Proceedings of the Fifth Asian Regional Maize Workshop

Hanoi, Ho Chi Minh City, Vietnam.

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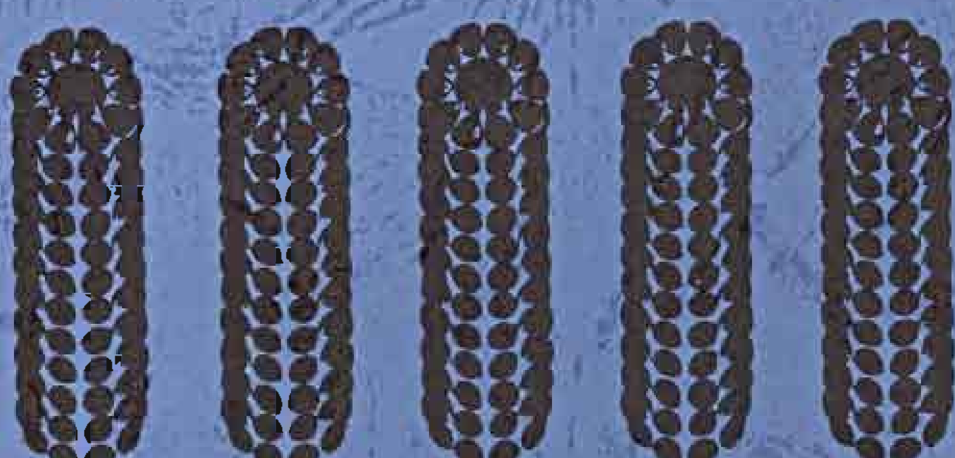

Organized by the Ministry of Agriculture and Food Industries of the Soc. Rep. of Vietnam and the CIMMYT-Asian Regional Maize Program.

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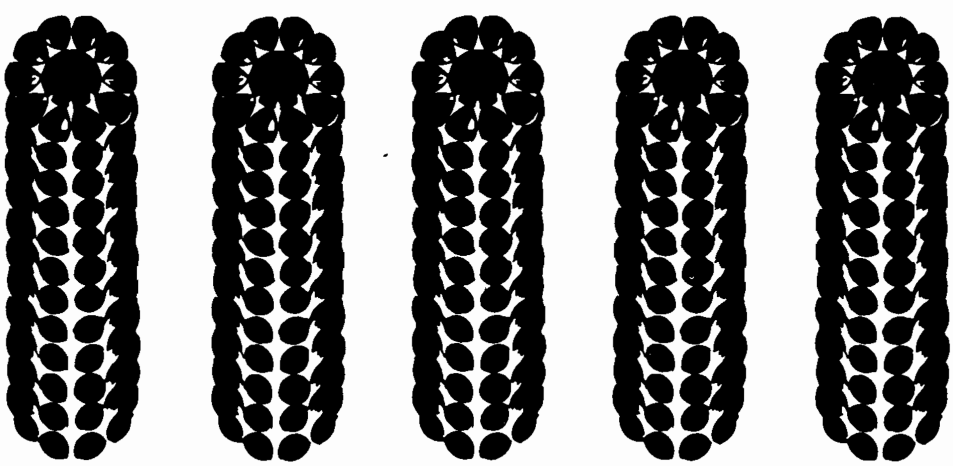

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The International Maize and Wheat Improvement Center (CIMMYT) is an internationally funded, nonprofit scientific research and training organization. Headquartered in Mexico, the Center is engaged in a worldwide research program for maize, wheat and triticale, with emphasis on food production in developing countries. It is one of 13 nonprofit international agricultural research and training centers supported by the Consultative Group on International Agricultural Research (CGIAR), which is sponsored by the Food and Agriculture Organization (FAO) of the United Nations, the International Bank for Reconstruction and Development (World Bank), and the United Nations Development Program (UNDP). The CGIAR consists of 40 donor countries, international and regional organizations, and private foundations.

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CONTENTS

FOREWORD

For several years, the Asian countries have had the highest rate of increase (3.6%) in maize production in the world. This has been due to the increasing demand of the grain for food, feed, and industrial purposes. Undoubtably, the largest volume has been directed to be used as animal feed.

One of the basic CIMMYT philosophies is to assist national programs in increasing their maize productivity. We believe that this broad objective can be achieved through the availability of improved maize germplasm, training of scientists, and technical consultancies. As part of the technical upgrading of scientists in the region, we believe that one important way to assist researchers in keeping pace with new scientific developments in our area of research, is through scientific meetings where we all can learn about the activities and experiences of colleagues in other programs. On this occasion, the CIMMYT Asian Regional Maize Program (ARMP) and the National Maize Program of the Soc. Rep. of Vietnam co-sponsored this 5th Asian Regional Maize Workshop, held in Vietnam November 15-20, 1993.

Being aware of the several success stories cited on hybrid maize in several countries, both in the developed and developing world, it was suggested that the theme of this 5th Workshop be on **Hybrid Maize in Asian Countries.** It will be through learning of the experiences of other countries in the region already involved in hybrid development that we can benefit from their positive experiences and avoid repeating those that represented setbacks in the adaptation of hybrid technology.

Technical sessions were held in both Hanoi and Ho Chi Minh City. There were presentations by representatives from various national maize programs from countries in the Asian region. We also had the participation of the FAO/RAPA Regional Plant Production and Protection Officer Representative who described the regional activities of that organization. Colleagues from private seed companies operating in the region also presented their activities on research and development of new germplasm. It is through this open relationship that we can all benefit from each other by increasing knowledge and experiences, improving our research which in turn will benefit the farmers in the region.

As in previous Asian Regional Maize Workshops, two Demonstration Nurseries were planted at two different environments, one at the Maize Res. Institute, Don Phuong in the North and the other one at the Hung Loc Expt. Stat. of the Inst. of Agric. Sci. in the South of Vietnam. These nurseries were planted to give an opportunity to participating scientists from various government and private sectors to submit and observe the varieties they have developed in their programs and the varieties developed by other programs in the region. A total of 241 entries were included in these Demonstration Nurseries. We have routinely encouraged the participants to request to the respective programs any entry that might be useful in their own programs. CIMMYT also included some of its high yielding, agronomically desirable experimental varieties with wide adaptation across locations in Asian countries. Special entries in the nurseries included those selected for tolerance/resistance to drought, acid soils, low nutrients, insects, and diseases.

We would like to acknowledge the very positive response of Cargill Seeds Co., Ciba Geigy (Thailand) Ltd., Charoen Seeds Co., ICI-Pacific Seeds Co., and Pioneer Overseas Corp., in financially supporting the trip of Dr. Arnel R. Hallauer, Prof. of Plant Breeding and Genetics, Iowa State Univ., to participate in this Workshop. Our appreciation goes also to Bioseed Genetics (Vietnam) and Maharashtra Hybrid Co. (MAHYCO) from India for sponsoring one banquet each the days of opening (Hanoi) and closing (Ho Chi Minh City) of the Workshop. CIMMYT thanks you all for your interest and invaluable partnership in our activities. To close this Foreword, our appreciation for Mrs. Chiraporn for spending so many extra hours typing these Proceedings.

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POSSIBILITIES OF HYBRID MAIZE PRODUCTION IN BANGLADESH

Kazi Murtaza Kabir [1/]

Abstract

The production and use of hybrid maize in Bangladesh is limited due to the absence of infrastructure required for the production and supply of seed at a commercial level. Maize is cultivated on only about 0.04% of the total cropped area, but the crop has a great potential. Areas that tend to be high and flood-free are best suited for maize cultivation. Economic studies have indicated that when maize is harvested for green cobs or for both grain + cobs, the profit is greater as compared to other field crops. In 1993, there was a more vigorous maize market than in the previous year. Recently, the poultry industry has grown by as much as 10%. The marketing system of maize is closely linked to wheat and rice markets. Development of postharvest technologies has been neglected and should receive major attention in future work plans (1994-95). The present strategy of the Bangladesh Agric. Res. Inst. (BARI) is to develop and utilize synthetics/composites in the short-term and hybrids in the long-term. Inbreds have been selected from CIMMYT and IITA germplasm for use in the development of synthetics/composites/hybrids. A synthetic recently developed by BARI is to be released soon. A few maize development agencies have studied the prospects of hybrid maize cultivation in Bangladesh.

Results are encouraging for a particular hybrid (Pac. 11), while yield superiority of the other hybrids over the composites were less. Economic studies with hybrids have also indicated that it might not be possible to get the highest yields at all locations/seasons and thus hybrids would not be profitable since the seed and other inputs are costly. The success of hybrids compared to BARI's composites suggests a future strategy of maize production consisting of two phases:

1. The selection of composites/synthetic varieties in relation to the existing cropping systems and seasons.
2. Development of infrastructure and programs for commercial production of hybrid seed to be produced in selected areas, and their gradual dissemination throughout other maize growing areas.

Acronyms

BBS	= Bangladesh Bureau of Statistics.
FAO	= Food and Agric. Organization of the United Nations.
GKF	= Rural Agric. Foundation (Grameen Krish Foundation), a non government organization.
CIMMYT	= Internatl. Maize and Wheat Improvmt. Center.
IITA	= Internatl. Inst. for Tropical Agriculture.
DAE	= Dept. of Agric. Extension.
BADC	= Bangladesh Agric. Developmt. Corp.
IFDC	= Internatl. Fertilizer Developmt. Center.
ICI	= Imperial Chemical Industries.
TSP	= Triple Super Phosphate.

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MP = Muriate of Potash.
CDP = Crop Diversification Program.

NGOs = Non-Government Organizations.
TK = Taka : Currency of Bangladesh.
1 US = 40 Taka (Oct. 1993).

1. Introduction

Maize is an exhaustive crop with respect to soil nutrient uptake. Hybrid maize because of its high yield, is all the more exhaustive. Thus, the present intensive production of other essential crops in the limited land area (14.08 m ha) of Bangladesh, is likely to restrict the large scale production of hybrid maize. Further, there is no infrastructure for the large scale production of hybrid maize on a continued basis, either in the public or private sectors.

The use of hybrid maize varieties has thus far been very limited in Bangladesh and also in other Asian countries compared to the US and Europe, where >90% of the farmers use hybrids. Recently, in India, China, Thailand, Philippines and South Korea, hybrids are being extensively cultivated.

Table 1. Area of maize by region.

Region	Area (ha)
Bangladesh	5,301
Bandarban	2,588
Chittagong	30
Chittagong Hill Tracts	1,104
Comilla	41
Noakhali	29
Sylhet	20
Dhaka	201
Faridpur	46
Jamalpur	30
Mymensingh	48
Tangail	15
Barisal	84
Jessore	39
Khulna	7
Kushtia	36
Patuakhali	90
Bogra	11
Dinajpur	324
Pabna	34
Rajshahi	441
Rangpur	83

Source: Bangladesh Agric. Census of Agric. and Livestock: 1983-84. BBS. Nov. 1986.

The existing distribution of maize cultivation throughout Bangladesh is depicted in **Table 1.** At present, most of the maize is reportedly cultivated in the region associated with the Chittagong Hill Tracts. There, in 1983-84, maize occupied about 3725 ha. During that same period, the next highest concentration of maize was in the Rajshahi region, with 445 ha cultivated. The third area was in the Dhaka region, with about 202 ha. All these areas tend to be high flood free land, best suited to maize and other crops.

The relative profitability of maize along with other crops has been studied by Kaul *et al*, 1987. On a full cost basis, including cash as well as non-cash costs, maize grain was comparable with T. aman (transplanted rice grown in mid July and harvested in mid Nov.), having a benefit: cost ratio of 2.5.

However, when maize is harvested for green cobs or a combination of both grain and cobs, the profitability was reported to be higher than any other field crop. This was established to be 2.8 for a harvest of 1:1 of cob: grain and 3.2 for a harvest of cobs only. **Table 2** gives the estimated area and production of maize in Bangladesh.

Table 2. Estimated area and production of maize along with rice and wheat in Bangladesh.

Year	Maize		Rice		Wheat	
	Area (000 ha)	Production (000 t)	Area (000 ha)	Production (000 t)	Area (000 ha)	Production (000 t)
1983-84	5	3	1,055	14,509	526	1,192
1984-85	4	3	1,023	14,391	677	1,441
1985-86	3	3	1,040	14,802	540	1,026
1986-87	3	3	1,061	15,163	585	1,074
1987-88	3	3	10,327	15,738	598	1,031
1988-89	4	3	10,229	15,298	560	1,006
1989-90	3	3	10,483	17,857	592	890
1990-91	3	3	10,440	17,852	599	1,004

2. Potential for maize in Bangladesh

The entire land area in Bangladesh has been appraised and its suitability to different crops determined (FAO, 1986). The necessary characteristics of land for the cultivation of maize in terms of drainage, flooding depths, and other soil characteristics have been determined. **Table 3** presents an estimate of land suitability for maize in Bangladesh.

Land potentially suitable for maize is about 21% of the total cropped area of Bangladesh. Presently, maize is cultivated on only about 0.04% of the total cropped area, and a great potential is there for maize production in Bangladesh.

The prevailing rainfall and ground water resources are sufficient to meet the probable crop water demand for maize estimated to range between 350 mm in the rabi season (from mid October to mid February) and 530 mm in the kharif season (from March to mid October). The rainfall data at different locations in Bangladesh are shown in **Table 4.**
different locations of Bangladesh.

Because of the favorable climatic conditions for maize, it may be grown throughout the year in Bangladesh. This is depicted in **Table** 5.

3. The present market for maize

The maize market has been recently estimated (Drexler, 1990) as shown in **Table 6.** The market segments have been described as first, second, and third priorities, depending on the need to introduce new concepts for maize consumption or new processing technologies and machinery. The first priority segments are expected to require little new technology and would be relatively easy to be promoted.

Table 3. Land suitability for maize in Bangladesh.

Division	Land suitability (ha)		
	Rabi [1/]	Kharif [2/]	Total
Chittagong	375,282	26,962	402,244
Dhaka	521,494	180,653	702,147
Khulna	146,653	44,763	191,416
Rajshahi	1,364,057	145,519	1,509,576
Total	2,407,486	397,897	2,805,383

1/ Land suitability estimated based on inundation depth, permeability, moisture holding capacity, soil nutrient supply, effective soil depth, salinity, soil reaction, agroclimatic data, land slope, and food hazard.
2/ Land suitability estimated on land type, soil texture, drainage, and rainfall distribution.
Source: BARC, 1985.

Table 4. Monthly rainfall (mm) data of Bangladesh (Aver. 10 yrs).

Station [1/]	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sept.	Oct.	Nov.	Dec.	Total
Barisal	17	16	31	63	150	437	309	370	306	351	25	9	2084
Chittagong	6	13	37	110	166	614	818	550	244	200	21	16	2795
Dhaka	8	14	52	93	222	377	395	329	276	172	32	2	1972
Dinajpur	9	6	43	60	134	343	440	337	268	108	10	1	1759
Sylhet	19	41	95	308	545	1021	782	742	462	202	25	2	4244

1/ The stations represent the regional diversity of climate in Bangladesh. Barisal represents the SW, Chittagong the SE, Dhaka the Center, Dinajpur the NW and Sylhet the NE.
Source: "Net irrigation requirement of rice and evapotranspiration of wheat and potato for different locations of Bangladesh."

Table 5. Maize development in Bangladesh for a medium maturity variety (Pacific 11 or Barnali).

Month	Sep.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.
Rabi [a/]		← planting →		← flower →		← harvest →							
Kharif 1 [b/]							← planting →		← flower →		← harvest →		
Kharif 2 [c/]	← flower →		← harvest →									← planting →	

a/ Total 140 days
b/ Total 110 days.
c/ Total 110 days.

There seemed to be a more vigorous maize market in 1993 compared to the previous years, when maize was promoted but failed due to a nonexisting market. However, the poultry industry has grown in recent years by as much as 10% per year. In addition, more people are now aware that maize can be eaten as a food and there is a general willingness to adopt it as part of the diet the same way as wheat was introduced over the past 30 years.

There has been a positive interest by the poultry industry in using the maize produced in rabi 1993. Initially, the industry was divided into those who were willing to buy maize at prices above that of wheat and those who preferred to wait until the price became lower than wheat. The interest by poultry farmers in yellow maize is because it colors the egg yolk a deeper yellow, which would fetch a premium price in the market.

