiza: rhizobium production.
Department of Agriculture	80	338	1051	235	Rice germplasm, variety improvement.
Department of Fisheries	9	50	82.21		Fisheries research & development.
Armed Forces Research Institute of Medical Science	1	25	2	73	Protection & baseline for soldiers diagnostic tool.
National Institute of Health		7	1.5		Vaccines, quality control of commercial vaccines.
National Blood Center		16	30		Blood quality controls, blood fractionation.
National Institute of Coastal Aquaculture		20	2		Marine aquaculture.
Total	307	689	1222.	374.61	

Source: Capability Development for Biotechnology-based Industries, Science and Technology Development Program, TDRI, March 1989.

B. Public Maize Research

Most maize research is done by the public sector. There are five centers of research and diffusion:

- the Field Crop Research Institute, Department of Agriculture, MOAC,
- the universities, particularly Kasetsart,
- the Seed Division, Department of Agricultural Extension, MOAC,
- private companies,
- international agencies.

While the mandate of the university is to do basic research, the government assigns to the DOA application of the results, which are then delivered to the farmer by the Department of Agricultural Extension. Private companies also use the research facilities and results from the University and the Department of Agricultural Extension to improve their products and sell them to the farmer. International research organizations provide links to the rest of the world as well as resources such as technical advice, material (germplasm) and money.

1. Scientists

For an effective research program, enough scientists are needed to form a "critical mass" in the subject area. Since research can take a long while, there should be enough "continuation" over time in the research program.

Maize research in Thailand seems to meet both these conditions. It is difficult to count the number of scientists involved in maize. Scientists from many disciplines conduct research directly and indirectly related to maize. But the most important maize scientist in Thailand is the maize breeder.

When the maize research program started in 1953 with aid from USOM, a group of Thai researchers was sent for training in the United States. Among them was Ampol Senanarong from the DOA. When he came back in 1966, he gradually took over the maize program from the foreign experts in the Guatemala improvement program at Phra Phutthabat and other research stations. At the same time, Dr. Sujin Jinahyon, from Kasetsart University, received a Rockefeller Foundation scholarship to study plant breeding in the United States. When he came back in 1967, he started to build his research team. Dr. Sutat Sriwatanapongse joined him shortly afterwards. These three researchers were the first generation of maize breeders in Thailand. Each contributed greatly to maize research in Thailand.

During the 1970s, the research team from the University became very strong, particularly in plant breeding. Many graduate students were trained at Farm Suwan. The better ones were sent abroad for further training (Rockefeller scholarships). This second generation of maize breeder graduated and came back towards the end of the 1970s and groomed the third generation of researchers, who are now in charge of the research program. However, the team was not as strong as expected because many researchers left to join the private sector.

To get maximum mileage out of the University research, the DOA in the 1970s shifted its focus to complementary research: foundation seed production, agronomy, soil research and other applied research which enhanced diffusion of new technology. Maize breeding continued but on a smaller scale and focused on open-pollinated varieties (human consumption baby corn and sweet corn).

Fifty-one researchers were working on maize in the early 1980s (Table 3.3) - about 1 per cent of the total number of agricultural researchers. However, an unknown number of researchers from other disciplines are doing maize-related research. At the annual reporting session of the National Corn and Sorghum Research Program (NCSRP), there were about 200-250 participants. Most have researched some aspects of maize.

Table 3.3
Number of Maize and Sorghum Researchers

Year	Maize/Sorghum Total	Maize/Sorghum Per cent	Pathology	Entomology	Chemistry	Others	Total
1975	11	0.55	138	188	175	1473	1985
1976	18	0.85	148	197	183	1582	2128
1977	44	1.94	158	220	190	1654	2266
1978	48	1.95	177	250	195	1787	2457
1979	51	1.94	177	250	197	1959	2634
1980	51	1.83	203	264	209	2063	2790
1981	51	1.83	203	264	209	2055	2782
1982	18	0.59	205	275	226	2312	3036
1983	18	0.59	205	276	226	2331	3056
1984	18	0.67	138	153	176	2201	2680

Source : Israngura, 1986.

2. Laboratories and equipment

A well-equipped laboratory is expensive and takes a large research volume to justify. The most important "laboratory" for maize research is Farm Suwan. This first-class research station was built with Rockfeller Foundation funds in 1966-1969. The Foundation also funded part of the research in the NCSRP. The Thai government contributed most of the operating costs. The annual budget was about 2 million baht during the first few years and rose to 10 million in 1984. Cumulative expenditure to 1984 was about 74 million baht (Table 3.4).

Table 3.4
Government Expenditures on National Corn and Sorghum Research Center
(Million baht)

Year	Normal	Extra-budgetary	Total	Cumulated
1969	2.327		2.327	2.327
1970	1.418		1.418	3.745
1971	2.558		2.558	6.303
1972	2.09		2.09	8.393
1973	2.119		2.119	10.512
1974	2.353		2.353	12.865
1975	3.096		3.096	15.961
1976	3.303		3.303	19.264
1977	3.582		3.582	22.846
1978	4.859		4.859	27.705
1979	4.191		4.191	31.896
1980	4.135	3.461	7.596	39.492
1981	4.877	2.753	7.63	47.122
1982	4.285	3.652	7.937	55.059
1983	5.026	3.482	8.508	63.567
1984	4.253	6.176	10.429	73.996

Notes : Extra-budgetary expenditures refers to the use of income generated by the Center itself. Investment from Rockefeller is not included.

Source : Dulyasatit, N., 1984; Annual Budget Documents; National Corn and Sorghum Research Center.

Besides Farm Suwan, the Field Crop Research Institute of the DOA has 7 field crop research centers and 12 satellite research stations. These centers are not as fully equipped as Farm Suwan but can support many research activities (varietal trials, crop protection, fertilizer application, soil and water management, cropping systems, seed technology, pre- and post-harvest technology). A major task of the research station is to supply foundation seed to the Department of Agricultural Extension. Another job is to conduct yield trials for crops.

3. Genetic Material

Maize germplasm is the genetic material on which maize breeding is based. Since Thailand is not in the center of genetic diversity in maize, there is not enough domestic material for the breeding program. Genetic material, elite lines and exotic material have to be got from abroad. Thailand has depended heavily on genetic material from CIMMYT.

There is interest in collecting local germplasm for maize. This is from maize brought to Thailand up to 400 years ago. These materials are now kept, together with the germplasm on rice, at the Rangsit Rice Experimental Station.

These three factors - scientists, equipment and genetic material - are partly determined by available funding. Thailand is fortunate to have USAID and Rockefeller Foundation funds. But in the long run, Thailand has to count on government support. So far, the government has invested very little in maize research. The research intensity (expenditure compared to value of output) on maize has been less than 0.5 per cent over the past decade (Table 3.5). This is dangerous because without proper government support, the present research program cannot be maintained, let alone advanced.

Table 3.5
Expenditures on Maize and Sorghum and Expenditures of the National Corn and Sorghum Research Center (NCSRC)
(Million baht)

Year	Total	Intensity[1] Per cent	NCSRC Center	NCSRC Per cent share
1969	na	na	2.33	na
1970	na	na	1.42	na
1971	na	na	2.56	na
1972	na	na	2.09	na
1973	na	na	2.12	na
1974	na	na	2.35	na
1975	7.10	0.13	3.10	43.61
1976	8.50	0.19	3.30	38.86
1977	15.60	0.57	3.58	22.96
1978	16.80	0.37	4.86	28.92
1979	18.50	0.31	4.19	22.65
1980	18.50	0.25	7.60	41.06
1981	20.10	0.27	7.63	37.96
1982	17.10	0.28	7.94	46.42
1983	26.80	0.31	8.51	31.75
1984	24.80	0.25	10.43	42.05

1. Research Intensity = Research Expenditure/Crop Value

Source : Israngura, 1986.