There is a traditional market for maize as "green roasted cobs". The centers of demand are the urban cities, mainly Dhaka, Khulna, and Chittagong and it is increasing also in the smaller towns. There are not special sweet corn varieties used for green cobs. The consumption of maize as dry grain is confined largely to the "*Behari*" community, a race of people of India preferring maize in their diets. Since some of them have been living in Bangladesh as a result of partition of British India, their source of maize was lost and they somehow forgot eating maize. However, they might soon revert back to a maize-based diet, once maize becomes available. In fact, they have started doing so.

The expanding poultry industry is regarded as the segment of the maize market that will develop the demand and result in an increased supply of maize. Traditionally, the poultry farmers use wheat as the main energy source in their feed. However, yellow maize may displace wheat because it colors the egg yolks increasing their price. In addition, yellow maize is favored among broiler farmers due to its higher energy than wheat and it also deepens the color of the meat, which is demanded by the consumer.

Table 6. Potential demand for maize.

Market segments	Potential demand	
	'000 t	Percent
1. First priority		
Poultry feed	40.0	16
Private poultry farms	24.0	10
Flour mills	60.0	24
Green cobs	22.0	9
SUB-TOTAL	146.0	59
2. Second priority		
Starch	25.3	10
Snack products	6.4	3
SUB-TOTAL	31.7	13
3. Third priority		
Cattle fodder	41.5	17
Cattle feed	12.0	5
Relief and rehabilitation	14.2	6
SUB-TOTAL	67.7	28
4. TOTAL MAIZE DEMAND	245.4	100

Source: Maize demand quantification study. A.E. Drexler, AST/CIDA, 1990.

An external factor that may affect the maize market is the import of about 0.8 mt of wheat per year (BBS, 1991) by the Ministry of Food for "Food for work" and other relief programs.

Depending on how this wheat is released into the market, this may lower the price of wheat and affect maize. Additionally, the private sector is also beginning to import wheat, although their portion presently does not exceed 15% of the total wheat imports.

Consumption of maize by poultry farms and flour mills would be a priority for the maize market because little extra processing is needed and the technology of using maize in feed and food rations is well known in the country. However, the promotion of maize in the food and feed sectors needs to be emphasized by advertising the use of maize.

The processing of maize by private industry into starch, sugars, blended flours, and pharmaceutical products, should also receive attention in the work plan of 1993-94 and future work plans. By adding value to maize through its processing into diverse products, it would enhance the benefits to the producers and therefore, encourage the further expansion of maize. Development of these processing activities would require introducing suitable processing technologies and management assistance to potential industrialists in the private sector. This may also require encouraging foreign companies to consider investing in Bangladesh.

Because of the requirement of the consumer and the supplier to safely store maize, there is a need to simultaneously develop postharvest technologies. Once maize can be successfully stored by traders, poultry farms, and flour mills, this would increase the possibilities for its safe marketing and processing.

4. Traditional maize markets in Bangladesh

The marketing system of maize grain is closely linked to that of wheat and rice. The maize trade should use the same traders as wheat and rice. Maize grain prices bear a close relationship to wheat prices. Conventional wisdom would suggest that maize prices would be at or below the price of wheat. This would reflect the present relationship between world prices of maize and wheat, where maize prices are generally below the price of wheat.

5. Starch production in Bangladesh

The yearly starch requirement in Bangladesh has been estimated at about 16,000 t (Kaul *et al.* 1987; Drexler, 1990). Starch is used in the manufacture of cotton threads and textile mills, of which there are 114 in the country. In addition, there are innumerable country weavers. All the textile mills use imported and locally produced starch. Country weavers use rice-starch. It is estimated that about 2,000 t of starch are required by this industry. The jute industry consists of 77 jute mills, comprising 30,000 looms. It is estimated that this industry requires about 4,000 t of starch per year.

6. Postharvest constraints

In the past two to three years, there have been indications that there is a good potential for maize production, especially in the rabi season. There are few agronomic problems. This was proved by the staff of the GKF who successfully produced upto 3,000 t of maize with high yields of 5-7 t/ha in the rabi season of 1992-93. While there are relatively few constraints in the field for high production, there are major postharvest problems to be overcome, i.e. drying maize grain to safe moisture levels for storage and subsequent marketing. The development of postharvest technologies has been generally neglected. This poses the greatest threat to expanding maize production in Bangladesh. Development of postharvest technologies should receive major attention in the next workplan for rabi 1993-94.

7. Research and development activities

BARI has been conducting research on maize for almost two decades with limited emphasis on hybrids. The present strategy is to develop and utilize synthetic/composite/hybrid varieties. Synthetic/composite varieties give good yields for 3-4 years and new seed for the farmers is not required each year. In the case of hybrids, fresh F1 seeds have to be regularly supplied every year, otherwise, the yield will fall sharply much to the disappointment of the farmers. Seed is imported at high prices every year. However, BARI has recently undertaken programs to develop their own inbred lines for use in the hybrid development program. Several inbreds from CIMMYT and IITA have been evaluated and selected for use in the development of synthetics/composites/hybrids. A synthetic has recently been developed from IITA inbred lines and is in the process of being released.

Recently, a few maize development agencies in Bangladesh, including BARI, Dept. of Agric. Extension, Bangladesh Agric. Developmt. Corp., IFDC and the CDP, have studied the prospects of hybrid maize cultivation in Bangladesh. During rabi 1992-93, CDP imported Pacific 11, a hybrid maize variety from Thailand for cultivation on an experimental and demonstration basis (**Table 7**). Besides, IFDC and some NGOs and private seed companies also imported hybrid maize seeds during rabi 1992-93. The area under maize cultivation during rabi 1992-93 is shown in **Table 8.**

Table 7. Maize area under the crop diversification program of the DAE, NGOs, and private growers excluding GKF. Rabi 1992-1993.

Agency	District	Area (ha)	Yield (t/ha)	Production (t)
DAE	Bogra	8.09	3.71	30.01
Private 1/		40.49	6.18	250.23
DAE (rabi)	Rajshahi	19.43	3.71	72.09
(kharif*) 1,2/		4.86	4.94	24.01
DAE	Magura	8.09	3.71	30.01
DAE	Meherpur	8.09	3.71	30.01
NGO (ETDA) 1/		2.02	6.18	12.48
NGO (ETDA) 1/	Chuadanga	2.02	6.18	12.48
DAE	Jessore	7.29	3.71	27.05
TOTAL		100.38		488.37

Notes: 1/ Pacific 11 and some Cargill hybrids were grown.
2/ MS 999, a synthetic var. from Thailand was grown.

Table 8. Organization, location and area under hybrid maize cultivation with seed delivery and use. Rabi 1992-93.

Organization	Location	Area (ha)		Seed use (kg)	
		Hybrid	Composite	Hybrid	Composite
GKF	Greater Rangpur District	405	202	8,500	8,000
Fertilizer dealer (private farmers)	Bogra	40	-	800	-
DAE	Jessore, Magura, Meherpur, Raj-shahi, Bogra	2	49	40	1,200
ETDA-(a NGO)	Chuadanga Meherpur	4	-	-	-
TOTAL	-	451	251	9,340	9,200
%	-	64	36	50	50

Individual field sizes in the GKF area ranged from 4.05 to 8.10 ha. In addition to the hybrid and composite maize varieties indicated above, there were about 28.34 ha of baby corn and popcorn in the GKF area. The majority of the harvest took place from mid-April to mid May. After drying and shelling, the harvest became available in mid-April, or 190 days after planting. The area and production in the GKF zone is shown in **Table 9.**

Table 9. Maize area and production managed by GKF in the Greater Dinajpur and Rangpur Districts.

Region	Total area (ha)	Area under hybrids and composites (ha)		Yield (t/ha)	Production (t)
Kurigram	68.82	Hybrid	50.20	6.17	309.73
		Composite	18.62	3.70	68.89
Rangpur	50.20	Hybrid	48.58	6.17	299.73
		Composite	1.61	3.70	5.96
Dinajpur	110.12	Hybrid	73.28	6.17	452.13
		Composite	36.84	3.70	136.31
Birganj	102.43	Hybrid	59.92	6.17	369.11
		Composite	42.51	3.70	157.29
Thakurgaon	82.59	Hybrid	70.04	6.17	432.15
		Composite	12.55	3.70	46.43
Birampur	97.16	Hybrid	75.30	6.17	464.60
		Composite	21.86	3.70	80.88
Gaibanda	22.26	Hybrid	21.86	6.17	134.88
		Composite	0.40	3.70	1.48
TOTAL	533.60	Hybrid	399.19	6.17	2462.93
		Composite	134.41	3.70	497.24

Since 1989, ICI Seed International has been testing the hybrids Pac. 10 and Pac.11. These yielded only slightly over 5 t/ha, although yields of over 12 t/ha were expected. Results of the block and plot demonstrations by the IFDC during kharif 1991 are presented in **Table 10.**

Results obtained by IFDC in plantings done in 1991-92 using 10 hybrids and 2 composite varieties showed that all the hybrids outyielded the composites (**Table 10**). Each variety was grown in 450 m^2 plots. Although it has been shown that Barnali yields 3.60 t/ha (**Table 11**), results showed that Barnali yielded 4.6-5.9 t/ha over locations and years (**Table 12**).

The potential for maize in Bangladesh can be qualified by reviewing recent past results of maize trials conducted by IFDC and BARI. Some of these results are presented in **Table 13.** The indications are that a hybrid like Pacific 11 gives a higher yield than the registered composite Barnali in both rabi and kharif seasons. In rabi, the superiority was 86% (Pac 11; 6.7 t/ha, Barnali: 3.6 t/ha) and in kharif it was 48% (Pac 11: 4.3 t/ha, Barnali: 2.9 t/ha). The performance of other hybrids indicated that the yield superiority over Barnali was less.

During rabi 1990-91, fertilizer rate trials of hybrid maize were conducted at six locations. The results indicate that by using 1.5 times the recommended doses of fertilizer, yield of the composite varieties were on average 4.98 t/ha. By adding triple the normal dosage, yields of up to 6.37 t/ha were obtained with composites (**Table 14**). This high fertilizer dose will be generally beyond the reach of common farmers. However, this yield is only 0.7 times greater than the highest yield of Suwan 2 (Kharif 1991) and only 0.12 times higher than that of Barnali (5.7 t/ha) for rabi 1990-91. Here, it is important to indicate that by using the fertilizer level recommended for the rabi season, Barnali yielded higher than the hybrids (**Table 12 and 16**).

Table 10. Yield of different maize varieties. Kharif 1991.

Variety	Yield (t/ha)					
	Bogra	Noagaon	Dhaka	Tangail	Mean	Plants/ha
Composite						
Barnali	2.7	2.5	3.3	3.0	2.9	47,800
Suwan 2	4.7	4.2	3.3	2.8	3.8	49,500
Hybrids						
Cargill	5.1	4.8	4.0	3.6	4.4	58,100
Pacific 10	5.1	4.6	3.5	3.9	4.3	53,100
Pacific 11	4.8	4.8	3.7	3.8	4.3	54,900

Source: IFDC, 1992.
Fertilizer dose: Urea = 543, TSP = 222, MP = 266, Gypsum = 166, Zn SO_4 = 16.6 kg/ha.

8. **Comparative yield and profit of hybrid and composite varieties**

From the yields and expenses of trials conducted during kharif 1991, the comparative profits of cultivating hybrids and composites is shown in **Table 15.** The hybrid Pacific 11 gave a total profit of Tk 19,200/ha and Tk 9,911/ha greater than that of Barnali and Suwan 2, respectively.

Table 11. Yield of different maize varieties. Rabi 1991-92.

Variety	Yield (t/ha)
P3252	7.20
P3276	6.40
P3234	5.70
P3250	5.30
P3274	5.20
P3248	4.80
Pacific 10	5.60
Pacific 11	6.70
Cargill	5.60
SMC 357	4.40
Suwan 2	3.90
Barnali	3.60

Source: IFDC Report, 1992.

Thus by spending additional Tk 2,300/ha, a profit of Tk 9,911/ha was obtained. The benefit:cost cost ratio of the hybrid is 2.03 and that for Barnali and Suwan 2 is of 1.04 and 1.67, respectively. IFDC reported that during kharif 1992, hybrid maize cultivation did not give a financial benefit significantly greater than that of Suwan 2.

From the yields of Barnali during rabi 1990-91 and 1991-92 (**Table 12**), it is evident that the profits from hybrid maize cultivation are negligible. The reason is that the average yields of all hybrids and composites during rabi were not significantly different (**Table 16**). However, P 3252 gave the highest yield of 7.20 t/ha (**Table 11**), in which case, hybrid maize cultivation

Table 12. Demonstration block results of Barnali.

Season	Area (ha)	Test sites	Yield (t/ha)
Rabi 1990-91	11.57	9	5.70
Rabi 1991-92	1.44	2	5.90
Farmers' plots and GKF Farm	60.20	16	4.60

Source: IFDC Report. 1992.

appeared to be profitable. Our farmers do not have experience on hybrid maize cultivation. Therefore, it might not be possible to get the highest yields for hybrids at all locations and all seasons.

9. Feasibility of hybrid maize under the existing socio-economic conditions of Bangladesh

Maize has not developed as a major cereal in Bangladesh. The farmers consider that its cultivation involves risks for many reasons. Reduction of the risks of maize farming by learning different methods of cultivation and utilization can assist in its dissemination. In this situation, can the use of a hybrid really help in reducing the risks of maize farming? At the moment, it is difficult to answer this question. However, it is expected that maize cultivation may expand in the near future provided due support is given by policy makers. Because there is no market for maize grain, corn is mostly sold as green cobs for roasting. The income generated from the sales of green cobs will be greatly reduced with the expansion of maize farming. In the international grain market, the price of maize is less than that of rice and wheat. With the expansion of maize cultivation in Bangladesh, the maize grain has to be sold at a lower price than wheat. Thus, only with an increased production, selling the produce at lower prices will be profitable. By the use of hybrid varieties, there is a possibility of increasing the yield and production of maize. According to the BBS, the yield of maize in farmers conditions is below 1 t/ha. With the exception of "Khoibhutta" the popcorn variety, the other 3 varieties developed by BARI under proper management condition in the farmers conditions yield an average of 5 t/ha. In research plots, yields of up to 8-9 t/ha have been obtained. At this stage more emphasis should also be given in Bangladesh to crop management aspects. Yields so far obtained from many hybrids can be closely matched by composites when using adequate crop management practices. Rich farmers that can afford costs of inputs can also get high profits by cultivating hybrids on a commercial scale. If farmers are interested in cultivating hybrids, would it really be worthwhile to yearly import seeds and go into its cultivation at a cost of limited hard currency? To answer this, an economic analysis of cost of seed importation versus development of expertise in hybrid seed production in the country needs to be done. But under no circumstances should stable agricultural production depend on imported seeds every year. So, the necessary infrastructure to locally produce hybrid seeds should be organized and developed at this early stage.

The ease of importation of hybrids and their success when compared with BARI's composite varieties, suggests that a future strategy of development for maize be of two phases:

1. Selection and large scale use of existing synthetic/composite variety(ies) with limited introduction of hybrids.
2. Strengthening capacity to produce hybrid varieties locally and support their large scale dissemination.

10. Strategy for developing seed of improved maize varieties in Bangladesh

Phase 1: (3-5 years)

Base the development of maize on a balanced supply of both composite and hybrid varieties. The composites would be supplied by BADC Seed Farms. BARI and BADC need to compete with private sector for the supply of seed. Subsidies on the price of BADC seed needs to be stopped to encourage private sector seed supplies. BADC should promote maize seed production through private sector by giving technical assistance and leasing its seed processing facilities to private seed companies. This would be in accordance with the new National Seed Policy. The hybrids that have already been tested would be imported from abroad. Seeds should be disseminated through official agencies. Research and development should continue to allow scientists and farmers to assess their performance and to identify suitable varieties for the rabi, kharif 1 and kharif 2 seasons. The rabi season requires a temperate-tropical hybrid variety with some cold tolerance, especially for northwest Bangladesh, whereas, the kharif seasons both require lowland tropical germplasm.

Table 13. Results of maize demonstrations and trials executed by IFDC and BARI.

Season	Variety	Area (ha)	No. locations	Yield (t/ha)
Rabi 90-91 1/	Barnali	11.6	9	5.7
Kharif 90-91 1/	Barnali	0.1	4	2.9
	Suwan 2	0.1	4	3.8
	Cargill	0.1	4	4.4
	Pac. 10	0.1	4	4.3
	Pac. 11	0.1	4	4.3
Rabi 91-92 1/	Barnali	1.4	2	5.9
	Barnali	60.2	16	4.6
Rabi 91-92 var. trial 1/	P3252	0.005	1	7.2
	Pac. 11	0.005	1	6.7
	P3276	0.005	1	6.4
	P3234	0.005	1	5.7
	Cargill	0.005	1	5.6
	Pac.10	0.005	1	5.6
	P3250	0.005	1	5.3
	P3274	0.005	1	5.2
	P3248	0.005	1	4.8
	SMC 357	0.005	1	4.4
	Suwan 2	0.005	1	3.9
	Barnali	0.005	1	3.6
Rabi 86-87 2/	EVT (14 entries)	15 m	5	$\bar{x}$ = 5.4
	Barnali (check)	15 m	5	4.9

Source : 1/ Maize Report, International Fertilizer Developmt. Center (IFDC), 1992.
2/ Annual Rept. 1986-87, Plant Breeding Div. BARI, 1992.

Synthetic varieties should also be tested and expanded if they show good performance. This should be initially based on germplasm developed by BARI and importing seed from abroad.

Phase 2: (5 years and on)

Depending on past performance and demand of farmers, continue to base maize development on a balance of composite, synthetics and hybrid varieties. Strengthen BADC's capacity to help the private sector supply seed of composite or synthetic varieties. The choice of varieties would depend on yield data and farmers' assessments.

Table 14. Effect of fertilizer doses on the yield of hybrids.

Fertilizer rate (kg/ha)					Yield (t/ha)	
Urea	TSP	MP	Gypsum	ZnSo4	Range	Mean
333	174	133	176	17	4.4-5.4	4.98
666	348	266	353	34	5.0-7.5	6.37

Source: IFDC Rport (without date). The low fertilizer dose was tested in 4 plots and the high fertilizer dose in 9 plots. Sowing time Oct. 30-Dec. 6.

Develop in-country seed of hybrid varieties. Need to become independent. This would probably be better done in private sector joint-venture with seed companies from abroad, rather than the public sector. With few exception, past experience in most other countries has indicated this is not an efficient manner to promote the crop. The time lag usually required to carry out research and develop hybrid seeds of tested varieties is eleven seasons (Hart, 1986).

Table 15. Comparative profits from the cultivation of hybrids and composites (Tk/ha).

Income-expenditure statement	Hybrid Pac.11	Composite		Enhanced expenditure/ profit comparison	
		Barnali	Suwan 2	Barnali	Suwan 2
Income	52,000	30,400	39,800	21,600	12,200
Cost of:					
Seed	2,500	200	200	2,300	2,300
Fertilizer	7,643	7,643	7,643	-	-
Irrigation	4,446	4,446	4,446	-	-
Labor	2,600	2,600	2,600	-	-
Total cost	17,189	14,889	14,889	2,300	2,300
Profit	34,811	15,511	24,900	19,300	9,911

Source: IFDC Report, 1992.

a. Cost of hybrid seed Tk. 100 kg; Composite seed Tk. 8/kg.
b. Urea 556 kg/ha. Cost/kg = Tk. 6.00.
c. TSP 278 kg/ha. " /kg = Tk. 7.00.
d. MP 278 kg/ha. " /kg = Tk. 5.00.
e. Gypsum 185 kg/ha. " /kg = Tk. 2.00.
f. ZnS04 18.5 kg/ha. " /kg = Tk. 25.00.

Limitations and scopes of hybrid maize production in Bangladesh.

a. In-country infrastructure for the development and production of hybrid seeds at a commercial level do not exist in Bangladesh. For field-scale introduction of hybrids, infrastructure must be developed.

Table 16. Average yields of composites and hybrids during the rabi season. Rabi 1990-91 and 1991-92.

Variety	Yield (t/ha)	
	Mean	Range
Barnali	5.4	4.00-5.90
Different hybrids	5.1	3.60-7.20

b. To import a large quantity of hybrid seeds every year is difficult and requires much needed foreign exchange.
c. High inputs that are needed for hybrids are often beyond the reach of the ordinary farmers.
d. Poor marketing prospects of the crop, affecting the promotion and use of hybrids.
e. Farmers' interests in maize production may be lost if hybrid maize production is not supported with the supply of necessary inputs including irrigation, and increasing marketing prospects.
f. Despite the limitations, hybrid maize has prospects because of its high yield per unit area. In an overpopulated country like Bangladesh with a very limited cultivable land area, emphasis must be given to the vertical increase of maize yield in selected areas, in which case hybrid maize must receive priority over the existing varieties.

References

Anonymous. 1986-87. Annual Report, Maize Research and Development Program. Plant Breeding Div. BARI, Joydebpur, Bangladesh.
Annonymous. 1988-89. Annual Report, Maize Research and Development Program. Plant Breeding Div. BARI, Joydebpur, Bangladesh.
AST. 1984. Socioeconomic survey to explore maize development potential in Bangladesh. Canadian Agric. Sector Team. Dhaka, Bangladesh.
BARC. 1985. A review of results of the National Coordinated Cropping Systems Research Project in Bangladesh. BARC, Dhaka, Bangladesh.
BARI. 1980. Agronomic study of on-farm maize trials in Bangladesh. BARI, Joydebpur, Bangladesh.
BARI. 1985. Summary of the proceedings and recommendations of the workshop on maize production and utilization policies. BARI, Joydebpur, Bangladesh.
BBS, 1986. The Bangladesh census of agriculture and livestock, 1983-84.
BBS. 1990. Yearbook of agricultural statistics of Bangladesh. BBS, Government of Bangladesh, Dhaka.
BBS. 1991. Yearbook of agricultural statistics of Bangladesh. BBS, Government of Bangla-desh, Dhaka.
BBS. 1992. Yearbook of agricultural statistics of Bangladesh.BBS, Government of Bangla-desh, Dhaka.
Charles, E.W. 1992. Maize in Bangladesh - A position paper.Integrated maize promotion project, project implementation unit. CDP. Ministry of Agriculture, Bangladesh.
Charles, E.W. 1993. Maize Report. Integrated Maize Promotion Project. Project Imple-mentation Unit. CDP. Ministry of Agriculture, Bangladesh.
CIMMYT. 1984. Development, maintenance, and seed multiplication of open-pollinated maize varieties. CIMMYT, El Batan, Mexico.
Drexler, A.E. 1990. Maize demand quantification study, AST/CIDA.
desh. An agronomic analysis. BARI, Joydebpur, Bangladesh.

Elias, S.M., F.S. Sikder and J.Ahmed. 1985b. A prospective of summer maize in Bangladesh. An agronomic analysis. BARI, Joydebpur, Bangladesh.

FAO. 1986. Land appraisal of Bangladesh.

Gopalan, C., B.V. Rema Sastri and S.C. Balasubramanian. 1981. Nutritive value of Indian foods. Natl. Inst. of Nutrition. ICMR, Hyderabad, India.

Hughes, U. 1990. Action plan for a regional approach to maize production and marketing promotion in Banglaldesh. AST/CIDA.

IFDC. 1991. Maize variety trials, kharif 1, 1991 (Mimeographed). IFDC, Dhaka, Bangladesh.

IFDC, Undated. Maize cultivation in Bangladesh. A comparative picture of financial gains between hybrids and composite cultivars (Mimeographed). IFDC. Dhaka, Bangladesh.

IFDC. 1992. Maize report, May 1992.

Islam, T.M.T. and A.K.Kaul. 1985. Prospects of maize in Bangladesh, FAO/UNDP project 'Strengthening the agricultural extension service'. DAE, Dhaka.

Kaul, A.K.and T.M.T. Islam. 1986. Agronomic aspects of pulses, maize and sorghum. USAID exercise in crop diversification in Bangladesh. Winrock International, BARC. Dhaka, Bangladesh.

Kaul, A.K., M.L. Rahman, and J. Ahmed. 1987. Maize study. Winrock International. Dhaka, Bangladesh.

Kim, S.K. 1987. Breeding of hybrid varieties of maize. *In* Hybrid seed production of selected cereal, oil and vegetable crop W.P. Feistritzer and A.F., Kelly, eds.. FAO Plant Production and Protection Paper No. 82. Rome.

Mohammad, A. 1985. Maize development - Its prospects for multiple use in Bangladesh - A background report. Canadian Agric. Sector Team, Dhaka, Bangladesh.

Rashid, M.H. 1991. Cost and return analysis of different crops with high input practices and irrigation under demonstration and farmers' improved management practices. Agric. Advisory Services.

Sami, M.A. 1979. Maize as a basis for economic development in Bangladesh. Tropical Agro-Consultant Ltd. Dhaka, Bangladesh.

Singh, B.D. 1983. Hybrid and synthetic varieties. p. 263-287 *In* Plant breeding. Kalyani Publ. New Delhi,India.

Thakur, C. 1980. Scientific crop production. Vol. 1. Food Crops. Metropolitan Book Co., Pvt.Ltd. New Delhi, India.

Questions to the author:

FROM : R. S. Paroda

Q. : There is practically no increase in both area and production of maize during the last 5 years. What is the strategy to meet local demand in future? It appears hybrid research in public sector is not aggressive neither public sector is taking up hybrid seed production. Please suggest as to how this situation could be improved further. BARI seem to be laying emphasis on composite program only.

A. : These has definitely been an increase in both area and production of maize during the last 5 years, though not significantly compared to other Asian maize growing country. The strategy to meet the local demand in the future is by increasing acreage and production and through importation. Hybrid research in public sector is not aggressive enough because of a lack of demand for the hybrids and market of the crop. This situation could be improved further by adopting the following measures: 1) Infrastructures and programs must be developed for field scale introduction of hybrids. 2) Large scale use of the currently imported/existing hybrid variety(ies). 3) With a very limited land area in Bangladesh, emphasis must be given to the vertical increase of maize yields in selected areas, in which case the hybrids must receive priority over the existing varieties.

BARI is not laying emphasis on composites only,but also on OPV's, synthetics, and hybrids. Research program on the development of inbreds and hybrids has already been undertaken.

FROM : N. N. Singh

Q. : 1. The requirement of water for growing rabi maize (350 mm) seems to be too low. Is it based on data or your observation?

2. Area in Bangladesh is going down and you said that there is scope to increase due to industrial demand. How much maize is imported every year to know the realistic demand?

A. : 1. The estimated crop water demand for maize in the rabi season (350 mm) is not too low and is surely based on reliable data and not on my observations.

2. At present, there is trend towards an increase in acreage of maize in Bangladesh. There is a demand for it in the poultry and livestock sector as feed and fodder. Also demand exists in the industrial sector viz. the confectionery factories etc. According to the Bangladesh Bureau of Statistics report of 1988-89, the amount imported that year was only 3197 kg. Presents statistics of imports.

MAIZE IMPROVEMENT PROGRAMME IN BHUTAN

N. Wangdi [1]

Maize is one of the most important staple crops of Bhutan. During 1989, maize was cultivated in 41,890 ha, producing about 31,130 t of grain. The national average yield of the crop is 740 kg/ha.

Nearly 90% of the maize in the country is grown under rainfed conditions on sloping terrain, and the remaining 10% in paddy fields. About 50% of the crop is found in the dry subtropics (1,200-1,800 masl), 30% in humid subtropics (600-1,200 masl), 10% in wet subtropics, and the remaining 10% in warm temperate areas (1,800-2,600 masl). The major maize growing areas of the country and their production are shown on Table 1.

Table 1. Area production, and yield of maize in various districts. 1988/89.

District	Area (ha)	Production (t)	Yield (kg/ha)
Thimphu	30	10	500
Ha	70	40	540
Punakha	80	60	770
Wangdiphodrang	60	na	na
Tongsa	380	270	720
Paro	*	*	*
Chhuka	1830	680	370
Samchi	7540	2490	330
Chirang	6380	2910	460
Daga	2360	890	380
Geylegphug	6990	2650	380
Samdrupjongkhar	4700	2650	560
Bumthang	10	20	1160
Shemgang	1060	1250	1180
Luntshi	1140	2480	2170
Mongar	2570	4530	1760
Pemagatshel	860	920	1060
Tashigang	5810	9230	1590
TOTAL BHUTAN	41890	31130	740

Source: Agronomic Survery, Central Statistical Office.
* : Sampling error too high for accurate estimation.

Based on the acreage and total production data, it is clear that the productivity per unit area is too low. This is due to a low inherent soil fertility on sloping terrain, presence and use of old, traditional varieties, and poor crop management practices.

A systematic research programme on maize has been recently organized. It dates back to the year 1989 when the National Maize Improvement Programme was launched. The main objectives of this programme are as follows:

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General objective:

To improvement the production practices so as to increase the crop productivity per unit area.

Subjective objectives:

1. Introduction and selection of suitable OP varieties.
2. Development of economically viable crop management technologies.

To begin the programme, experts from CIMMYT-ARMP, Thailand, were invited for the necessary advisory services. Since then, ARMP has been instrumental in providing required germplasm, technical advice, and relevant training to the Bhutanese scientists.

The extensive research so far carried out has generated significant information for the formulation of single technologies and to reorient ourselves for future research.

Varietal improvement

Approximately 140 experimental varieties of exotic germplasm have been evaluated throughout the major maize growing agroclimatological zones of Bhutan. A large number of those entries have been discarded at different stages of the evaluation since they were unsuited to our conditions. Among the CIMMYT populations tested, 28 and 29 seem to be quite promising. Two of the CIMMYT entries that have so far reached the multilocation production evaluation stage are Suwan 8528 and Palmira 8529.

The Thai variety Suwan 1 was officially released by the Variety Release Committee in early 1992 under the name Yangtsipa. This variety is recommended for cultivation up to an elevation of 1,800 m. The details of the performance evaluation of Suwan 1 are presented on **Tables 2 and 3**, and **Figs. 1 and 2**.

Table 2. Results of on-farm trials on Suwan 1. 1990.

Dzongkhags	Gewogs	Village	Elevation (masl)	Yield (kg/ha) No fertilizer Local	Yield (kg/ha) No fertilizer Suwan	Yield (kg/ha) With fertilizer Local	Yield (kg/ha) With fertilizer Suwan
Mongar	Salling	Zangdung	-	1484	3343	1932	3578
Mongar	Salling	Thidambi	-	5400	6171	5538	7219
Mongar	Salling	Pangsibi	-	1610	2522	2556	2810
Mongar	Ngachang	Yadi	1500	1766	2937	3492	4034
Mongar	Mongar	Yaderbi	1450	1366	1387	2858	3505
Mongar	Mongar	Rhidaza	1500	3151	4313	3441	4269
Tashigang	Samkhar	Tash. Pam	1200	3541	4780	5793	6644
Tashigang	Samkhar	Tash. Pam	1200	2726	5889	4280	5605
Tashigang	Samkhar	Tash. Pam	1200	6202	5264	6724	6288
Tashigang	Kanglung	Rhongtong	1700	1170	1632	2914	3131
Tashigang	Jangphu	Khamdang	-	2133	2133	2667	2400
Tashigang	Jangphu	Khamdang	-	1667	1667	2000	2133
Tashigang	Jangphu	Dolepchan	-	1333	1333	1600	1867
Tashigang	Jangphu	Dolepchan	-	2133	2267	2933	2667
		MEAN		2549	3260	3481	4010

The major agronomic production constraints identified are:

1. Low plant population at harvest time.
2. Weeding is an expensive operation.

Table 3. Results of on-farm trials on Suwan 1, 1991.