C. Private Maize Research

Involvement of the private sector began around 1978. Release of Suwan 1 in 1974 interested the private seed companies. Production of seed by the University and the DOA, and the Seed Division, Department of Agricultural Extension, was not enough to satisfy growing demand for improved seed. This gap was filled by private seed companies.

Before 1978, most seed companies dealt only with vegetable seed. Since then, the number of seed firms has greatly increased. Of 200 companies, over 150 dealt with maize and other field crops (Setboonsarng, *et al.*, 1988).

The first maize seed companies were subsidiaries of major foreign seed firms - DeKalb, Pioneer and Continental Grain (Australia) (Table 3.6). Their interest in Thailand was as a market for their hybrid varieties. To lay down the marketing structure for their hybrid seeds, all except Pioneer started to produce and distribute open-pollinated Suwan seeds (Suwan 1 and 2). They also started research stations in the main production area to develop their hybrids for the Thai environment. By this time, some plant breeders directly or indirectly trained under the NCSRP were returning to Thailand - the future third generation of the program. These younger plant breeders and some of the top personnel at Farm Suwan and the DOA joined the private seed companies. They greatly strengthened the private sector and weakened the plant breeding capacity of the public sector.

Table 3.6
Foreign Partners of Major Field Crop Seed Companies

Company	Foreign Partner	Type of Venture
1. Pacific Seed	Continental Grain	Subsidiary
2. Ciba-Geigy	Ciba-Geigy	Subsidiary
3. Bangkok Seed (a CP Group Company)	DeKalb	Joint-venture
4. Pioneer Hybrid Co. (Thailand)	Pioneer International	Subsidiary
5. Cargill Seed	Cargill	Subsidiary

Source : Survey.

The number of small private seed companies grew rapidly in 1982-1984. Many just cleaned maize grain and sold it as seed. No research was needed. But some small Thai firms also produced seed from their own breeding programs and had to conduct research. These companies also produced hybrid seed using the inbred lines bought from the NCSRP.

The private seed companies launched their hybrids in 1980 but found it difficult to compete with the public Suwan 1 and 2 because these hybrids were only marginally better than Suwan. The market share of hybrid was less than 10 per cent during the early 1980s and improved only slightly in 1986-1987. Another reason for slow adoption of hybrid was the low world price of maize at this time (1986-1987). The marginal benefit, if at all, was not enough incentive for the farmer to make extra investment in seed.

Apart from its better response to fertilizer, hybrid is also more drought tolerant. So when rainfall was irregular after first coming early in the season, yields of open-pollinated varieties fell drastically but hybrids would perform better. After a few years' experience, the farmer started to appreciate hybrid seed. Drought tolerance is among the top characteristics private sector plant breeders put into their hybrid[13].

There were six Ph.D and fifteen MS level researchers in the seven major private seed companies. These companies dealt mainly with maize seed, both open-pollinated and hybrid (Table 3.7). Most Ph.D researchers were trained under the NCSRP. Total investment in the research stations is 94 million baht. This is higher than cumulative government expenditure in the NCSRP. More interesting is the operating budget. The seven companies spent about 40 million baht each year on research and production of foundation seed while the government spent about 30 million baht. This funding allowed the private sector to be relatively more flexible in its research program.

Table 3.7
Maize Research in the Private Sector

Year Began	Name	Research Station	Annual Budget (mill. baht)	Scientists Ph.D	MS	B.S.	Other Workers	Crops
1978	Pacific Seed	20	3.5	-	3	-	16	Maize, Sorghum Sunflower
1978	Chareon Thanyaphut	30	9	2	1	6	68	Maize, Sorghum Sunflower, Soybean Rice
1979	Cargill Seed	10	6	1	3	2	35	Maize, Sorghum Soybean, Rice
1980	Pioneer Hi-br	10	7	1	4	-	35	Maize, Sorghum
1981	Ciba-Geigy	20	8	1	2	5	69	Maize, Sorghum
1982	Thai Seed Ind	3.7	2	-	1	1	20	Maize, Sorghum
1984	Uni-Seed	-	4	1	1	2	14	Maize, Sorghum Mungbean, Vegetables
Total		93.7	39.5	6	15	16	257	

Source: Suwantharadol, 1989.

D. Interaction Between Public and Private Research

There are spill-over effects between public and private sector research in the production stage and in the output. Research requires many inputs, e.g., scientists, laboratories, equipment and research material. Interaction among scientists in the public and private sector, sharing of a central laboratory or equipment and sharing of research material are examples of spill-over at the research production level. At the same time, there is also interaction in the final outcome of research. For example, an improved open-pollinated variety of maize can have an effect on the direction and pace of research on hybrid maize. The following discussion focuses on interaction between public and private maize research production because there is only limited information available on private research outcome to analyse the interaction of research output.

1. Scientists

The pool of scientists in the public sector is much stronger than that in the private sector. When the private companies began operations in 1978, some major researchers, most of them trained at Kasetsart, left the public sector (University, DOA and Department of Agricultural Extension) to join private firms.

Aside from better pay (as much as eight times more) a big attraction of the private sector is that it is more flexible and not obstructed by bureaucratic red-tape. This "brain drain" is actually raising productivity of agricultural scientists in Thailand, at least in the short run. In the long run, the danger is that there will be no goose to lay the golden egg.

2. Research stations and equipment

Research stations and some laboratory equipment are quite expensive and too big for the limited size of the private sector. So the private sector has to use public sector facilities. The DOA is doing regional field trials for hybrid entries from both public and private sectors. These yield trials provide information for the companies and for other researchers.

3. Germplasm

The public sector will lose out here in the long run. In the early 1980s, it had more relevant germplasm for Thailand. But after 1985 the private sector, especially those firms with foreign parent companies, were stronger in this respect. The private sector had access to public open-pollinated germplasm and public inbred lines. The NCSRP was selling its inbred lines. In a few years these germplasms can be incorporated into collections in the parent companies. Some private firms, particularly Pioneer Hi-bred, have bigger germplasm stock than the CIMMYT. This is the spill-over of public research into the private sector. But there is little from the private to the public sector.

E. An Assessment of Technological Capability[14]

Technological capability can be assessed in terms of ability to acquire, operate, adapt and innovate.

1. Acquisitive capability

The maize research community in Thailand has a sound ability to search for, assess, test and transfer potential advances in maize technology.

2. Operative capability

This is the ability to control, maintain and upgrade the skills of the researcher and user (farmers). Experience has shown the researcher can adjust to use new technology quite quickly. Two examples in other crops are use of tissue culture in orchid and hybrid tomato seed production. Use of hybrid maize is another example. The slow adoption of hybrid maize was not due to the ignorance of the farmer. Many studies show hybrids are simply not economical.

3. Adaptive capability

As seen in Section A above, there are many bachelor and master degree students in agriculture and this pool of personnel has proven competent in modifying available technology to fit Thai conditions. Availablity of research centers around the country is vital for this. The research institute in biotechnology also enables research to be done to adapt new technology to Thai conditions.

4. Innovative capability

Making radical change or inventing new technology for maize is difficult in Thailand. The main reason is lack of support in basic research in all fields necessary for generation of new knowledge. The discussion in the previous sections indicates the strength of maize research in Thailand lies in maize breeding. Much stronger support from basic research on plant physiology, plant pathology, entomology, soil physics, etc., is needed before the maize research program can innovate.

The strength of the system is in acquiring, operating and adapting research. Its weakness is invention of new research. However, it is arguable whether invention should be the aim of a research system, especially in a developing country like Thailand.

IV. DIFFUSION OF MAIZE TECHNOLOGY

Farmers are the target end-users of maize technology. Knowledge from research is transferred to the end-user in many forms. The most important advances in maize technology come from plant breeding. So technology is roughly either embodied or not in the seed[15]. For technology embodied in the seed, diffusion is through the seed market. For the research result not embodied in the seed, the extension system in both public and private sectors is the means of diffusion.