Dzongkhags	Gewogs	Village	Elevation (masl)	Yield (kg/ha) No fertilizer Local	Suwan 1	With fertilizer Local	Suwan 1
Mongar	Mongar	Hurungpang	1380	2869	3097	2878	3369
Mongar	Dramtchi	Waichu	1270	3209	3344	4703	4441
Mongar	Ngatshang	Yadi	1530	1165	2129	2990	3346
Mongar	Kenghar	Doktang	1430	3439	3306	3760	3034
Mongar	Kenghar	Doktang	1300	3997	5112	4424	7207
Mongar	Kenghar	Pangthang	1310	4596	6992	5438	7435
Mongar	Chakaling	Challi	1000	2704	3965	4296	5376
Mongar	Chakaling	Challi	1100	3205	4236	6041	4633
Mongar	Chakaling	Challi	1120	1624	1974	1463	1797
Mongar	Chaskhar	Sangmary	1740	5376	4909	5557	4992
Mongar	Chaskhar	Barbang	1750	4935	4337	4209	4113
Mongar	Thangrong	Pangline	1430	4744	5265	4513	6851
Mongar	Thangrong	Pangline	1350	5290	4517	4250	5271
Mongar	Thangrong	Dongline	1380	2595	4205	3583	4890
Tashigang	Radhi	R. Pangthang	1680	1270	1659	2721	2473
Tashigang	Radhi	R. Pangthang	1590	1791	2649	1893	2941
Tashigang	Radhi	R. Pangthang	1580	3665	3164	3048	4296
Tashigang	Phongmey	Yerchelo	1610	4271	3171	1876	4788
Tashigang	Phongmey	Yerchelo	1610	4659	4931	5474	5591
Tashigang	Phongmey	Yerchelo	1650	712	1229	1165	1165
Tashigang	Yangneer	Lakthang	1800	553	588	667	836
Tashigang	Khaling	Dangray (*)	1950	4438	3080	5602	5209
Tashigang	Khaling	Dawzor (*)	2050	5203	3630	5788	6106
Tashigang	Thrimshing	Berdhungma		1480	1710	2147	2427
Tashigang	Thrimshing	Thungkar		1521	1545	2330	2370
Tashigang	Bartsham	Ketpowong	1910	2726	4533	3277	3473
Tashigang	Barsham	Ketpowong	1890	3261	4480	4490	5720
Tashigang	Barsham	Ketpowong	1930	3577	4916	4405	5759
Tashigang	Bidung	Manzor	1740	4498	3972	3523	5142
Tashigang	Kanglung	Wuunkhar	1580	3156	4570	2793	6334
Tashigang	Jangphu	G/dung	1970	386	998	1506	3066
Tashigang	Jangphu	Sally	1850	1261	1435	2171	2297
Tashigang	Yallang	Yallang	1790	3416	3366	4416	5410
Tashigang	Yallang	Yallang	1760	3804	5600	5041	5936
Tashigang	Yallang	Yallang	1750	4458	4101	5532	5446
Tashigang	Shongphu		1300	2011	2169	2908	3025
Lhuntshi	Khoma	Khoma	1360	3477	4296	3892	4841
Lhuntshi	Khoma	Khoma	1360	6918	7421	7906	9569
Lhuntshi	Khoma	Khoma	1360	7031	7511	8272	9765
Lhuntshi	Myetsho	Obee	1550	642	1216	998	1282
Lhuntshi	Myetsho	Tongtrum	1860	533	1882	1109	2108
Pemagatshel	Zobel	H. Chamkhar	1800	1251	2695	2887	2117
Pemagatshel	Sumar	J. Brangsa	1550	582	1455	1616	1859
Pemagatshel	Sumar	Barchamey	1500	353	918	1624	1341
Pemagatshel	Sumar	Barchamey	1350	742	742	1112	2596
Pemagatshel	Sumar	Nangkhor	1150	627	1144	1291	1384
Pemagatshel	Sumar	Kholakpa	1000	1328	2465	1328	3414
Pemagatshel	Sumar	Kholakpa	1000	631	631	901	2253
		MEAN		2746	3273	3314	4082

(*): Excluded from analyses because of wrong site selection and poor quality of trials.

3. Low level of soil fertility.

Experiments to address the above constraints have been conducted. Important information has been obtained from these experiments.

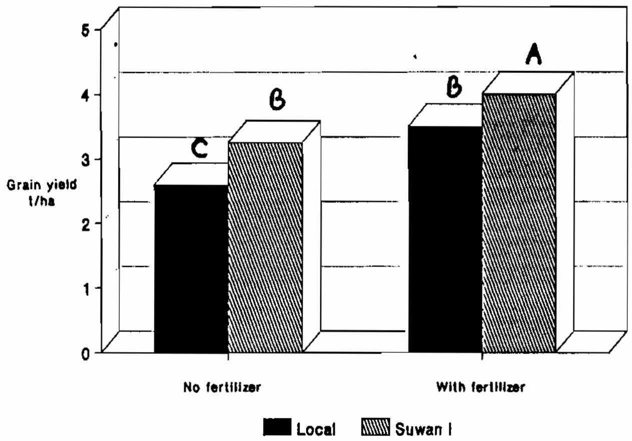

Fig. 1. On-farm trial on Suwan 1. 1990.

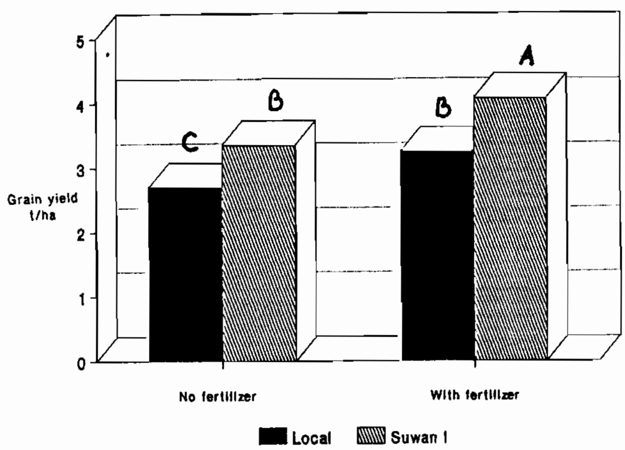

Fig. 2. On-farm trial on Suwan 1. 1991.

Fertility requirement studies.

The farming systems in mountainous Bhutan integrate cropping, livestock-keeping, and use of forest products. Because soil fertility is low, the farmers must rely on the external inputs of plant nutrients. Traditionally farmers have been using nutrients from forest grassland and biological nitrogen fixation, being able to sustain the agricultural production without the use of chemical fertilizers. However, with the increase in demand for more food, the pressure on the cultivable land has been increasing. Therefore, the main research thrust at present in arable agriculture is to increase production per unit area, while ensuring sustainability of the production systems.

Studies carried out on maize had shown that an application of 40 kg N and 20 kg of P_2O_5 can increase the yield by 27% in local varieties and 19% in Yangtsipa (1990 data). In 1991 the increases were 17% and 20%, respectively.

The higher levels of nitrogen and phosphorus i.e. above 40:20 did not increase the yield appreciably, but certainly increased the cost of production. The economic analysis carried out also revealed the authenticity of economic viability of our present fertilizer recommendation of 40:20 $N:P_2O_5$ for sole maize cropping.

Study on maize weed control.

The weeding operation has been the most expensive operation in maize husbandry practices. This is mainly because 90% of the maize is grown in rainfed drylands. Most of the important weeds encountered are broad leaf perennials. The major among them are *Fagopyrum dibotrys, Persicaria runcinata, Commelina maculata, Galinsoga parviflora*, and the grass weed *Digitaria ciliaris*. Although farmers have been able to control these weeds, research on manual weeding is needed. Therefore, attempts have been made to study the efficacy of manual weeding emphasizing two of its important functional components viz. time and number of weedings. The research results indicate that the most crucial time for crop x weed competition occurs at 25-30 days after crop emergence and continues until 50-55 days.

The avoidance of crop x weed competition after 60 days of crop emergence shows little or no effect on yield.

Therefore, to harvest a normal yield, farmers should keep their maize crop free of weeds at least for a period of 23-50 days and up to 50-55 days after crop emergence. This can be achieved by two hand weedings given at one month intervals. If farmers can do only one weeding, they should do it 25-30 days after crop emergence.

Maize density x fertility study :

In spite of the high seeding rate used by farmers, the final plant stand at harvest time is always about 25,000 to 30,000 plants/ha. The lesser number of plants at harvest is mainly attributed to the following factors:

1. Cutworm damage at seedling stage.
2. Mechanical injury at time of weeding.
3. Damage by stray cattle and wild animals.
4. Smothering by aggressive weeds.

Efforts have been made to study the effect of plant population on yield at different levels of soil fertility. The main aim is to determine the ideal plant population to suit the fertility levels.

Results have indicated that both density and fertility seem to affect the final crop yield, although the effect of density seemed more significant than fertility.

At the lowest fertility level (10 t/ha farm yard manure), there was a 21% increase in yield when doubling density from 25,000 to 50,000 plants/ha. At the higher density of 75,000 plants/ha the increase in yield from doubling the plant density was only 5%, and the crop growth and development were poor. At moderate fertility levels (40:20 N P_2 O_5 kg/ha) an increase in yield of 43% was obtained by doubling density from 25,000 to 50,000 plants/ha. With a population of 75,000 plants there was a 40% increase in yield, and again the plant growth and development observed were comparatively poor. Crop responses observed at high fertility level (80:40 N P_2 O_5 kg/ha) were similar except that the plant growth at this fertility level was normal at all the density levels. The yield increased 24% at double density and 19% in triple density.

HYBRID MAIZE IN BHUTAN

Hybrid maize was introduced in Bhutan in the early 1980's. The parental seeds of the varieties Pioneer 410 and 440 were acquired from Hyderabad Pioneer Seed Co. (India). The F1 seed was produced in Tashiyangtsi, Bhutan, to be later sold to farmers.

Cost of certified seed was US$ 0.7/kg.

Yield 3-4 t/ha at farmers condition.

Impact of hybrid seed programme.

Since the Bhutanese farming is basically for subsistence the hybrid seed programme failed to make any impact among the Bhutanese farming community. The main reasons for this failure were:

1. Cost of parental seed increased year after year until it was nearly US$ 40/kg.
2. Lack of skilled technical manpower in seed production.

3. Farmers could not afford to purchase hybrid seed year after year owing to their low debt repayment capacity.

Questions to the author:

FROM : R. S. Paroda

Q : Area, production, and productivity over the last one decade has shown a negative trend. Yield/ha has gone down from 1.4 t/ha to 0.9 t/ha. How can this situation be improved, and what are the reasons for this decline?

A : It can be improved by introduction and selection of suitable OP varieties, and development of economically viable crop management technologies. The reasons for this decline were use of local varieties, low inherent soil fertility on slopey terrains, presence and use of diverse land races and traditional crop management practices.

CURRENT STATUS OF MAIZE HYBRID BREEDING AND ITS STRATEGIES IN CHINA

Peng Zebin [1] and Chen Zehui [2]

Abstract

China is now the second largest maize producing country in the world behind the USA. In 1991, total maize area reached 21.6 m ha and the average yield was 4.6 t/ha. The area planted with hybrids is over 80% of the total cultivated area, and in 1992 a total of 27 hybrids were grown in areas over 100 thousand ha. There were four main germplasm sources of hybrid maize, but nearly 34% of the hybrid production reported contained Lancaster germplasm. Ludahonggu germplasm, with 19.07%, was the second most important, followed by Reid and Tangsipingtou with 14.4% and 13.8% area, respectively. The narrow genetic background is the main problem maize breeders are facing. In 1992, 52.21% of all new inbred lines were selected from single crosses, 10.44% from synthetics, and 10.44% from three-way crosses. The plant ideotype is an important character considered in hybrid development in China. Many hybrids with good plant architecture have been developed in recent years.

The area planted to maize in the three southwest provinces (Yunnan, Guizhou, and Guangxi) is large, but with low productivity due to a low percentage of area planted with hybrids and poor maize growing conditions. The germplasm used in the region includes temperate, subtropical, tropical highland and tropical lowland materials. Single crosses, three-way crosses, double crosses, top crosses, and OPV's are popular in this region.

Maize hybrid breeding in China

Maize hybrid breeding in China was initiated in the 1950's. Similar to some developed countries, maize hybrid breeding in China began with varietal cross hybrids, followed by top cross hybrids, double crosses, three-way crosses, and single crosses. It was through the utilization of maize hybrid breeding technology that varietal cross hybrids such as Fangza 2, Chunza 2, and the topcross hybrids Nongda 1, and Wuding 1 were successfully released. A group of double crosses such as Nongda 4, Nongda 7, and Chunza 12 were widely used since 1956, contributing a great deal to increase maize production of China. In the late 60's single cross hybrids were developed and put into production. The research efforts of more than twenty years led to the rapid increase of maize production in China. China now is the second largest maize producing country following the USA. In 1991 the total maize area reached 21.574 m ha with an average yield of 4.575 t/ha (**Table 1**), according to the statistics of the National Seed Administration. In 1992, there were 112 hybrids grown in areas above 10,000 ha. Today the maize area planted with hybrids is over 80% of the total maize area cultivated in China (**Fig. 1**).

The varieties have been renewed four times since the adoption of single crosses in the late 1960's. The typical varieties used at various times were:

Generation one: Xindan 1, Baidan 4
Generation two: Qundan 105
Generation three: Danyu 6, Zhendan 2, Jian 101
Generation four: Zhongdan 2, Yandan 14, Danyu 13

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Table 1. Hybrid maize production in China 1988-1991.

Year	Maize area (m ha)	Yield (t/ha)	Use exceeding 1 m ha			Use between 0.99 and 0.1 m ha			Used in less than 0.1 m ha			Total		
			No.	Area (m ha)	%	No.	Area (m ha)	%	No.	Area (m ha)	%	No.	Area (m ha)	%
1988	19.692	3.930	2	4.981	25.29	21	7.380	37.48	99	2.849	14.47	122	15.210	77.24
1989	20.353	3.885	3	7.175	35.25	18	6.050	29.73	114	2.995	14.72	135	16.220	79.69
1990	21.401	4.530	3	6.112	28.61	19	6.495	30.35	125	3.024	14.13	147	15.631	73.04
1991	21.574	4.575	4	7.715	35.76	18	5.486	25.43	135	3.092	14.33	157	16.293	75.52

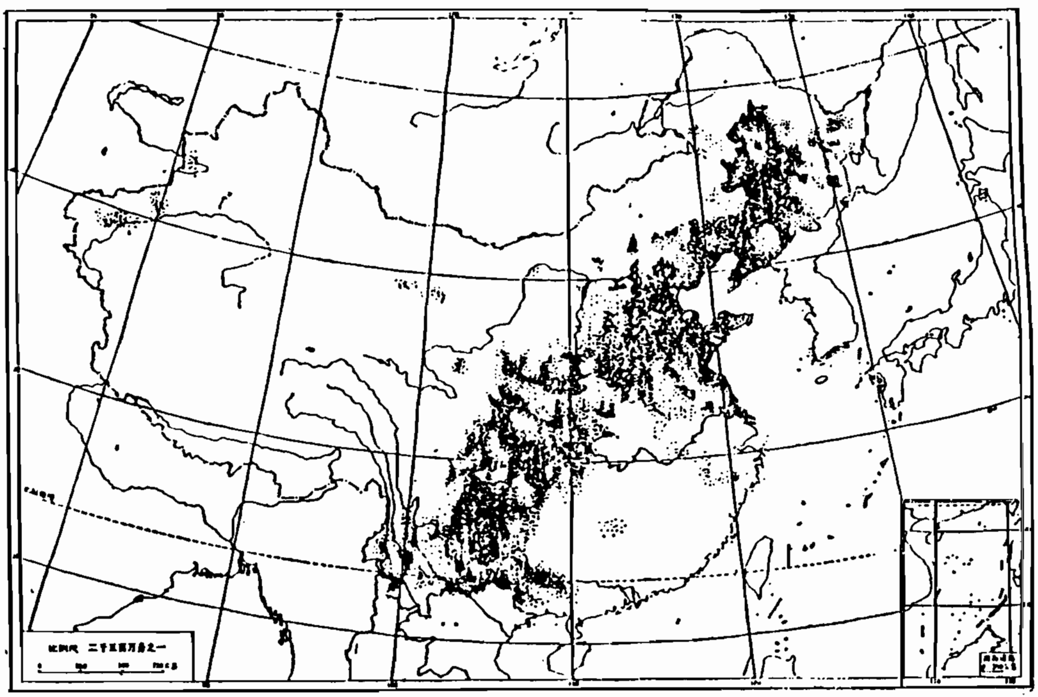

Fig. 1. Corn Belt of China.

At present, the fifth generation varieties such as Yedan 12, 13, and Shendan 7 are rapidly expanding.

Maize production in China has been greatly increased by the adoption of hybrids. The yield per ha increased from 1515 kg/ha in 1965 to 4530 kg/ha in 1990. The yearly increment was 120.6 kg/ha. Li Jing Ziong (1992) attributed 40% of the increases to maize breeding and the rest to the improvement of cultivation conditions and agronomic practices (**Figs. 2, 3**).

In the early 1980's maize breeding was thought to have a difficult period. Zheng Sanxing (1990) pointed out that the situation has changed in recent years. It is after the national maize collaboration research was organized that the new hybrids were extensively used. Thirty-two hybrids were rapidly propagated in the 6th five years period, and thirty-three in the first

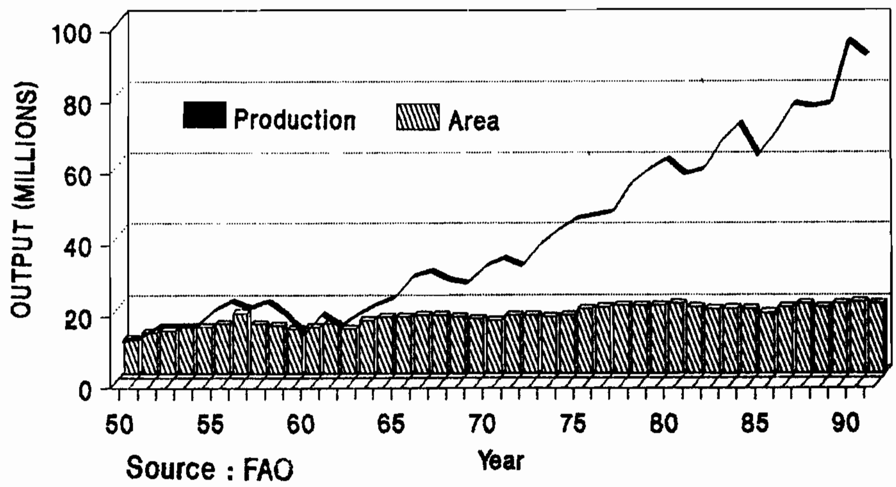

Fig. 2. Maize area and production in China.

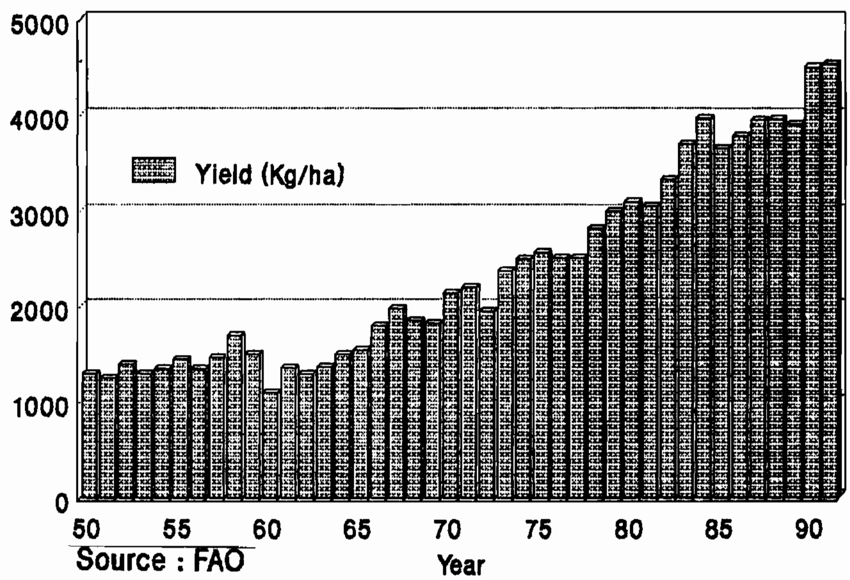

Fig. 3. Maize yield in China.

three years of the 7th five year period. In 1992, out of the 27 varieties grown over 1,000,000 ha, only 6 varieties were old ones dated back to 1983. Furthermore, the area planted to 3 of these six old varieties was rapidly declining. It was proved that in the last decade, most of the hybrids in production have been recently developed.

Germplasm development

This analysis of maize germplasm contemplates two aspects. One is the hybrids widely used in production and the other is the research effort on inbred lines as conducted in 1983 and 1992 during the compilation of the "Handbook of Maize Breeding".

"The Extension Statistics of Main Crop Varieties in China" is published annually by the National Seed Administration. The information on maize includes those varieties grown on over

100,000 mu (1 ha = 15 mu). From 1988 to 1992 the area planted to hybrid seed was 90% of the total. From 81.5% to 85.4% of the area planted to hybrids involved varieties which were planted over 0.1 m ha.

In 1993 and 1992, a total of 303 and 249 inbred lines, respectively, were surveyed. The germplasm source of these inbred lines was one of the main characters to be surveyed. The area of hybrids reported represented the contribution from each inbred line. For example, if Mo17 occurred as a male parent in 2 m ha planted with single crosses in 1978, then 1 m ha have been credited as the contribution of Mo 17.

Most important maize hybrids and their distribution

In 1992, twenty-five maize hybrids were each planted in more than 0.1 m ha, and all were single crosses (Table 2).

The hybrid Danyu 13 was planted in 2.18 m ha covering 17 provinces or municipalities. The hybrid Zhongdan 2 was planted in 2.986 m ha in more than 13 provinces or municipalities. Yedan 2 was cultivated in 1.425 m ha in 8 provinces or municipalities. In addition, the hybrids Yandan 14, Yedan 13, Yedan 4, etc. were also widely planted (Table 2). The above six hybrids covered 45% of the total maize area, or 8.537 m ha. It can be concluded that only a few hybrids predominated in maize production.

Table 2. Maize area planted with single cross hybrids, 1992. (000 ha)

Hybrid	Parents	1987	1988	1989	1990	1991	1992	Distribution
Danyu 13	Mo17 x E28	2249	3043	3501	3008	3123	2186	17
Zhongdan 2	Mo17 x Zi330	1715	1937	2289	2067	1851	1986	13
Yedan 2	Huangzao4 x Ye107	922	1157	1385	1372	1568	1425	8
Yandan 14	Huangzao4 x Mo17	1802	1516	1439	1206	1011	1035	12
Yedan 13	478 x Dan340					118	981	16
Yedan 4	Huangzao4 x U8112	31	171	497	1244	1190	924	11
Shendan 7	5003 x E28	7	410	324	522	628	700	6
Yedan 12	515 x 478					121	571	11
Benyu 9	7884-7 x htMo17					17	521	2
Sidan 8	Xi 14 x Mo17	972	806	625	341	205	486	3
Baidan 9	ZaG546 x Ji63	158	316	508	431	632	461	3
Qisandanjiao	77 x Zi330	351	404	428	489	443	423	6
Dongnong 248	Dong46 x Dong237	108	305	237	359	425	382	3
Tiedan 4	Ti 63 x Zi330	377	191	239	138	224	312	3
Sidan 16	446 x Mo17				74	347	275	2
Sidan 19	444 x Mo17						259	2
Danyu 15	Mo17 x Dan340		110	147	97	127	252	4
Nongda 60	5003 x Zong31			15	36	221	210	5
Luyu 10	U8112 x H21						174	1
Yandan 17	Ye107 x Wenhuang31413					80	171	1
Lomgdan 8	Hai014 x Chang3				67	78	141	2
Jingza 6	Zi330 x Xu052	299	309	234	178	152	130	4
Jindan 9	Jihuang 795 x Mo17					50	129	1
Tiedan 8	Liu9 x Tie7922			43	107	240	131	1
Nongda 65	Zong8 x 42-1				9	79	123	2
Sc-704	B73 x Mo17	39	91	99	106	116	121	1
Tieyu 1	N46 x V22					59	108	1

Number of provinces or municipalities.

The maize inbred lines in 1992

There were 25 main lines grown over 10,000 ha; four of them were planted over 1 m ha, i.e., Mo17, Huangzao4, E28, and Zi330 (Table 3), which covered 54.75% of the total area planted with lines (8.059 m ha). The other 13 lines, such as Ye107, 478, Dan340, U8112, 5003, etc. covered 35.87% of the total line area, (0.2-1.0 m ha). The above mentioned 17 lines covered 90.62% of the total line area in hybrids planted over 0.1 m ha. From these data, it is reasonable to believe that the 17 lines represent the present genetic composition of most of the maize hybrids in China.

Table 3. Parent lines of hybrids planted exceeding 100,000 ha in 1992.

Line	Area (000 ha)	% of total area	Line	Area (000 ha)	% total area
Mo17	3,496	23.75	ZaG564	231	1.57
Huangzao4	1,694	11.51	Dong46	213	1.44
E28	1,443	9.80	Dong237	213	1.44
Zi330	1,426	9.69	77	212	1.44
Ye107	795	5.40	446	138	1.44
478	776	5.27	Zong31	105	0.93
Dan340	617	4.19	H21	87	0.71
U8112	604	4.10	Wenhuang31413	86	0.59
5003	455	3.09	Xu052	65	0.58
Ji63	387	2.63	Jinhuang795	65	0.44
515	286	1.94	873	61	0.44
7884-7Ht	260	1.77	Jing7	50	0.41
M14	243	1.59			

The planting area of inbred line is half of the area of the related single cross.

Development of maize hybrid germplasm

For a long time, it has been known that several main lines covered most of the total line area. Since 1978, the utilization of the main lines is shown in Table 4. In 1978, five lines were used in more than 8% of the total line area but covered 51.4% of the total requirement. Only 15 lines meeting more than 1% of the total need took up 70.9% of the total need. Four main lines, although different in different periods, have dominated maize production, occupying 45.9% to 70.7% of the total line area. Furthermore, 87.9% to 97.1% of the total area was covered by a dozen main lines at different periods.

Table 4. Utilization of some elite inbred lines in hybrid maize production.

Year	Use exceeding 8% of total need % of total requirement		Use between 7.9% and 1.0% of total need % of total requirement		Total % of total requirement	
	No.lines	%	No.lines	%	No.lines	%
1978	5	51.4	10	19.5	15	70.9
1980	4	45.9	14	42.0	18	87.9
1982	4	53.0	15	44.1	19	97.1
1984	4	56.3	13	42.7	17	89.0
1986	4	67.1	8	21.0	12	88.1
1988	4	70.7	9	18.3	13	89.0
1990	4	68.0	9	23.9	13	91.9
1992	4	54.8	12	35.6	16	90.6

\+ The planting area of inbred line is half of the area of the related single cross.

In China, there have been seven main germplasm sources of inbred lines. These sources are:

1. Golden Queen and its derivatives. Examples: Aijin525, Jin02, 03.
2. Huobai and its derivatives. Examples: Houbai, Huo112, 732.
3. Lancaster and its deriveratives. Examples: Mo17, ZI330, 445, Va35, 150.
4. Ludahonggu and its derivatives. Examples: Lu28, Lu9, E28, D340.
5. Tangshansipingtou and its derivatives. Examples: Tangsipingtou, Huangzao4, Jing7, 515.
6. Reid Yellow dent and its derivatives. Examples: B73, Ye107, 478, 5003.
7. Others. Examples: Ji63, Dian11, Zong31.

Since 1988, the inbred lines derived from Huobai or Golden Queen have disappeared from those hybrids planted in an area greater than 100,000 ha (**Table 5**). The use of Tangsipingtou continually decreased since 1978, and it was gradually replaced by Huangzao4. Similarly, E28 was substituted for Lu28. The lines derived from Reid, such as B73, U8112, Ye107, 5003, etc. have continued to be used. Only inbred 478 has rapidly developed in recent years. Mo17, and Zi330 have continued to be used as main lines, but their utilization seems to be declining.

Table 5. Development of hybrid maize germplasm in China.

Germplasm source	Inbred line	Year 1978	1980	1982	1984	1986	1988	1990	1992
Golden Queen	Aijin525	8.5	5.2	2.3	1.1	0.7			
Houbai	Houbai	10.5	11.6	9.0	4.8	2.2			
Tangsipingtou	Tangsipingtou	11.0	8.4	10.3	2.4	0.8			
	Huangzao4			4.0	11.2	16.7	12.3	15.7	11.5
	515								1.9
Ludahonggu	Lu28	8.9	8.3	6.5	2.4				
	E28					3.5	13.7	13.8	9.8
	Dan340							4.2	
Lancaster	Mo17	1.3	5.8	11.9	17.5	28.1	32.9	27.2	23.8
	Zi330	12.6	17.7	21.8	17.5	13.9	11.8	11.3	9.7
	Weifen322	0.4	1.3	5.0	1.8	0.8			
Reid	Ye107				0.8	3.3	4.6	5.4	5.4
	U8112							5.6	4.1
	478								5.3
	Yuanwu02		1.3	5.2	4.7	3.4			
	5003					1.6	1.7	3.1	
All other	M14	4.5	6.0	4.6	10.1	8.3	3.2	1.9	1.7
	Zaodahuang	2.8	4.0	0.9	1.1	0.3			
	Ernan24	2.1	2.3	3.9	1.1	0.7			
	Ji63	1.9	3.5	2.9	6.0	4.1	2.0	2.9	2.6
	Tie133	1.7	1.5	0.7	0.3				
	Bup44	1.5	4.0	0.4	1.6	1.0			
	Luoxi3		1.7	2.2	1.2				
	77	1.1	1.4	3.0	1.7	2.0	1.6	1.9	1.4
	ZaG546							1.7	1.6

* Unit: A percentage accounting for the total area of maize hybrids.

Germplasm sources of maize hybrids of China in 1992.

In 1992, there were four heterotic groups used in hybrid maize (**Table 6**). Nearly 34% of the reported hybrid production contained Lancaster germplasm. Ludahonggu germplasm, with 19.07%, was the second in importance, followed by Reid and Tangsipingtou with 14.40% and 13.80%, respectively. The total of the above 4 groups accounted for 81.2%, with 18.8% being derived from other sources.

Germplasm sources for newly developed lines in China

The results of the survey carried out in 1992 showed that 52.21% of the lines were developed from single crosses (**Table 7**). Exotic x adapted cultivars and adapted exotic cultivars amounted to 2.81% and 6.06%, respectively. Selection in backcrosses, double crosses, and open pollinated cultivars and "other" category account for 3% or less in each case. Synthetics, composites, and populations improved by recurrent selection contributed 15.68% of the lines. Three-way crosses accounted for 10.44% of the effort.

Table 6. Heterotic groups included in 1992 hybrid production.

Heterotic group	Area (ha)	% of total production
Tangsipingtou (e.g., Huangzao4, Jing7, 515, H21)	2,031,400	13.80
Lancaster (e.g., Mo17, Zi330, 446)	4,994,000	33.93
Reid (e.g., B73, U8112, Ye107, 478, 5003)	2,119,700	14.40
Ludahonggu (e.g., E28, Dan340, Lu9)	2,807,500	19.07
All others (e.g., Ji63, Zhong31, M14)	2,747,400	18.80

Table 7. Parental sources for new inbred line development.

Source	% of total effort	
	1983	1992
Single crosses	35.31	52.21
Three-way crosses	2.62	10.44
Double crosses	7.26	1.20
Backcrosses	1.32	2.41
Open pollinated cultivars	20.79	3.21
Synthetics or composites	6.27	10.44
Populations improved by recurrent selection	0	5.22
Exotic x adapted cultivars	10.00	2.81
Adapted exotic cultivar	12.54	6.06
Others	3.96	2.41

A comparison between 1983 and 1992 sources, showed a great increase in single crosses, three-way crosses, and synthetics or populations as sources. The amount of effort in double crosses and open pollinated cultivars greatly decreased.