A. The Maize Seed Market in Thailand

With a cultivated maize area of 1.9 million hectares and a seed rate of about 20 kg/hectare, about 38,000 tons of seed are required each year. Before 1980, farmers met most of their needs by retaining seed from the previous harvest. But more and more farmers are buying seed. CIMMYT (1987) reported that 53 per cent of the seed used in Thailand is commercial seed[16]. The market for maize seed in Thailand ranks second after vegetable seed.

1. Public seed production and distribution system[17]

A small portion of maize seed came from the public seed program and a slightly larger portion from private seed companies. In 1987, provision of seed by the government met only 6 per cent of total seed requirements compared to 7.4 per cent in 1982 (Table 4.1). Seed supplied by the public sector has declined.

Table 4.1
Open-Pollinated and Hybrid Seed Sold

Year	Seed Required (tons)	Open-Pollinated				Hybrid			
		DOAE (tons)	Share (per cent)	Private[1] (tons)	Share (per cent)	NCSRC (tons)	Share (per cent)	Private[2] (tons)	Share (per cent)
1981	31,295.59	na	na	1,492	4.77	na	na	40	0.13
1982	33,527.68	2,487	7.42	3,910	11.66	1.9	0.01	145	0.43
1983	33,712.29	2,511	7.45	6,750	20.02	45.0	0.13	449	1.33
1984	36,276.42	2,706	7.46	15,750	43.41	16.0	0.04	897	2.47
1985	39,543.50	2,619	6.62	11,000	27.82	120.0	0.30	1,740	4.40
1986	36,957.13	2,493	6.40	7,200	18.48	30.0	0.08	1,810	4.65
1987	34,955.40	2,097	6.00	7,000	20.03	4.0	0.01	1,638	4.69
1988				9,000				3,000	

Sources: Agricultural Statistics of Thailand, OAE; National Corn and Sorghum Research Center (NCSRC);

Notes: 1. Jitsing, 1988.
2. Suwanthradol, 1988.

In the public sector, breeder and foundation seeds are produced by the National Corn and Sorghum Research Center (NCSRC) and the DOA. They receive genetic material from international research centers like CIMMYT and ICRISAT. Once the research program establishes a "good" variety, it will be passed on to the propagation mechanism. The foundation seed will be produced by the DOA at its research stations around the country. For maize, Nakorn Sawan Research Center of the Field Crop Research Institute is the designated maize research center. For Suwan varieties, the DOA supplied only about a third of the total foundation seed. The rest came from the NCSRC (Table 4.2). This is because the DOA has to get breeder seed from the NCSRC. With the release of Nakorn Sawan 1 (NS 1), it is expected that supply of foundation seed from the DOA will increase.

Table 4.2
Production of Foundation Seed

Year	DOA	NCSRC				Total
		SUWAN 1	SUWAN 2	Sup.Sweet	Total	
1982	43	233	71	2.3	306.33	49.3
1983	71	365	48	5.0	418.0	489.0
1984	110	479	34	4.5	517.5	627.5
1985	110	303	106	9.5	418.5	528.5
1986	108	300	80	10.0	390.0	498.0
1987	108	128	111	77.0	316.0	424.0

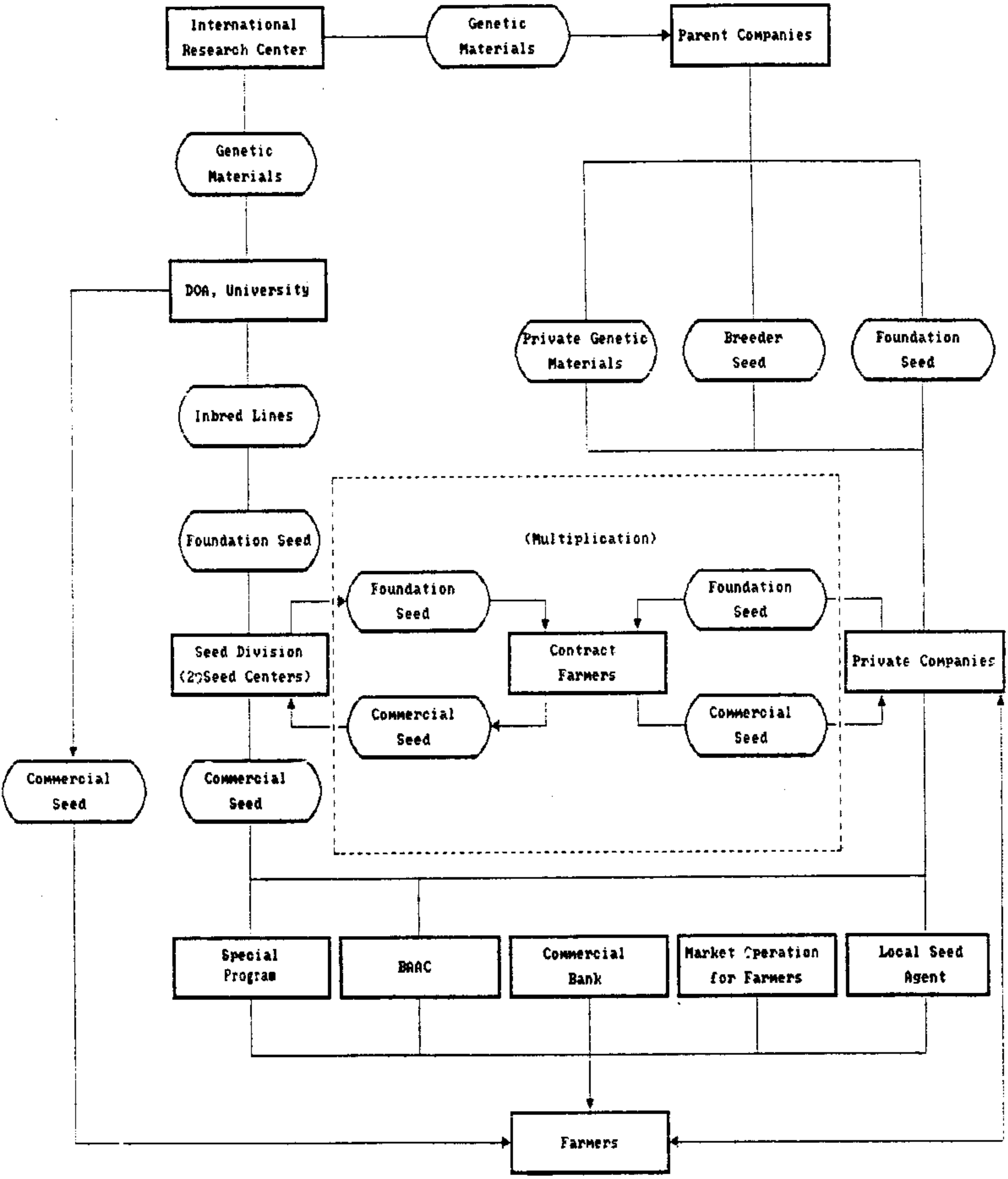
Sources: Department of Agriculture; National Corn and Sorghum Research Centre.

The NCSRC also produces and sells inbred lines to the private sector, both Thai and foreign companies in Thailand, at about 10 baht per seed (Ruangchan, 1984). The argument is that it helps the small firm compete better with the big foreign firms in the hybrid market.

These foundation seeds are delivered to seed centers of the Seed Division, Department of Agricultural Extension, to be multiplied. The seed centers contract with farmers to multiply the seed. The buy-back price of maize seed from the contract farmer is 10-15 per cent above grain price. Once the seed center gets these seeds from the farmer, it dries, cleans, selects and coats the seed with chemical (to prevent rot) and packages and stores it. The seed from each center is then shipped.

Most maize seed produced by the seed centers is distributed through special programs (85 per cent of it in 1986), such as drought relief and other farm subsidy programs. About 10 per cent is sold directly to farmers. The structure of public seed production and distribution is shown in Figure 4.1.

Figure 4.1


International Research Center
Genetic Materials
Parent Companies
Genetic Materials
DOA, University
Private Genetic Materials
Breeder Seed
Foundation Seed
Inbred Lines
Foundation Seed
(Multiplication)
Foundation Seed
Foundation Seed
Seed Division (2?Seed Centers)
Contract Farmers
Private Companies
Commercial Seed
Commercial Seed
Commercial Seed
Commercial Seed
Special Program
BAAC
Commercial Bank
Market Operation for Farmers
Local Seed Agent
Farmers

For the seed sold to the farmer, credit organizations (the Bank of Agriculture and Cooperatives or commercial banks) are the agencies the Seed Division will approach to distribute seed to the farmer.

All seed sold by the Department of Agricultural Extension is open-pollinated. The DOA does not produce and sell hybrid seed. Although some hybrid research is done at the DOA, it is not for production and sale. Research aims more at understanding technology and monitoring it effectively.

Maize seed provision by the Seed Center and the NCSRC regulates the seed market in terms of quantity, quality and price. The yield of open-pollinated seed is the basis for pricing hybrid seed because the price of hybrid cannot exceed that of open-pollinated seed, plus the marginal gain from using hybrid seed. Research on open-pollinated varieties is thus very important in maintaining this bargaining position for the farmer. Sales of inbred lines from the NCSRC is also a way to maintain competition in the hybrid market.

2. Private seed companies

The private maize seed companies have become important over the past decade. Many big companies started operating in the late 1970s and early 1980s (Table 4.3). In the early 1980s, there were more than 80 maize seed companies. The main cause of their rapid growth was shortage of Suwan seed. When farmers accepted Suwan, demand for its seed rose dramatically. Production of Suwan seed by the public sector was only 5-6 per cent of total demand. If the Seed Division had expanded its production of Suwan seed, it would have had a big marketing problem because its distribution system was geared to meet the needs of other public programs, not for the maize farmer. This was a big opportunity for private seed companies.

Table 4.3
Seed Production Capability of Private Sector

Year Started	Companies	Plant and Equipment (Million baht)	Capacity (ton/year)	Workers Field	Plant	Others	Total
1978	Bangkok Seed Industry (CP)	60	20,000	19	32	110	161
1979	Pacific Seed	31	10,000	2	1	30	33
1979	Cargill Seed	60	15,000	15	12	80	107
1981	Pioneer Hi-bred	10	3,000	7	3	20	30
1983	Thai Seed	2	2,700	3	3	30	36
1984	Uni-Seed	3	5,000	4	4	20	28
1986	Ciba-Geigy	-		5	-	7	12
Total		166	55,700	55	55	297	407

Source: Suwantharadol, 1989.

In 1988, the seven big maize seed companies put over 166 million baht into plant and equipment. Their total capacity is 55,700 tons a year. This is calculated at a one-shift capacity. Each company is producing more than just maize however. Most are also producing sorghum seed. About 400 workers work in the field and at processing plants. This is a small number. The firms can easily increase production capacity by hiring more workers. So these seven companies can meet the needs of the entire Thai market.

Table 4.1 shows the market share of private companies for open-pollinated varieties (especially Suwan 1) rising from 4 per cent in 1981 to about 20 per cent in 1987. However, the aim of the private seed companies is not to sell open-pollinated seed. Their target is hybrid seed. The share of hybrid seed started from a small 0.13 per cent in 1981 and was 5 per cent in 1987. In 1988, hybrid seed sales almost doubled, partly because of drought and partly because of good maize prices. If this trend continues for a few years, the private seed companies will have total control over the maize seed market.

Private seed companies are selling open-pollinated seed. This helps the government disseminate the technology. But the gain for the seed companies is not the small profit they make on improving the quality of these open-pollinated maize grains. The main benefit comes from establishment of market infrastructure for their hybrid seeds. It is an investment in building up marketing power, a time-consuming process, (Setboonsarng *et al.*, 1988).

The maize seed market in Thailand is highly competitive (Table 4.4). The major junction in the seed marketing channel is the local dealer. These are usually agricultural input suppliers. Seed is a relatively small item in sales volume for them. So to promote the seed, the seed company has to stimulate demand from the farmer instead of giving incentives to the seed seller. This strategy is expensive if potential customers are scattered and not homogeneous. Fortunately, maize farmers tend to concentrate in a particular area for agro-ecological reasons. So on-farm demonstration is the way most seed companies promote their products.

Table 4.4
Selling Price of Improved Seed from DOAE and Private Seed Companies
1986 and 1987
(Baht/kg)

Crops	DOAE		PRIVATE		KU	
	1986	1987	1986	1987	1986	1987
Maize (Suwan 1)						
(Suwan 2)	12	10	12-16	6-12	12	12
Hybrid corn	-	-	32-35	18-33	30	30
Sorghum	7	7	(-)	15	12	12
Hybrid sorghum	-	-	40	37-39	-	-
Sweet corn	40	40	15-35	15-39	50	50

Source: Setboonsarng *et al.* (1988).

3. Public versus Private

The private sector's sales of open-pollinated seed suggests research in the public sector is more advanced than in the private sector. Should the public sector slow down? The response from the private sector is that the government should keep up its research and promote hybrid seed more vigorously. There is a clear spill-over of benefit from the public maize research program to the private sector both in terms of germplasm development, trained personnel and research station services.

A finer question is the public sector role in hybrid seed production and distribution. The likelihood of increasing the yield of hybrid is much higher than increasing the yield of open-pollinated varieties[18]. This is because hybridization is a faster and easier way to draw from the genetic pool of dent corn, which offers higher yield. If the public sector moved into hybrid maize research and sold the inbred line to private companies, who would benefit? For the consumer, there would be more maize and the price of maize would drop. For the producer, companies that used these inbred lines in their foreign markets would benefit. Since the maize market in Thailand is probably smaller than elsewhere, the potential spill-over may be greater than the marginal gain in the Thai market. The government may have to weigh this benefit and cost carefully.

4. Regulations in the seed market

The Seed Law of 1964 require traders (collectors, importers and retailers) to register with the Seed and Agricultural Control Sub-division, Department of Agriculture. All seed sold must meet a minimum standard. For maize seed, a minimum germination rate of 68 per cent and purity of 90 per cent are required. Importers are also required to observe standards stipulated in the Seed Law. The aim of the seed law is to protect the farmer from low quality seed.

A tariff of 6 per cent on imported seed protects the domestic producer. However, a small amount of maize seed is imported. There is no tax on seed exports. Some seed (mostly hybrid) is exported to neighboring countries, especially Indonesia. These are mostly transactions among subsidiaries of multinational corporations, mainly to unload surplus or relieve temporary shortages in a particular market. Private seed companies do not foresee a large international trade in maize seed because the difference in cost structure does not offer high enough profit to offset the transportation costs. There is no government barrier to trading in seed.

5. Seed certification

There is no seed certification system in Thailand. Private seed companies have asked the DOA to set one up since it is quite well equipped, especially with research centers and stations around the country. The manpower requirement is not high. A few additional personnel would be sufficient.

The DOA replied that managing a certification system is more than just running a few yield trials. It involves monitoring the performance of a certified variety over a period. It added that in the past, this encouraged bribery and could be used against competitors in the market.

However, there is a "release variety" system which subjects a candidate variety to tests in different parts of the country before release to the public. Its characteristics under various conditions are made known to the public. The DOA will do a yield trial test for varieties of a private company and release the result as public information. Both open-pollinated and hybrid seed are tested.

B. Dissemination of Disembodied Technology

The DOA organizes a "field day" each year to allow farmers to see new maize varieties and distributes sample seed. The Department of Agricultural Extension has a demonstration field plot in many maize-growing areas to promote maize technology, including new varieties and hybrids. Other items such as herbicides, fertilizers and pesticides are promoted more through leaflets and personal contact. Transfer of disembodied technology to the farmer is not too successful.

C. Diffusion of New Technology

Diffusion of improved maize varieties is quite extensive in Thailand. Since the release of Suwan 1 in 1974, adoption has been growing rapidly. By 1981, about 75 per cent of farmers were using Suwan 1 and this increased to 84 per cent in 1985 (Table 4.5). CIMMYT (1987) was less optimistic. It reported that only 70 per cent of the total area was under improved varieties in 1985. This would be correct if white maize and other native maize were taken into consideration. All areas are probably under modern varieties now.