If a new inbred line comes from a single cross made up of similar parents in adaptability, it will have a narrow germplasm base, and the more similar the parents are, the more narrow its germplasm basis is. On the other hand, if a new inbred line comes from a single cross with parents greatly different in adaptability, maturity, and genetic background, it will have a broad germplasm base. Four main lines (Mo17, Zi330, Hungzao4, and E28) occupy more than half of the actual maize germplasm in China, indicating that a lot of effort towards line development may be coming from similar germplasm sources. So, utilizing new and exotic germplasm sources to develop inbred lines is very important in China.

Development trend

Similar to many countries in Europe and America, the planting density of maize hybrids in China increased as the production level increased. Li Jing Xiong (1992) pointed out that the biggest progress of maize production in the past depended upon increasing plant density fertility levels. Selection interia should be adjusted if such agronomic practices are continually adopted to increase production. Selection for tall plants and large ears should be modified by emphasizing the relations between plant type and population density. More selection intensity should be placed on stalk lodging resistance in positio at the middle of the plant erect leaves, and average to large size ears as the planting density is increased. Pan Caixian (1992), indicated that in China, it would be more effective and profitable to increase the planting density to exploit the yield potential, rather than to enlarge ears to increase the yield per plant. The ideotype maize plant is an example of this tendency, which has developed rapidly in China during recent years. A lot of ideotype hybrids were developed such as Yedan2, 4, 12, 13. Lines such as U8112, 5003, 478, 515, and Dan340 derived from semi-ideotype and ideotype maizes combine well with traditional types of inbred lines such as Huangzao4. Some provinces in China have divided the regional tests into 2 groups: ideotype and normal type.

Problems to be solved

From the above analysis, it can be concluded that the narrow genetic background in most available germplasm is the main problem that maize breeders are facing in China. The hybrids produced in 1992 are mostly crosses including four inbred lines: Mo17, Zi330, Huangzao4 and E28. It would cause a great loss if one of these lines or hybrids such as Zhongdan2 or Danyu13 become susceptible to any disease or pest due to race variation. Therefore, emphasis should be put on widening the germplasm basis. For this, the following measures should be taken:

1. Full exploitation of the potentialities of germplasm sources, by actively collecting, studying, and utilizing the new germplasm sources. Local varieties (open pollinated cultivars) are an important part of new germplasm sources. In the past decades some breeders in China ignored the exploration and utilization of local varieties and concentrated on recycling lines from the current single crosses. Many excellent inbred lines have been derived from local varieties. For instance, Tangsipingtou was developed directly from local germplasm source Tangshansipingtou; Huangzao4 was selected from Tangsipingtou; Lu9 directly from local cultivar Ludahonggu, and Ku Kan was derived from Lu9. The famous inbred line E28 was developed from Lu9 Kuan and A619 Ht.
2. Emphasize the introduction of exotic germplasm to enrich the maize germplasm resources in China. At present there is a shortage of maize germplasm sources and most improved populations are not good enough for large scale production because of low yield potential. There are not enough useful genes accumulated and the negative genes have not been effectively excluded. Sometimes there are possibilities to select new elite lines from the offspring of good exotic materials and good domestic germplasm. This has been proved by breeding practices in China during the last decades. A lot of inbred lines now being used, or to be used such as 5003 (5005), U8112, Ye478, and Tie7922 have developed from newly introduced germplasm. There have been several elite lines developed from exotic hybrids in recent years.
3. Population improvement and creation of breeding materials. There has been encouraging progress. Dozens of populations with wide or narrow genetic background were developed, which are still being improved. Some populations such as Shanzong 3 have been used directly for commercial production. Some lines derived from populations have been used in hybrid production as is the case of Zhong31, Baihunghun, D729, and Liaolun814. Great progress in China has been achieved in utilization of tropical and subtropical germplasm in the temperate zone, where the elite inbred lines Yetie21, Zhong7490, Zhong128, Zhong271, Zhongxi05/02 have been developed from some tropical germplasm sources.

Certainly China is not alone in having the problem of a narrow genetic base. The problem is of world wide importance. In the United States, the biggest maize production country in the world, the basic germplasm for hybrids are mainly "Reid" and "Lancaster". So, it will take a long time of hard work for maize breeders to create, exploit, and utilize the proper germplasm resources:

Maize breeding in the three southwest provinces

1. Introduction: Maize area of Yunnan, Guizhou, and Guangxi provinces occupies 2.1 m ha (9.9% of China maize area) with a total production of 5.767 m t (5.8% of China's maize production), and

a mean yield of only 2.771 t/ha.

These three provinces are located at a low latitude and much of the area is a high plateau with hilly land (Fig. 4). The maize area of the region is large, but yields are low because:

a. Low percentage of hybrids: The percentage of hybrids in the main maize growing area in the nation is 80%, but it is only 60.9%, 43%, and 26% in Guizhou (1991 data), Yunnan (1992 data) and Guangxi (1989 data), respectively. Additionally, there are not very good adapted hybrids for this region, especially hybrids for highlands and infertile soils.

b. High percentage of poor soil: The fertile soil is about 10%, while the hilly eroded soil covers 50-70%, and poor and highland soils are 20-30% of the total area.

c. Climatic factors: cool in highland and drought in the rest of the region.

d. Low fertilizer availability.

e. Poor cultural practices.

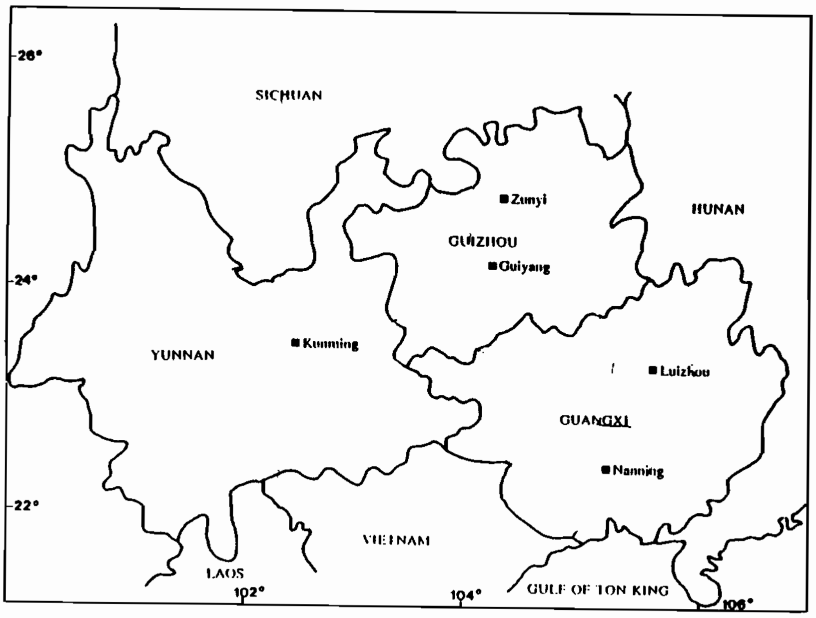

Fig. 4. China (southern provinces)

2. Limited germplasm for maize breeding.

Before the 1970's, most maize germplasm used for breeding were local materials and temperate germplasm. During the 1970's and 1980's, tropical maize germplasm was introduced from CIMMYT, Thailand, and other countries.

Guizhou, Yunnan, and Guangxi are rich in local germplasm with good eating quality, resistance to diseases, cold and drought tolerance, tolerance to infertile soils, and have wider adaptability, stable yield, and high specific combining ability with temperate and tropical maize. However, their plant height and resistance to lodging needs to be improved.

In this region, temperate materials have good performance. Until now, temperate hybrids are still growing in a large area. But they have been found susceptible to *turcicum* and *maydis* leaf blights, as well as several other diseases.

Some temperate materials in the three provinces show strong thick stalks, good root systems, and resistance to lodging, drought, infertile soils, and several diseases.

3. Breeding methods.

a. Inbred lines.

i. Directly introduced temperate inbred lines (Mo17, Zi330, 5003, 53 etc.)

ii. Inbred lines developed from temperate hybrids and composites, from local varieties (Jiao51, Duzi, Guanhua, etc.), from tropical populations (Gui102, M9, Bai M9, Fm9, FS1, 449, Dao13, Da19, SSE232 etc.).

b. Combinations used for single crosses:

Temperate line x temperate line (in Guizhou, Yunnan).
Line from local material x temperate line (in three provinces).
Line from local material x tropical line (in three provinces).
Temperate line x tropical line (most popular in three provinces).

Since there are complex climatic conditions, poor soil, severe drought, and low yielding seed parents of single crosses, it is more economical to develop mostly three-way, double cross, and top cross as well as improved OPV's in this region.

c. Combinations for three-way hybrids

(Temperate line x local line) x tropical line.
(Temperate line x tropical line) x tropical line
Temperate hybrid x tropical line.

d. Combinations for double crosses:

Temperate hybrid x (local line x tropical line)
Temperate hybrid x (tropical line x tropical line)

e. Combinations for top crosses:

Temperate hybrid x tropical OPV
Tropical OPV x temperate line
(Temperate line x tropical line) x tropical OPV

f. Improved OPV's

Using temperate, local, and tropical materials, two or three of them are crossed followed by recurrent selection procedures.

4. Main hybrids/varieties.

a. **Guizhou**: several hybrids/varieties were released for different ecological zones over the province.

Mo17 x Zi330 (temperate hybrid)
77 x Zi330 (temperate hybrid)
Jiao51 (local line) x Zi330
Mu6 (temperate line) x Mu4 (local line)
(Mu6 x Mu4) x Suwan 1
411 (temperate line) x 449 (from Tuxpeno)

Hybrids with one inbred line developed from Tuxpeno as parent have covered total area of 200,000 ha since 1988.

Improved OPV's : Qianqun 1, Qianqun 2.

b. **Guangxi**: (area covered in the 1980's)

(Mo17 x Zi330) x Amarillo Dentado, 221,446 ha.
Amerillo Dentado x Mo17, 15,447 ha.
(7087 x Gui102) x Amarillo Dentado, 80,840 ha.
(Gong N-2-3 x Mom2-2) x Amarillo Dentado, 86,293 ha.
Nan60-1 x 705-16, 37,333 ha.
(Nan60-1 x 705-16) x Tuxpeno1 and
(Nan60-1 x 705-16) x Amarillo Dentado, 120,000 ha.

In the 1980's the area of Amarillo Dentado as one parent in all crosses was 415,000 ha and 138,000 ha in 1990. From 1986 to 1990, the area using Suwan 1 as one breeding material was 745,000 ha.

c. **Yunnan**: hybrids Jingza6, 77 x Zi330, Mo17 x Zi330, Yedan, Huidan, SSE232 x Zi330, SSE232 x Mo17, Siliao, Qin3, etc. The area of hybrids is 400,000 ha per year.

Improved OPVs: 81-17, Jidonghuang, Fongrehuang, Lisantou, Suikouhuang, etc. covering an area of is 100,000 ha per year.

References

Chen Zehui. 1993. Maize plastic mulching and transplanting in Guizhou.

Chen Zong Long. 1993. Maize cropping system in Yunnan.

Darrah, L.L. *et al*. 1986. 1985 United States farm maize germplasm and commercial breeding strategies. Crop Sci. 26: 1109-1113.

Dong Pingya. 1992. Maize growing zones in China.

Food Crops Institute, YAAS. 1993. Some information of maize cooperation between Yunnan and CIMMYT.

Li Jing Xiong. 1992. Recent advances in maize breeding. p. 8-14, 1st ed.

Proceeding of the 35th Annual Corn & Sorghum Industry Res. Conference. 1980, 234-249.

Wu Jingfen. 1983. A review on the germplasm bases of the main corn hybrids in China. Scientia Agric. Sinica, 16: 1-9.

Zeng Sanxing. 1990. The maize germplasm base of hybrids in China. Scientia Agric. Sinica, 23: 1-8.

Zhang Sukuang. 1993. Exotic germplasm in Guangxi.

Questions to the author:

FROM : L. C. Onn
Q : What is the cost of production of maize in China and what is the largest cost component?
A : Labor, chemical fertilizers, seeds, and chemical pesticides. The largest cost is labor.

FROM : C. Chutkaew
Q : Your hybrid corn growing areas expand very fast. When do you expect China will grow hybrid corn on 100% of the area?
A : It's very difficult to achieve 100% because there are still some highland, or areas with very poor soils for growing maize which are not convenient for hybrids.

FROM : G. Granados
Q : One of the main factors for yield reduction in South China is drought. Have you identified sources of resistance to drought, and if so, how are you using them?
A : We have identified sources of resistance to drought from local varieties by China National Maize Program. Now we are developing inbred lines from those sources.

MAIZE IMPROVEMENT IN INDIA - AN OVERVIEW WITH EMPHASIS ON HYBRID RESEARCH.

N. N. Singh [1], S. J. Patil [2], Sai Kumar [3] and Tej Kumar [4]

Abstract

Maize is an important crop not only in India but worldwide. India grows maize in an area of approximately 6 m ha annually out of which a production of 10 m t is realised. The productivity as compared to other countries of East Asia is low. Among various factors responsible for low production, the lack of assured weather conditions and nonavailability of seed of improved cultivars deserve special mention. Efforts towards the improvement of maize were initiated in 1957 in the form of a Coordinated Project with the assistance of the Rockefeller Foundation. Since then the project has taken up work on various facets of maize improvement. A number of hybrids and composite varieties in various maturity groups have been made available for farmers. In the field of hybrid research initial emphasis was laid on the development of double-cross and double top cross hybrids. However, at present we have three-way hybrids which have also gone to cultivation. A number of single cross hybrids are in the process of development and have given satisfactory yields. These are to be released soon for commercial cultivation. Attention has also been given to the development of maize cultivars having specific traits like amylose and amylopectin type of starches with high oil content to develop various industrial products, thereby making maize a more remunerative crop. Suitable cultivars in sweet and pop corns have each been released for cultivation. High lysine maize cultivars with hard endosperm have also been developed. In the field of agronomy, entomology, and pathology, significant contributions have been made which are highlighted in the paper.

Introduction.

In Asia, maize is grown more extensively than any other cereal crop, the obvious reason for this being existence of a high yield potential. In the Asian region, 33 countries produce maize while rice, wheat, millets, and sorghum are grown in 30, 26, 20, and 17 countries, respectively. The area, production, and productivity of maize in major maize producing countries of Asia are given in Table 1. On the global maize scenario, India ranks fifth in area and tenth in total production. An area of approximately 6 m ha is planted to maize annually, out of which a production of 10.0 m t and yield of 1.76 t/ha is realized, which amounts to 6.6% of the total cereal production of the country. There are various factors which are responsible for this low productivity, the most important being: i) cultivation under rainfed conditions (85% of area) and ii) very little (30%) area under improved cultivars. Since maize is the staple food for the lower strata of the society, it found a place as one of the major crops selected under "Special food grain production program" launched by the Government of India.

Historical background.

The first ever coordinated Project for crop improvement program was set up by the Indian Council of Agricultural Research (ICAR) in maize in 1957, on the suggestions of Drs. U.J. Grant and E.J. Welhausen of the Rockefeller Foundation. Initially, the Rockefeller Foundation assisted by way of providing germplasm, field and laboratory equipment, and scientific personnel. Prior to this the various research stations in the country were engaged in research on hybrid maize as

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ad-hoc projects. After the inception of the Coordinated Project the physical research facilities available in these stations were consolidated. To start with, only a few maize breeders were associated with this project and they had the specific objective of developing high yielding maize hybrids. However, they also carried out some investigations on agronomic aspects.

Table 1. Area, production and productivity of maize in the Asian region (1989-91).

Countries	Area harvested (000 ha)	Yield (t/ha)	Production (000 t)
MIDDLE EAST			
Afghanistan	264	1.6	436
Turkey	513	4.0	2,067
Iran	3	0.9	40
Iraq	42	2.9	121
Saudi Arabia	02	-	-
Syria	59	2.7	158
SOUTH ASIA			
Bhutan	52	1.5	81
Burma (Myanmar)	124	1.5	190
India	5,856	1.5	8,975
Nepal	760	1.6	1,222
Pakistan	856	1.4	1,185
SOUTH EAST ASIA			
Indonesia	3,037	2.1	6,445
Philippines	3,699	1.3	4,677
Thailand	1,644	2.5	4,035
Vietnam	484	1.5	720
EAST ASIA			
China	20,804	4.3	89,922
North Korea	710	6.3	4,450
South Korea	24	4.3	105
Taiwan	84	4.0	332

The Coordinated Maize Breeding Project was further strengthened in the year 1963-64 by adding to it the disciplines of agronomy, entomology, and pathology. Though these disciplines were financially supported by PL-480, for technical purposes the staff functioning under them was an integral part of the project. In the year 1964, after the addition of the above disciplines, the project was redesignated as All India Coordinated Maize Improvement Project (AICMIP), as it exists today.