More interesting is the size of the market for hybrid maize. The increase in maize price has induced a big increase in demand for hybrid seed. Its share of 16 per cent in 1985 reported in Table 4.5 is too optimistic. Seed sales suggested a planted area of less than 10 per cent in 1988. But it is important to note its rapid expansion.

Table 4.5
Diffusion of Improved Maize Varieties

Year	Per cent of Farmers in Each Variety					
	Native	P.B.X.[1]	Th. Compo.[1]	Suwan 1	Suwan 2	Hybrid
1978	68.4	19.7	-	11.9	-	-
1979	64.1	12.5	-	23.4	-	-
1981	7.9	3.7	0.4	75.2	12.8	-
1982	1.2	-	-	81.4	17.4	-
1983	3.7	-	-	75.9	16.7	3.7
1984	-	-	-	29.4	70.6	-
1985	-	-	-	84.2	-	15.8

Note: 1. P.B.X. refers to the all Pra Bhuthabat varieties; Th. Compo. refers to all the Thai Composite varieties.
Source: Setboonsarng *et al.* (1988).

D. Interaction with Research in Other Crops

Maize and sorghum research began at about the same time. The rapid increase in maize production attracts more resources and attention than sorghum, whose planted area is less. However, the similarity of the two crops makes research into maize, which grows faster, benefit research into sorghum. There are a few open-pollinated and hybrid sorghum varieties released by the Department of Agriculture and the University.

Research on the cropping system of maize also involves studying other crops, chiefly mungbean and soybean grown after the main maize crop.

One important impact of increased maize production through technological improvement is lower price. This and its availability are a big encouragement to growth in the poultry sector. Thailand now exports about 100,000 tons of poultry meat. Maize is the most important component of poultry feed (about 65 per cent of its weight).

V. FUTURE MAIZE TECHNOLOGY IN THAILAND: POTENTIAL AND LIMITS

Two very important changes in the maize market will dictate its direction in the coming decade. The first is the constraint of the land frontier. The major source of output growth in the past was expansion of cultivated area. The land frontier has been closed since the early 1980s. Moreover, in the past, maize had expanded into many watershed and high slope areas. As the government is now more strict about conservation, those areas may be forced out of maize. Thus, the potential maize cultivation area will probably be reduced. The second factor is the increase in the domestic demand for maize. Foreign markets have been the major determinant of maize development in Thailand. This will change considerably in the coming decade. The sharp increase in demand from the domestic feed industry may force Thailand to become a maize importer or at least a major source of demand.

A. Regional Differences in Source of Growth

The increase in maize production over the past decade can be attributed to both area expansion and yield increase. The index of output, planted area and yield between 1981-87 in Table 5.1 shows a general decline in production after its all-time peak in 1985. It is unlikely Thailand could increase the maize cultivation area beyond the 1985 level (1.9 million ha).

Table 5.1
Index of Output, Planted Area and Yield

Year	Output					Area					Yield				
	NE	UN	LN	CP	BV	NE	UN	LN	CP	BV	NE	UN	LN	CP	BV
1981	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00
1982	79.12	70.64	89.04	94.94	97.54	103.89	113.84	104.10	113.62	116.25	76.90	62.05	85.53	83.56	83.90
1983	96.44	89.54	111.35	104.65	100.81	93.02	105.70	115.39	121.62	114.89	103.68	84.71	96.50	86.05	87.74
1984	108.55	103.03	134.65	68.81	126.04	94.84	110.33	126.73	75.47	129.39	114.46	93.38	106.21	91.17	97.41
1985	129.23	107.02	146.77	145.17	162.63	107.10	110.67	129.82	164.15	149.74	120.66	96.70	113.06	86.44	108.61
1986	108.10	130.60	132.13	134.58	130.28	107.88	123.61	128.00	160.83	139.85	100.31	105.65	103.23	83.67	93.16
1987	80.67	85.88	69.92	60.16	96.58	90.79	98.05	116.38	103.25	136.12	88.85	87.58	60.08	58.27	70.95

Source: NCSRC.

In the area and yield indices in 1985, there is a wide variation in the source of growth across regions. In the Northeast, 20 per cent of its 29 per cent increase in output comes from yield. Only 7 per cent comes from planted area. For the lower North, the major production area, 13 per cent of its 46 per cent growth comes from yield. However, in the new area in the East-West region, 49 per cent of its 62 per cent increase in output comes from area expansion, while yield contributes only about 9 per cent. Yield indices for the upper North and Central regions decrease because of rapid expansion in planted area.

An important cause of decline in planted area after 1985 is the relatively attractive price of soybean. Increased protection against the import of soybean meal and soybean oil since 1984 gave rise to a protection of about 35 per cent on the price of soybean. The area used for production of both soybean and maize in the Central and East-West region felt this most strongly.

B. Government Maize Production Policy

The target of maize policy is to increase production to accommodate both the export and domestic markets.

To increase production, the Agriculture and Cooperatives Policy and Development Planning Committee of the MOAC divided maize production into three zones : export (10 provinces, 57 per cent of maize area), general (8 provinces, 21 per cent) and a zone requiring special attention (about 22 per cent of maize area). Policy is to raise yield in all these regions: from 2.5 to 2.8 tons/ha in the export zone, from 2.2 to 2.5 tons/ha in the general zone and in the special zone the minimum should be 2.2 tons/ha.

To do this, the government plans to emphasize investment in research and extension. For research, the first priority is to breed a higher-yield variety with drought and insect resistance. Secondly, to determine a cropping system which reduces damage from environment and disease. Thirdly, research to prevent aflatoxin at farm and collecting level. And finally, technology should be cheap and affordable by the small farmer.

Limits on land have become a major problem in maize production. In 1989, the MOAC withdrew all its logging concessions to prevent encroachment of forest areas. This indirectly affected expansion of the maize cultivation area which depended on bringing virgin forest land into cultivation. So the maize cultivation area will fall from about 1.9 to 1.44 million hectares.

This means the government may have to focus its efforts on the first two zones - export and general. Can it do this? The bottom line is that there will be less cultivated area for maize.

C. Potential Yield Increase

Given the Suwan 1 yield of 6 tons/ha at research station conditions and a 30 per cent yield gap for farmer's field, the potential for Suwan 1 is still as high as 4.2 tons/ha. There is great potential for increasing maize yield in Thailand because the national average is only 2.2 tons/ha. Table 5.2 shows the yield per farmer in an integrated farming system to be twice as high in 1987 and 68 per cent higher in 1988 than that of a farmer outside the system.

Table 5.2
Farmers In and Outside the Integrated Farming System

Year	Planted Area	Number of Members	Average Yield In Project (kg/ha)	Average Yield Not in Project (kg/ha)
1987	3,222.08	1,148	3,550	1,756
1988	45,398.56	16,685	4,047	2,406

Source: Thailand Corn and Sorghum Research Institute, 1987;

To boost land productivity, there are two major routes: increase land utilization and increase input use. Land utilization can be increased by either boosting the density of plant per area or increasing cropping intensity. Better farming practice and cropping systems are the two ways to achieve this.

Three major inputs can increase yield per land area: better seed, fertilizers, herbicides and pesticides.

From the verification trial of six treatments at the farmer's field in 20 locations in 1985, the yield increase is analyzed holding the soil properties of each location constant. The result, shown in Table 5.3, is discussed below.

Table 5.3
Yield Changes for Five Treatments

Ordinary Least Squares Estimates	
Dependent Variable	YIELD
Number of Observations	120
Mean of Dependent Variable	4755.19167
Std. Development of Dependent Variable	1636.39262
Std. Error of Regression	1491.98408
Sum of Squared Residuals	.24264E+09
R - Squared	0.23856
Adjusted R - Squared	0.16871
F-Statistic (10, 109)	3.41507
Significance of F-Test	0.00068
Log-Likelihood	-1041.4
Restricted (Slopes = 0) Log-L	-1057.8
Chi-Squared (10)	32.695
Significance Level	.30643E-03
Durbin-Watson Statistic	1.7786
Estimated Autocorrelation (Rho)	0.1107

Table 5.3 (continued)

Variable	Coefficient	Std. Error	T-Ratio	(Sig. Lvl)	Mean of X	Std.Dev. of X
One	4251.49	460.905	9.224	(.00000)	1.0000	.00000
Black Soil	415.397	280.174	1.483	(.13693)	.60000	.49195
PH	146.941	87.5947	1.678	(.09229)	5.4900	2.8148
Om	-524.705	172.825	-3.036	(.00313)	2.0400	1.3358
P	-11.173	11.3161	-0.987	(.32737)	16.140	17.298
K	-0.417301	1.71414	-0.243	(.79502)	120.55	114.59
Treat. 1	293.45	471.807	0.622	(.54266)	.16667	.37424
Treat. 2	549.3	471.807	1.164	(.24538)	.16667	.37424
Treat. 3	1559.2	471.807	3.305	(.00144)	.16667	.37424
Treat. 4	613.2	471.807	1.300	(.19333)	.16667	.37424
Treat. 5	1477.6	471.807	3.132	(.00238)	.16667	.37424
Sigma	1491.98	96.3072	15.492	(.00000)		

1. *Application of commercial open-pollinated seed (Suwan 1) and recommended plant spacing*

The result of this treatment shows a yield increase of 293 kg/ha (about 6.17 per cent of the farmer's practice level). However, this increase gives a high level of variation and so is not statistically significant.

2. *Application of weed control (2.5 kg of atrazine/ha) on top of the first treatment*

This increases yield by 549.3 kg/ha, an addition of 255.85 kg, or 6.05 per cent. There is a decrease in yield variation but the result is still not significant statistically.

3. *Application of an additional 190 kg/ha of fertilizer, 21-0-0 on top of the second treatment*

The yield increases by 1,559.2 kg/ha from the farmer's level, a marginal increase of another 1,009.9 kg/ha or 21.24 per cent from the second treatment. This increase in yield is less variable and hence statistically significant from the farmer's level. The increase in fertilizer application is technologically the most important source of growth.

4. *Using hybrid seed (Suwan 2301) with recommended plant spacing arrangement and weed control*

This will increase the yield by 613.2 kg (11.63 per cent) from the farmer's level and 63.9 kg (or about 1.33 per cent) from the similar treatment using open-pollinated seed. This treatment is not statistically different from the farmer's practice.

5. Application of fertilizer (190 kg/ha of 21-0-0) on top of 4

The yield increase from the farmer's level is 1477.6 kg/ha, but 81.6 kg/ha less than that with open-pollinated seed. This treatment is significantly different from the farmer's practice but the fertilizer response is not as good as the open-pollinated seed.

Harrington (1987) analyzed the data from similar verification trials at 59 farms between 1983-85 using the partial budget analysis and found that the highest pay-off for the farmer is in applying herbicide (atrazine). The second highest pay-off is to use improved seed (Suwan 1) with new farming practices. Application of 21-0-0 fertilizer is the third choice. He also found that use of hybrid seed usually has a negative pay-off. This is confirmed by yield trials at Farm Suwan using private hybrid seed sold on the market (Table 5.4).

Table 5.4
Comparison of Open-Pollinated and Hybrid Varieties, Farm Suwan, 1985

	Early Season			Late Season		
	Open-Pollinated		Hybrid	Open-Pollinated		Hybrid
	Suwan 1	Suwan 2		Suwan 1	Suwan 2	
Average Yield						
kg/ha	7,137	6,373	7,168	4,915	4,821	5,628
C.V.	9.9	8.5	13	10.2	8.3	7.8
% germination						
Lab.	92	97	98	92	97	97
Average	3.9	2.2	2.8	7.8	1.6	2.9
C.V.						
Field						
Average	84	88	89	66	66	73
C.V.	8.3	8.3	6.6	8.8	7.1	8.1

Source: Rungchang, P., *et al.*, "Corn and Sorghum Seed Production", 1985, Thailand National Corn and Sorghum Program, 1986 Annual Report.

Although fertilizer application can increase yield, it is not popular because fertilizer is expensive in Thailand. The nitrogen price is about six times the price of maize (Table 5.5). Another reason for the low use of fertilizer is that most maize is grown in the rain-fed area. High variation in rainfall in maize areas increases the risk in fertilizer application. So the expected economic return from fertilizer application is low.

Table 5.5
Price of Nitrogen and Price of Maize
1988
(Baht/kg)

Month	Price of Nitrogen	Price of Maize	Ratio
May	17.49	3.12	5.60
June	17.49	3.02	5.80
July	17.96	3.23	5.56
August	18.90	2.95	6.42
September	18.90	2.91	6.49
October	17.96	2.98	6.03
November	17.96	3.04	5.90
December	17.96	3.08	5.84
Average			5.95

Perhaps the quickest way to improve yield is to give the farmer a higher yielding seed. The verification trial data shows that although hybrid seed can give higher yield, the marginal increase in yield is not attractive enough. Aside from costing more (about three times), hybrid grain cannot be retained as seed. Also, the hybrid seed used in the trials is from the NCSRC, not from private companies. Hybrids from private companies may perform better than public hybrids.

So better plant spacing and use of herbicides can increase maize yield by 11.55 per cent.

The results of the integrated maize cultivation program of a big animal feed company shown in Table 5.2 found the main source of growth was use of hybrid and application of fertilizer. Farmers in the program could apply fertilizer because their maize field was irrigated. If irrigation is made available, maize yield often doubles. Since irrigation is a big investment and common resource, it is unlikely a large area can be brought into maize cultivation under this program.

It is also found that land preparation technique (deeper ploughing and cross-ploughing) can enhance maize's tolerance of drought (Kongtrakultian, Montri, 1989). This would prevent loss rather than increase yield, but it can be used to increase total output of maize.

D. Future Maize Technology

1. General strategy

Leading maize technologists in Thailand believe the most important future source of maize yield will be better hybrid varieties. The advantage of improving maize variety over increasing inputs is the better diffusion system (the active maize seed market).

a) Going "dent". To breed for yield increase, the research program has to move into "dent" varieties (from "flint" maize). Most private hybrid maize varieties on the market are now semi-dent.

b) Hybrid over open-pollinated. The potential to expand the yield of the open-pollinated variety is restricted because of the limited germplasm available to improve the existing population.

With the present research budget and facilities, a new variety can be achieved within five years. The minimum level of yield increase will be as much as 200 kg per rai or about 1.2 ton/ha.

This would require coordination of all research resources in maize. The total research budget in maize is currently some 25 million baht a year. So about 125 million baht is needed plus use of existing research facilities.

2. Breeding aims

The primary breeding objective will be yield enhancement with resistances as secondary objectives.

a) Disease resistance. Breeding for disease resistance is more promising than for insect resistance. Insect resistance is difficult to breed into the plant because the insect can build up its resistance level. There are also many pests in the tropical environment. Breeding for disease resistance is the main area where genetic engineering can be applied. It can greatly speed up research.

b) Drought resistance. Drought is becoming more severe. Greater rainfall irregularity increases the risk to maize production. However, drought resistance research is not popular in the public sector because research in drought-prone areas is high risk. A failed experiment does not count towards career promotion. It is a bad mark, so it has a low priority on the public research agenda. This is very different from the private sector. All private seed compaines make drought tolerance their top breeding objective. This is partly because they are dealing with hybrid seed. To induce the farmer to increase investment in buying hybrid seed, this safety measure should be there to protect them against this loss.

3. Technique

For the coming decade, research into maize will still be dominated by plant breeding. New techniques, like tissue culture, will speed up plant breeding. Genetic engineering could be very important. But for Thailand, where agricultural research is still limited, laying the foundation and appropriate infrastructure is the major task for the next decade.