Soon after the inception of the AICMIP, a large number of inbred lines and hybrids were introduced from USA and the Caribbean region. These hybrids along with Punjab hybrids and top crosses involving about 100 inbred lines were put into trials. Out of these, 28 promising inbred lines were picked up for subsequent use. In 1958, several hybrids from southern USA, particularly NC-27, Texas-26 and Dixie-18 performed very well under Indian conditions. However, these hybrids could not become popular among Indian farmers as they possessed dent grain type and farmers had a preference for flint grain type. Keeping this objective in mind the breeders also collected indigenous genotypes having yellow flint grain type and used them along with exotic germplasm. During this process, emphasis was placed on development/selection of elite inbred lines possessing good general combining ability, desirable agronomic traits, and resistance to diseases and pests. With the results of this activity, by the year 1961, four double cross hybrids namely Ganga-1, Ganga 101, Ranjeet, and Deccan were released for cultivation. In the following year, another hybrid VL 54 and in 1963 two double top cross hybrids Ganga Safed-2 and Hi-starch were released. Presently more than two dozen hybrids (double cross, double top cross, three way crosses) are available for cultivation.

Though during all these years emphasis was laid on the development of inbred lines and production of hybrids, a systematic program of collection and evaluation of a large number of indigenous and exotic germplasm also continued. Later, the Indian maize materials were classified/grouped on the basis of their maturity, seed color, grain type, etc. which is known as "Indian Maize Complexes" (Table 2). During the mid 1960's a program on development and improvement of composites was initiated with the objective to provide maize cultivars to the farmers and also to extract more productive inbred lines from such broad based improved populations. By the year 1961, six composite varieties, namely Kisan, Jawahar, Sona, Vijay, Amber, and Vikram were released for commercial cultivation. The population improvement program was taken up for extracting better varieties by using recurrent selection procedures.

Table 2. Indian maize collections.

State	No. maize collections made and evaluated	No. collections used in the complexes	No. complexes available
Andhra Pradesh	27	27	3
Assam, Manipur, Tripura & NEFA	96	71	10
Bihar	259	154	10
Bombay	-	16	4
Gujarat	26	23	6
Himachal Pradesh	77	56	10
Jammu and Kashmir	221	134	12
Kerala	7	5	2
Madhya Pradesh	247	160	15
Madras	4	4	1
Maharashtra	29	-	-
Mysore	9	7	2
Orissa	57	31	3
Punjab	170	195	13
Rajasthan	82	5	2
Uttar Pradesh	186	135	11
West Bengal	94	51	9
Total	1594	1074	113

Since most of the hybrids and composites released for cultivation had low levels of lysine and tryptophan in their amino acid contents, a massive program for the development of high quality maize was launched. This comprised of incorporation of opaque-2 and floury-2 genes in selected genotypes resulting in three high protein quality cultivars namely Shakti, Protina, and Ratna released in 1971. Efforts were also directed towards the development of hard endosperm cultivars with high protein levels. In this direction, success of a high order has been achieved.

It has adequately been shown that in the presence of opaque-2 the lysine and tryptophan content is nearly doubled. This increase in the level of these two amino acids results in the marked increase in the biological value. In spite of this nutritional superiority, the lack of extensive acceptability of the opaque-2 varieties is due to their soft chalky endosperm, the opposite of the vitreous endosperm types of the flint to semiflint maize varieties. The opaque-2 varieties have a similar problem to those associated with the soft kernel type, which face difficulties for safe storage since they are more prone to weevil attack when stored at lower elevations. Considerable variation in kernel vitreousity exists within a opaque-2 broad based populations and it was, therefore, thought appropriate to improve the frequency of hard endosperm (HE) types.

Intensive work in this direction was started in 1971, with the release of three opaque-2 composite varieties. Selection approaches adopted were: individual kernel selection, ear-to-row selection, and reciprocal full-sib selection. Among the three selection approaches, more promising results were obtained with reciprocal full-sib selection, primarily because of the presence of reciprocal/maternal effects. A broad based hard endosperm opaque-2 composite, SO/SN has been developed. In terms of yield and frequency of HE the Indian cultivars are comparable with HE materials developed at CIMMYT, Mexico. Realizing the popularity of sweet and pop corns in the country, attention has also been laid for the development of their improved cultivars. Two cultivars, Madhuri and Madhu Makka in the sweet corn group, and Amber pop and VL-Amber pop in popcorn group have been released so far.

To date, more than five dozen hybrids and composites have been released for commercial cultivation with either yellow or white grain color, flint to semiflint texture, early to late maturity range, and adaptation for irrigated and also for rainfed conditions. Also, these cultivars posses a fairly good level of tolerance/resistance to important diseases and pests.

Development of maize cultivars suitable for various farming systems.

The cultivars released prior to 1971 belonged to the full season maturity group. In 1974 a program to develop materials of medium and early maturity was initiated with the result that we have today improved cultivars belonging to various maturity groups, thereby farmers have a wide option to choose a maize cultivar to fit in their cropping system (**Table 3**).

Synthesis of broad-based pools for the development of varieties.

A few broad based pools representing various maturity groups and grain color were developed to cater to needs of various agro-ecological regions of the country. Mobilization of desirable progenies selected from these pools yielded promising varieties. After the proper evaluation and selection, the promising materials were used to synthesize composites or varieties. The following five broad based pools mobilizing the available elite materials were formulated: pool AB-yellow, AB-white, BC-yellow, CD-yellow, CD-white, representing three maturity groups and two grain types. After initial synthesis, each of these pools has undergone six cycles of random mating. The individual pool was grown in a half-sib nursery and the 1-2 most promising ears in nearly 40% of the elite progenies were retained and tested at 4-6 locations during summer season. The seed from selected ears was grown during the winter season in a half-sib recombination block to random mate the population and develop progenies for next cycle. Again, from this nursery 1-2 best ears from each of the progenies were retained for next cycle (second cycle of half-sib selection). Selected elite half-sibs were used to synthesize an improved version of the population.

Gain through intrapopulation improvement selection.

The intrapopulation improvement program at the national level was initiated in 1974 using ten elite composite varieties representing different maturity groups. A full-sib family selection scheme with two levels of selection intensity was used. Under this selection program about 250 full-sib progenies were evaluated at 4-6 locations for grain yield and other agronomic characters. In addition, these progenies were also evaluated for one or more important disease(s) and insect pests under artificial inoculations and infestations. After harvest, based

Table 3. Details of medium and early maturing hybrids & varieties of maize recently developed and released by AICMIP.

Name	Year released	Yield range t/ha	Maturity	Grain type	Area of adaptation
HYBRIDS					
VL-42	1988	3.5-4.0	Early (85-90 days)	Yellow semiflint	Recommended for cultivation in kharif season in hilly area of U.P., J & K, Himanchal Pradesh, and Peninsular India. Tolerant to turcicum leaf blight and other diseases.
Deccan 1	1989	3.5-4.0	Early (85-90 days)	Yellow semiflint	Recommended for cultivation across the country for rabi season.
Deccan 107	1992	4.0-4.5	Medium (90-100 days)	Yellow semiflint	Three way hybrid recommended across the country for kharif season.
COMPOSITES					
Pusa Comp. II	1988	3.5-4.0	Medium (90-100 days)	Orange Yellow semiflint	Recommended for cultivation in kharif season in Rajasthan, Punjab, Haryana, and Delhi.
Pusa Comp. I	1988	3.0-3.5	Early (75-80 days)	Orange Yellow semiflint	Recommended for kharif cultivation in central and peninsular India.
VL-88	1988	3.0-3.5	Very Early (75-80 days)	Orange semiflint	Recommended for kharif season planting in hilly areas of U.P., H.P., and Himalayan region.
Surya	1988	3.0-3.5	Very Early (70-80 days)	Yellow orange semiflint	Recommended for cultivation across the country in kharif season and Diara areas of U.P. and Bihar.

on overall performance, 40% of the best progenies were used in the following winter season to synthesize progenies for the next cycle of evaluation. In addition, using 4% selection intensity, location specific and across location improved varieties in each of the populations were synthesized. These improved varieties were evaluated in advanced generation trials. After comprehensive evaluation, the promising ones were released for commercial cultivation.

Improved varieties of various populations were compared with their respective base populations at different cycles of selections. Gains realized through selection showed a great deal of variation. In a few populations no improvement was recorded, while in others, general gains of 3-5% per cycle of selection were recorded. Gains were rather high in composite Diara (an extra early variety) from which three improved versions have been subsequently released.

From studies of the various populations under improvement, it was noted that the varieties selected on across location testing gave better stability and higher grain yield than those of location specific ones. It was also observed that the use of advanced generation full-sib progenies in general yielded higher than those from F1 seed material. Based on this observation, full-sib progenies in several populations were advanced to F2 in the summer season. The next cycle, progenies as well as improved varieties were developed in the ensuing winter season using F2 seed. Thus, through this process, one cycle of full-sib selection is completed in two crop seasons (summer and winter).

Development of maize varieties for specialized uses.

The starch industry has expressed a need for developing waxy (high amylopectin) and high oil content varieties. Considerable progress with waxy maize has been made and a number of waxy maize varieties are under advanced stages of evaluation. Preliminary evaluations indicate that the waxy types yield 10-15% less than the best normal materials. Work on high amylose types is also in progress.

Normally, maize contains 3.0-5.4% oil which is highly unsaturated (**Table 4**). Some of the high oil selections obtained from the USA have been under *per se* evaluation and as parents of double top cross hybrids. While these introductions *per se* have limited commercial use, some of them can be used in hybrid combinations. A few hybrids have shown 1.5-2.0% increase in oil content with yield levels comparable to the check hybrid.

Varieties for forage.

Little work has been done on the development of maize varieties suitable for forage. Composite varieties like Kisan and Vijay were being cultivated and also used for forage, as they possess dark green foliage. By mobilizing the tropical germplasm, a new composite "*African Tall*" has been developed which is very popular as fodder maize. It is a full-season composite with abundance of foliage and good seed yield. Yields of 1 t/ha per day of green forage has been reported at Kolhapur (Maharashtra) and several other places. This composite is suitable for cultivation in both summer and winter seasons. It possesses white dent grain and long ears.

A simple recessive gene bm_3 with distinct morphological marker is known to reduce the lignin content of fodder and increase its digestibility. This gene was incorporated into the genetic background of a number of elite population of various maturity groups. The selection with bm_3 had lower lignin content and higher *in vitro* digestibility, compared to the normal types at various stages of crop growth. The reduction in lignin in different maize varieties varied from 2 to 3%, while the *in vitro* digestibility was improved by 2-5%.

Winter maize program.

Research carried out at various research stations of the AICMIP has shown that winter maize can be successfully grown in almost all parts of India except the hilly regions. The yields obtained during the winter season are substantially higher than those of the summer crop. Yield levels of 8-10 t/ha have frequently been obtained. However, yield of 4-6 t/ha in farmer fields is not uncommon. Based on this convenient situation, the AICMIP now regularly conducts trials in winter. Thus the research stations (except those of Zone I) are engaged in breeding activities of cultivars suitable for winter season and regularly carry out two sets of trials, in summer and winter seasons. This testing is needed to explore the possibilities of further increasing the yield levels of the winter maize with the use of more productive hybrids.

Table 4. Seed index protein, oil and starch (on dry basis) in maize released varieties and hybrids.

Varieties	Seed index (g/100 kernel)	Starch (% dry basis)	Oil (% dry basis)	Protein (% dry basis)
D-765	18.7	69.22	5.41	10.32
Deccan-103	28.5	71.12	5.58	9.79
Sweta	20.0	69.22	5.19	11.66
Renuka	26.0	67.97	5.34	12.62
Hi-starch	34.0	71.86	5.20	10.22
Arun	19.6	67.90	5.62	10.89
Deccan-105	21.4	67.01	5.11	11.83
Dhawal	32.8	66.20	3.80	12.63
Harsha	20.4	63.31	4.55	12.62
Ganga-11	30.0	69.47	4.81	10.76
Vikram	25.0	65.14	4.89	12.50
Varun	18.8	66.21	4.39	11.96
Diara-3	17.0	67.16	4.97	9.16
Ageti-76	22.3	69.12	4.71	10.61
Parbhat	24.3	69.97	5.17	9.46
NLDDFP-106	22.7	65.19	4.10	12.66
Shakti	20.4	66.78	5.36	10.12
Navjot	22.7	66.60	3.72	10.04
Rattan	25.5	65.04	5.32	9.71
Sona	25.6	68.08	4.97	10.62
Kiram	20.7	69.27	4.70	11.60
MCU-508	20.1	71.32	4.33	10.66
Kisan	21.4	69.05	3.94	12.51

* Based on 96% value of pure starch.

STRENGTHENING OF HYBRID PROGRAM.

In 1989, ICAR initiated a special program aimed at the development of hybrids in nine selected crops including maize. In maize, major emphasis has been given on evolving high yielding hybrids suitable for winter (rabi) cultivation. Similarly, for summer season a need for development of early maturing hybrids has been realized. Also the necessity of developing single cross hybrids with higher yield potential has been felt.

Development of broad based pools for the hybrid program.

As indicated elsewhere, a program was initiated for extraction of inbred lines by composite breeding methodology, however the lines so derived could not yield to the expected levels. Development of inbred lines out of heterotic pools yielded more productive hybrids in a relatively shorter period of time. Eight pairs of complementary heterotic pools in various maturity groups have been developed to meet the above need as a long term strategy. For stepping up genetic variability in the conventional hybrid breeding and for developing cultivars for specialized uses, new genetic variability has been introduced in the breeding materials.

Even though originally eight broad based gene pools have been developed, many more are in developmental stages to meet the specific needs of the breeding programs. For instance, it is a priority for the AICMIP to generate a pool for building up multiple disease resistant stocks, increasing the frequency of favorable alleles for stalk borer, and a pool to improve resistance to soil moisture stresses.

Enhancing tolerance to inbreeding and development of single cross hybrids.

Many measures have been taken to enhance the hybrid performance and tolerance to inbreeding depression in heterotic populations with the aim to produce vigorous inbred lines viable enough for seed production, as to be utilized in production of single cross hybrids. The existing heterotic pools and synthetics did not respond very satisfactorily to inbreeding depression. Introduction of a selfing phase in the intrapopulation improvement program helped in eliminating deleterious recessives and also in improving tolerance to inbreeding depression of the genotypes. To enhance the cross performance, interpopulation improvement was initiated in those populations known to belong to different heterotic patterns.

It is a matter of great satisfaction that based on this approach, a three way hybrid (Trishulata) has been released for cultivation to the farmers. Also, many full season and early maturing double cross, three-way, and single cross hybrids have shown a very high productivity level under experimental conditions. These are presently in the advanced testing stage and will soon be released both for summer and winter cultivation (**Tables 5-9**).

Table 5. Performance of early maturing three-way hybrids at Pantnagar (Pant), Almora (Alm) and Udaipur (Udai). 1992 Summer.

Pedigree	Yield (kg/ha)			Mean	% over check
	Pant	Alm	Udai		
EHF 1061	4168	7721	1709	4533	11.43
(D741 x 1-2-4-1-2 x Tarun x 36-1-1-4) x D831	4219	6391	2554	4388	7.86
EHF 1101	3485	7734	1486	4235	4.10
Navin (check)	3681	6306	2218	4068	

Table 6. Performance of early maturing experimental single cross hybrids. 1992 Summer.