4. Role of private seed companies

Their increasing share of the commercial seed market suggests private companies will become more important. With the greater importance of hybrid maize, the role of the private sector is even more obvious.

E. Obstacles to Research

To provide the maize farmer with the best seed, all three major actors - government agencies (including universities), private companies and international agencies - should work together to develop and diffuse the new knowledge. This would require appropriate incentives at each level to guide their research.

1. Public

Public sector research has two main obstacles: limited budget and inadequate incentives. Agricultural research generally has a long-term pay-off, so investment in it is not popular because politicians who decide the budget prefer fast response. For maize, the budget is about 0.3 per cent of total maize value.

A more damaging constraint is its incentive structure and administrative procedure. Non-university researchers' salaries in the public sector are low and they are not allowed to earn income from doing projects like the university researcher. So better researchers either join the university, international agencies or private companies. This problem is more severe now salaries in the private sector are increasing rapidly with economic growth, while in the public sector they increase less than the inflation rate. Only the more senior and more established maize researchers remain in the public sector. Almost all the younger and more active are in the private sector.

The promotion procedure in the public sector is subject to Civil Service Commission (CSC) rules which are harmful to the agricultural research community. Since the CSC, which has the final say in approving promotion of a researcher, does not have the expertise to evaluate the quality of research, it goes by the number of projects done, which have thus expanded rapidly. There are many other administrative details not conducive to good research. For example, promotion is based on diversity of topics researched.

Coordination is also a big problem in public sector research. An outside catalyst is needed to pull these scattered resources together.

2. Private

There are two possibilities for private sector maize research: spending more on research in seed companies, or setting up a private company which specializes in maize research and sells the research results.

There are two kinds of private seed companies: foreign companies (subsidiaries or joint venture) and local Thai companies. The two types differ greatly in access to research support. Foreign companies usually have access to a larger germplasm stock, both from their parent companies and from the public sector, while the local Thai company depends on domestic public research support.

The major constraint to private company research is the size of the potential seed market. There are at least seven major seed companies. If each had an equal share, it would be about 15 per cent[19]. This would not justify much investment in research. So the strategy for each seed company is to invest enough to do applied research, to extend the research results of the parent company and of the public sector. The local company has limited resources and cannot embark on any serious research. They depend on the public sector for more basic research, while their experimental stations concentrate on applied research.

Market size also rules out setting up private firms to do research and sell the results. However, the private seed companies in Thailand, both foreign-based and local, can buy technology (germplasm and expertise) from specialized maize research firms in developed countries. This has not happened yet because the price of such research is high and foreign expertise is not geared to a tropical environment.

Two legal questions relate to research investment: intellectual property rights and seed law.

a) Intellectual property rights. The small market is a disincentive to private companies to develop basic research in Thailand, which will be done at the headquarters of major seed companies. Intellectual property rights would be intended to protect research in the developed country, not to encourage research investment in Thailand.

Plant breeders would welcome such rights and/or patents of maize variety. But they do not think it would stimulate additional research in Thailand. On the contrary, it might be used as an excuse by politicians to cut public support for agricultural research.

Trade secrecy is not a good alternative for protecting knowledge in plant breeding, especially in such a competitive market. Most researchers feel exchange of knowledge and cooperation is more beneficial.

Since private sector research is more applied, its applications are area-specific. Each seed company seeks to build up its own market infrastructure. Markets are segmented and each company is developing a special variety to retain its territory.

An important obstacle to intellectual property rights legislation is enforcement. The court system is not sophisticated enough to do it. The CSC's problem with the promotion of public sector researchers is an example of such lack of manpower.

b) Seed Law. The Seed Law 2518 (1965) aims to protect farmers from fraud and prevent export of commercially important germplasm. As noted, there is no seed certification system in Thailand. It is felt the public sector should at least install a simple seed certification system. The DOA provides a yield verification test for private seed varieties and makes the results public.

Private seed companies promote their brand names and varieties and competition forces them to do research to keep up with each other. Here, they are fully protected by the Seed Law. But there is insufficient trained manpower at the DOA and lack of coordination with the police, who can arrest and punish the violator.

To sum up, with the shrinking of the potential maize area and growing domestic demand, increased production will have to come from increased productivity of land. The best source of growth is application of fertilizer. But most of the maize area is in rain-fed conditions. Where rainfall is irregular, application of fertilizer is very risky. Moreover, fertilizer is expensive compared with maize. The best choice is to use herbicide with proper plant arrangement. This would increase yield about 11 per cent. To go beyond that, technology would have to breed a higher-yield maize variety. The existing germplasm indicates hybrid dent corn as the future of maize research. The major constraint would be coordination of resources among government agencies and private companies. The major block to private investment in maize is its relatively small market. This dictates the extension nature of private maize research in Thailand. Intellectual property rights and patents for new maize varieties would benefit plant breeders in foreign countries, not Thailand, because of the applied nature of the research. Private companies would however benefit from better enforcement of the Seed Law.

VI. CONCLUSIONS AND COUNTRY PROSPECTS

In the coming decade, there will be a major change in the maize market in Thailand. On the supply side, its traditional source of growth from land expansion will not only be discontinued but the planting area will be reduced. On the demand side, the increase in the domestic demand for animal feed will dominate its traditional export demand. Moreover, there is a rapidly growing demand for baby corn for export. Although this is small it will take some of the maize area away from production for animal feed. The most important source of future maize growth is yield increase.

The maize research system in Thailand evolved from a mass-selection stage in the 1960s to applied plant breeding techniques in the 1970s and 1980s. Thailand started genetic engineering research in the early 1980s. Agriculture and medical research are the main aims of these programs.

Maize research in Thailand is designed for adaptive research. It cannot innovate and its basic research capacity is still being developed. The market is not big enough to accommodate serious basic research.

Biotechnology may speed up research into plant breeding, but genetic engineering will take some time to bear fruit. Breeding for a new hybrid dent variety will be the future direction of research in Thailand. But the major obstacle to yield increase is the problem of applying fertilizer.

Intellectual property rights would not benefit the Thai research community much. If it does adopt the system, enforcement could not be effectively carried out and the cost for a private company to enforce its rights would be very high. Enforcement manpower is not there and the present level of competition in the seed market does not call for such a law.

Market size is a dominant constraint in luring research investment from the private sector. For an investment on maize to have adequate pay-off, the regional market would have to be considered. The opening up of Laos, Vietnam and possibly Myanmar would offer this market opportunity. Thailand is a regional power in maize technology. So building the base in Thailand, where the infrastructure exists, is a good strategy.

NOTES AND REFERENCES

1. He brought two dent corn varieties: Nicholson's Yellow Dent and Mexican June. Their seed was multiplied and sold to farmers in the Northeast. (Krisdakorn, 1936).

2. The Friendship Highway was built by the United States for military purposes during the Vietnam War. It was to facilitate movement of military equipment to the Thai border and control insurgency in the Northeast.

3. Both Japan and Taiwan have a large trade surplus with the United States and prefer to buy agricultural products from the United States as a way of reducing US pressures.

4. Guatemala variety (Tequisate Golden Yellow Flint) was introduced to Guatemala by Prof. I.E. Melhus, from Iowa State University, from a composite of Caribbean collections (Sriwatanapongse, undated).

5. It yielded 3-4 tons/ha at the research station. At farm level, its yield was 50-70 per cent of that. This was much higher than the average yield then (about 1.1 ton/ha).

6. The research station was called Farm Suwan after Luang Suwan Vajokkasikit, former rector of Kasetsart University.

7. Increasing the speed of research is a great virtue. Modern techniques like tissue culture offer this.

8. Dr Sujin Jinahyon, leader of the research team from Kasetsart University, was instrumental in the overall organization of research at Farm Suwan.

9. Sources of Thai Composite #1 are: 16 from the Caribbean; 6 from Mexico and Central America; 5 from South America; 5 from India and 4 from others.

10. Yield tests in 1972 showed Thai Composite #1 (S) C_2 gave 4.72 tons/ha while PB15 gave only 3.9 (Thailand National Corn and Sorghum Program Annual Report, 1973, p.34).

11. It is interesting to note that Thai Composite 1 DMR is the basic material used for Suwan 1.

12. Aflatoxin is the toxin produced by the fungus (Aspergillus flavus) which grows on wet maize. It is associated with cancer in humans.

13. Drought tolerance has a low priority in the public research program because results of experiments in drought-prone areas are uncertain. Since promotion for a public sector researcher depends on a "successful" project, researchers prefer doing their research at well-irrigated research stations to working in a drought-prone area. Researchers in the private sector do not have this problem because a drought-damaged experiment is still considered as generating information.

14. This section is based on discussions with the top maize scientists at a workshop on "The Future of Maize Technology in Thailand", organized by the Agricultural and Rural Development Program, TDRI, on 23 September, 1989.

15. For example, a plant pathologist's knowledge of the biology of downy mildew is used in breeding the downy mildew resistant maize variety. Buying seed resistant to downy mildew is consuming the biological information on downy mildew.

16. Table 4.1 shows a slightly smaller number because it does not include the sales of small private seed companies.

17. This section relies heavily on "The Seed Industry in Thailand: Structure, Conduct and Performance", by Setboonsarng, Wattanutchariya and Phutigorn, IVO, Research Report No. 32, Tilburg, Netherlands, 1988.

18. Workshop on "The Future of Maize Technology" in Thailand, ARD, TDRI, 23 September, 1989.

19. Given the total seed market of about 40,000 tons, the commercial seed market can only be as big as 80 per cent, or about 32,000 tons. The largest market share any single company can have is about 40 per cent, or about 12,800 tons. If a company makes 1 baht profit per kg, the total profit would be about 12.8 million baht a year. If the company is going to recover its investment in five years, the investment would be 64 million baht.

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APPENDIX
AGRO-ECOLOGICAL ZONES OF THAILAND

This Appendix is taken from Rain-fed Farming Practices and Systems of Relation to Agro-ecological Zones of Thailand, a joint research report by the Thai Department of Agriculture and FAO in 1979.

The agro-ecological zones of Thailand have two parameters: rainfall and soil types. Rainfall is classified into six regimes and soil types into seven groupings.

A. Rainfall Regimes

The six rainfall regimes are arranged according to their degree of wetness.

Symbol	Description
R_1	Adequate or surplus rainfall throughout the year with no significant intervening dry period. The annual sequential rainfall usually follows a uni-modal pattern.
R_2	Adequate rainfall and soil moisture throughout the year with a weakly-expressed intervening period of moderately low rainfall and/or moderately low soil moisture. Annual sequential rainfall usually follows a bi-modal pattern where it falls within the Equatorial type of climate, and follows a uni-modal pattern where it falls within the Tropical Rainy Summer type of climate.
R_3	Adequate rainfall and soil moisture during the main annual cropping season followed by a well-expressed dry season of at least three consecutive dry months.
R_4	Moderate variability between years, but usually adequate rainfall and soil moisture within the main annual cropping season followed by a well-expressed dry season of at least three consecutive dry months. Moderate probability of a short drought as well as excess rain and flooding during the main cropping season. Annual sequential rainfall usually follows a uni-modal pattern.
R_5	Moderate to high variability between years as well as within the main cropping season. But rainfall usually exceeds total evaporation during the wet season and is followed by a well expressed dry season of at least three consecutive dry months for a uni-modal annual rainfall, or at least six consecutive dry weeks for a bi-modal annual rainfall. There is a significant probability of medium duration drought during the main cropping season.
R_6	Great variability within the main annual cropping season, following by a strongly-expressed dry season of at least three and a half consecutive dry months. There is also a high probability of soil moisture deficiency for variable periods during the main cropping season. It also includes rainfall regimes within the Equatorial type of climate where there are less than two consecutive wet months.

B. Soil Groupings

The seven soil groupings are arranged in increasing order of soil profile development, except for the last one.

Symbol	Soil unit represented by FAO-UNESCO	Equivalent soil order in soil taxonomy
S_1	Fluvisols, Gleysols	Entisols
S_2	Xerosols, Yermosols	Aridisols
S_3	Lithosols, Regosols Cambisols, Andosols	Entisols Inceptisols
S_4	Vertisols	Vertisols
S_5	Luvisols, Nitosols	Alfisols
S_6	Acrisols Ferralsols	Ultisols Oxisols
S_7	Histosols	Histosols

C. Short Description of Agro-Ecological Zones of Thailand

From a combination of the two parameters, Thailand can be divided into 12 agro-ecological zones. A short description of each follows:

1. R_1S_1 represents an area on the east coast in the south of Thailand where rainfalls are heavy, receiving both the Northeast and the Southwest monsoons. Average rainfall recorded at 2203.4 mm. annually. Rainy season begins in April and continues until January. Important crops are rubber trees, rice, coconut, oil palm and coffee.

2. R_1S_6 This is the area in the south where rains come principally from the Northeast monsoon. Average rainfalls 2119.4 mm. annually. Crops are rubber tree, rice , coconut and coffee.

3. R_2S_6 The southern part of the country and an area along the east coast of the Gulf of Thailand. Important crops are rubber trees, cassava, coconut and fruit trees.

4. R_3S_5 The area in the west and east of the country, where rainfall varies from small to medium. Its staple crops are rice, groundnut, mungbean, sugarcane, cassava.

5. R_3S_6 This is a vast area covering mostly the Northern region of the country as well as parts south of the Northeastern region. Most parts of this area are mountainous, interspersed with valleys where people farm in low and middle terraces and flat-bottom lands. Important crops are rice, tobacco, corn, cotton, mungbean, soybean and sesame.

6. R_5S_1 Mostly the Central Region and part of the Northeastern region. Most of its soils are poorly drained. Rainfalls are moderate. Staple crops include rice, mungbean, maize, and mulberry trees.

7. R_5S_5 This Northeastern region and some parts of the Central region as well as some in the North. Major crops include rice, kenaf, tobacco, mulberry trees and castor bean.

8. R_5S_6 This covers mostly the central part of the Northern region together with the upper part of the Northeast. Rainfalls are low due to a natural barrier against the southwest monsoon. Main crops are cotton, tobacco, maize, soybean, mungbean and groundnuts.

9. R_6S_1 This is in the middle of the Northeast region, where it scarcely rains because of the Petchaboon mountain range prevents the south-west monsoon from coming in. Major crops are rice, tobacco, cotton, kenaf, mulberry trees and castor bean. The Zone also covers part of the Central region where rice is the main crop.

10. R_6S_5 This covers mostly the central part of the Northeastern region together with an area on the western side of the country, where there is less rainfall due to mountain ranges barring the South-West monsoon. Major crops are rice, tobacco, cotton, kenaf, mulberry, trees, castor bean, cassava and maize.

11. R_6S_6 This is a small area in the North where rainfalls appear to be low due to protection from the monsoon by mountains. Its staple crops are rice, maize, sesame, soybean, mungbean and fruit trees.

12. R_3S_1 The is the Central region of the lower part of the North where rainfalls are considered moderate. Its soils are poorly drained. Rice is the main crop.

Table A gives the total area and the share of each zone.

Table A
Agro-Ecological Zones of Thailand

Zones	Area (hectare)	Percentage
R_1S_1	939,000	1.83
R_1S_6	3,576,411	6.97
R_3S_1	3,037,640	5.92
R_2S_6	2,740,034	5.38
R_3S_6	18,292,550	35.65
R_3S_5	1,847,214	3.60
R_5S_1	3,832,969	7.47
R_5S_5	6,506,298	12.68
R_5S_6	3,412,215	6.65
R_6S_1	3,643,117	7.10
$R_{61}S_5$	3,484,051	6.79

Source: Department of Agriculture, *Rain-fed Farming Practices and Systems in Relation to Agro-Ecological Zones of Thailand*, 1979.