Pedigree	Yield (kg/ha)			Mean	% over check
	Pant	Alm	Udai		
D832 ⊗ 41-1-1-2-1 x D831 ⊗ 60-2-2-1-1	4798	6731	2883	4804	32.09
Tarun ⊗ 83-1-3-2 x D831 ⊗ 39-2-1-1	5217	6663	2436	4772	31.20
D831 ⊗ 140-1-2-1 x Suw. 1 ⊗ 201-1-1-2	4452	6912	2603	4656	28.02
D741 ⊗ 1-2-3-2-1-3 x Tarun ⊗ 50-1-1-1-2	4287	6227	3312	4622	27.08
VL 42 (check)	3035	6211	1665	3637	

Production of homozygous diploid inbreds through the haploidy route.

Attempts are being made to develop a suitable technology for quick production of homozygous diploid lines of maize through the haploidy route. The haploids are being isolated through the genetic selection technique. Haploid-inducer lines with haploidy potential of 5% have been developed. The haploids are screened at the dry seed stage with the help of genetic markers. No standard technique is yet available for efficient doubling of the haploids. Two approaches have been followed, (i) colchicine treatment to germinating plumule of young seedlings and (ii) culturing haploid tissue and regeneration following doubling of chromosome number. So far, the best success (18.5% doubling) has been obtained with treatment of germinating seeds (having the plumule tip cut) with 0.06% colchicine solution with dimethyl sulfoxide for 8 hr at 18C.

Table 7. Mean performance of experimental hybrids at Hyderabad and Arbhavi. 1992 Summer.

Experimental hybrids	Yield (kg/ha) Hyd	Yield (kg/ha) Arb	Mean	% over check
BH-44151	4376	8954	6665	31.4
BH-44181	4725	8376	6550	29.2
BH-44071	4669	7725	6202	22.3
BH-44081	4342	8049	6195	22.2
BH-43831	4724	7612	6168	21.6
BH-44201	4721	7502	6111	20.5
BH-43921	4280	7398	5839	15.1
BH-44131	3255	8287	5771	13.8
BH-44101	4489	7021	5755	13.5
Trishulata (check)	4047	6096	5071	

Table 8. Mean performance of single cross hybrids at Hyderabad and Arbhavi. 1992-93 Winter.

Experimental hybrids	Yield (kg/ha) Hyd	Yield (kg/ha) Arb	Mean	% over check
BH-6055	8774	8488	8631	26.68
BH-6060	8063	9149	8606	26.32
BH-6066	7181	8798	7990	17.28
BH-6063	6854	9007	7931	16.41
BH-6084	7140	8596	786	15.49
BH-6078	8074	7638	7856	15.31
BH-6064	7315	8285	7800	14.49
DHM-105 (check)	7162	6464	6813	

Crop management research.

The agronomic investigations led us to conclude that during the summer season in the plains of northern India, the planting of maize may be taken up any time between last week of May to last week of June. For hilly regions, first week of April has been found to be most appropriate. To ensure optimum yield planting spacing of either 75 x 20 cm or 60 x 25 cm along with a fertilizer dose of 120-60-40 kg N-P_2O_5 -K_2O/ha has been found to be ideal. Under experimental conditions intercropping of maize with leguminous crops like black or green gram, and oil seed crops such as groundnut, has been found to be more remunerative as compared to monoculture of maize. For the management of weeds, preemergence application of Atrazine at 0.5 kg ai/ha is found to be most effective.

The yield potential of maize during winter season has been found to be much higher due to the fact that the crop is comparatively free from vagaries of the weather and there is a lower incidence of diseases and insect pests. For winter maize cultivation, it is recommended to maintain a plant population of about 80,000 plants/ha and apply a higher dose (180 kg/ha) of N. Like summer, in winter crop also intercropping with potato, lentil, peas, rajmas, and cluster beans has been found to be profitable. Based on research done at Ludhiana and Dholi, one of the important findings for winter maize has been the adoption of transplanting maize seedlings to

Table 9. Performance of cold tolerant hybrids tested in Punjab (3 locations). 1992-93 Winter.

Experimental	Mean	Days to 50% silk	% over check
JH-6154	8619	142	16.49
JH-6151	8563	139	15.73
JH-6165	8289	139	12.03
Ganga 11 (check)	7399	142	

avoid delayed emergence due to low temperature (Table 10). The other advantage of the adoption of such methodology includes a good alternative to late sown wheat crop, and it also helps in eradication of the weed *Phalaris minora* which grows along with wheat. Further experiments on the transplanting technique, age of nursery, and time of transplanting are being studied more critically.

Table 10. Response of direct seeded and transplanted maize to different dates of sowing at Dholi (Bihar). Rabi 1991-92 and 1992-93.

Date of planting	Planting method	Grain yield (t/ha)			% increase due to transplanting
		1991-92	1992-93	Mean	
Nov. 15	Direct sown	4.15	4.68	4.42	-
Nov. 30	Direct sown	3.07	3.87	3.47	
	Transplanted	2.52	4.57	3.54	2.0
Dec. 15	Direct sown	2.60	3.38	2.99	
	Transplanted	3.25	4.90	4.08	36.5
Dec. 30	Direct sown	1.53	2.53	2.03	
	Transplanted	2.76	4.18	3.47	70.9
Jan. 15	Direct sown	1.18	2.17	1.68	
	Transplanted	2.59	3.18	2.88	71.4
	C.D. at 5%	0.5	0.74		

Entomological research.

In the field of maize entomology, the stem borer (*Chilo partelus*) and the pink borer (*Sesamia inferens*) have been identified as major pests. Keeping in view their importance, a massive artificial infestation program has been in operation. Accordingly, a suitable methodology for mass rearing these insect pests in artificial diet has been worked out which has proved very effective. Also, a growth stage between 10-17 days after germination and about 25 larvae per plant have been found to be appropriate in evaluation of maize germplasm for tolerance to these borers. A 1-9 numerical rating scale has also been developed for categorizing the test entries into resistant/susceptible classes, where a rating of 1-3 represents least susceptibility and 7-9 highest susceptibility.

A reasonably good level of resistance has been identified in inbred lines derived from ETO 25, Cuba 9, Barbados 1, Suwan Source 6, and H 207.

Pathological research.

In the field of maize pathology, a significant contribution has been made by AICMIP. Suitable techniques of creating artificial disease epiphytotics in the field have been developed for the most important maize diseases occurring in India. Suitable rating scales for classification of materials into resistant/susceptible categories have been developed. A high level of resistance has been identified to several diseases based on field evaluation and an inventory of resistant sources to major diseases has been released. In the case of turcicum and maydis leaf blights durable resistance in two inbred lines has been detected. This resistance has stood for almost 17 ears and at as many as 19 locations. Very encouraging reports about the stability of this type of resistance have been received from other countries.

Chemical control schedules, wherever their economics have been worked out, have proved very effective for the management of several foliar diseases. In the case of *Pythium* stalk rot, an integrated disease management strategy has been worked out. Similarly, for the management of banded leaf and sheath blight a very effective and economic cultural method has been reported.

Biochemical investigations.

Since maize is used as a staple food in the form of *chapatees*, one of the problems faced is the development of bitterness of the flour within a short period which leads to its unpalatibility. This phenomenon is attributed to the hydrolytic rancidity which leads to accumulation of acid. The problem can very well be overcome by giving heat treatment to the maize grains which not only leads to inactivation of enzymes responsible for bitterness, but also minimizes moisture content (**Table 11**).

Table 11. Effect of heat treatment of maize kernels (1 hr at 80 C) before grinding on shelf life of maize flour.

Storage period (days)	Acid value	
	Untreated	Treated
0	0.9	1.0
2	12.7	1.1
10	23.2	2.4
20	27.7	2.4
30	33.2	2.7

Collaborative research projects.

Since 1992, six ICAR-CIMMYT Collaborative Projects in various facets of maize improvement have been in operation. These are i) genetic resource, exploration, cataloging, and conservation, ii) evaluation of inbred lines for more productive hybrids; iii) maize cultivation under excess soil moisture and drought conditions iv) economic studies on maize development, v) genetic improvement of gene pools for resistance to turcicum leaf blight and sorghum downy mildew, vi) multiple insect resistance and development of borer resistant maize germplasm in South and East Asia. The progress made so far under these projects has been more than satisfactory. Hopefully in the years to come some good materials possessing tolerance to important biotic and abiotic stresses will come out. CIMMYT's Asian Regional Maize Program has almost agreed for two more new projects in the field of maize pathology. Under these projects, if finalized, stress would be laid on banded leaf and sheath blight and post flowering stalk rots which are of economic importance not only in India but also in other Asian countries.

PRODUCTION POTENTIAL AND FUTURE THRUSTS.

The production potential of maize should be looked at from a wide perspective in comparison to the other crops in a country and maize in the neighboring countries. Since a higher genetic potential is not easily attained due to stress environments and difficulties in obtaining an ideal genotype, there is need to identify gene(s) which will increase the genetic performance of a new maize plant more efficient in utilizing nutrients, specially nitrogen, and efficiently partitioning it in the grain; increase the genetic potential for response to high plant density; and increase the desirable chemical component of maize to increase its value in various industrial uses. Also for winter maize, the efforts for judicious and systematic introgression of temperate germplasm into tropical maize must be strengthened.

Breeding for early maturity is one of our important objectives. Therefore, there is a need to understand the physiological and genetic basis of earliness and to investigate the procedures to break the linkage, or at least reduce the adverse effects of earliness on grain yield. There is need to take up studies on economic threshold injury by pests and diseases, durable resistance, and integrated pest management for developing appropriate technologies with judicious use of chemical fertilizers and pesticides, and in the possibility of adopting maize-based cropping systems. More serious attention may be paid to better understanding various abiotic stresses and the integrated stress management systems to increase the productivity of maize.

Questions to the author:

FROM : M. Saleem

Q : 1) Do you think tolerance to inbreeding depression improves combining ability in maize inbred lines or facilitates seed production?

2) Indian Maize Program has released a number of improved varieties and hybrids. What is the yield increase per hectare from these releases?

A : Tolerance to inbreeding depression helps to breed seed parent viable enough to go for single cross hybrid seed production without altering the combining ability.

FROM : C. De Leon

Q : What is the demand of extra early maize germplasm, for what regions in India, and what are you doing to breed for this germplasm?

A : The extra early maize germplasm is required for "Diara" land in U.P. and Bihar and tribal areas of Gujarat, Rajasthan and Madya Pradesh. This is about 10% of area of total maize growing area in the country.

FROM : C. Chutkaew

Q : 1) You have done an excellent job on Composites and Hybrids. How much of the yield increase occured in the last one or two decades as compared to the total time spent on maize improvement?

2) How much of investment you put on Biotechnology in the past and how more you expect to put on it in the future?

A : 1) Our coordinated efforts for maize improvement started in the year 1957. At the time productivity of maize was 600 kg/ha. Today we have reached up to 1.76 t/ha.

2) We are using conventional breeding approaches only. We do not want to deplete our scanty resources for Biotechnological work.

RESEARCH AND DEVELOPMENT OF HYBRID MAIZE IN INDONESIA

Marsum Dahlan [1/]

Abstract

Maize is Indonesia's second food crop after rice. The average maize area harvested during 1982-1991 was 2.8 m ha. The yield increased from 1.57 t/ha in 1982 to 2.15 t/ha in 1991. Maize is mostly used for human consumption, however the proportion for food has decreased from 77.9% in 1975 to 48.4% in 1985. On the other hand, the proportion of maize used for feed has increased from 15.1% to 38.3% in the same period of time.

Out of the total maize acreage cultivated in Indonesia, 79% is planted in rainfed upland, 10% in rainfed lowland, and 11% in irrigated land. About 31% of maize areas are considered productive land because of enough rainfall and fertile soils. On the productive areas hybrid maize can produce high and stable yields, which make hybrid growing a profitable activity.

Indonesia released its first hybrid maize variety in 1983. During the period 1983 to 1992, a total of 11 maize hybrid varieties have been released. Hybrid maize has shown 10-30% higher grain yield than standard open pollinated varieties on irrigated land. It is estimated that only 3.5% of the total maize area is planted with hybrid maize. Many farmers grow F2 hybrid seed, and the reduction of grain yield is about 8-10%, but in more advanced generations the yield reduction is higher (26%). Low adoption of hybrid maize is due to higher cost of the hybrid seed, reaching more than 12 times the price of grain. Planting maize in rainfed upland is highly risky due to frequent droughts.

The MARIF maize hybrid breeding program emphasizes the development of hybrids with early maturity, and high and stable yield under rainfed upland conditions. Inbred lines are extracted from CIMMYT populations, Malang Composites, Bogor Pools, and Suwan populations.

A reciprocal recurrent selection method is being used to improve the performance of hybrids developed from two pairs of synthetic varieties (J1-J2 and K1-K2 synthetics).

Introduction

Maize is Indonesia's second main food crop after rice. The maize area harvested varies from year to year with an average 2.8 m ha during the period 1982-1991 (**Table 1**). Most of the maize produced is used for human consumption. However, the amount of maize used for food has decreased from 77.9% in 1975 to 48.4% in 1985. On the other hand, the amount used for feed has increased from 15.1% to 38.3% in the same period. The demand of maize for food and feed is continuously increasing. It is estimated that by the year 2000 the demand of maize will be of approximately 7.5 M t.

Almost 79% of the area planted to maize is on rainfed land (upland), and only 11% of maize area is on irrigated lowland, which is considered as the most productive maize growing area. The other 10% of the maize area is grown in rainfed lowlands. In the lowland, maize is planted after rice (Tunmer, 1987). The maize yields vary from area to area mostly due to differences in rainfall, soil fertility, and production systems. However, in the last 10 years, the yields have continuously increased from 1.57 t/ha in 1982 to 2.15 t/ha in 1991. To meet the demand of this grain in the year 2000, it is projected that the maize yield in the year 2000 will have to be 2.65 t/ha.

This paper highlights the status of maize hybrid research and development in Indonesia.

1/ Maize Breeder, Malang Research Institute for Food Crops (MARIF), P.O. Box 66, Malang 65101, Indonesia.

Table 1. Maize area harvested, production, and yield in Indonesia.

Year	Area harvested (ha)	Production (t)	Yield t/ha
1982	2,061,299	3,234,825	1.57
1983	2,832,443	4,860,127	1.72
1984	2,924,981	5,071,546	1.73
1985	2,306,717	4,148,888	1.80
1986	3,092,187	5,866,161	1.90
1987	2,626,033	5,155,680	1.96
1988	3,405,751	6,651,917	1.95
1989	2,944,199	6,192,512	2.10
1990	3,158,092	6,734,028	2.13
1991	2,909,100	6,255,906	2.15

Source: Central Bureau of Statistics, Jakarta.

Hybrid maize breeding.

In Indonesia, maize breeding has been done since 1950 (Sjofjan, 1956). During those days, the best single crosses yielded more than 200% of the highest yielding variety used as the source of lines. However, this program was discontinued, due to difficulties in seed production. In addition, some new Carribbean germplasm was introduced such as Tequisate Golden Yellow, which yielded as high as the newly developed single cross hybrids.

In the 1960's a new effort was established to develop hybrids. The single crosses generated at that time produced 40% higher than Harapan, a high yielding open pollinated variety (Subandi *et al.*, 1987). But the program was again discontinued.

In 1983, the government released a double top cross C1 hybrid maize developed by Cargill Co. In 1985 Pioneer released the hybrid variety P2, and CPI-1 was released by CIP (Charoen Pokhand Co.). Also in 1985, a hybrid developed at Bogor Agric. Univ. was later released (**Table 2**). Evaluation of these maize hybrids at three sites for two seasons in E. Java showed that the hybrids yielded 23-42% higher than the OPV Arjuna (**Table 3**). These hybrids require 100 days to maturity and are not suitable for cropping systems normally practiced by farmers in some areas.

In 1987, the Malang Res. Inst. for Food Crop (MARIF) initiated a breeding program to develop hybrid maize with less than 100 days to maturity. Base populations used for inbreeding were CIMMYT populations, Malang composites, and Bogor pools. The heterotic pattern among these base populations was unknown. Suwan 1, Suwan 2, and Suwan 3 are also used in developing inbreds. S3 lines were crossed with GM15 to find lines with good combining ability with the tester parent. In 1992, two maize hybrids, Semar 1 and Semar 2 were released. These hybrids are three way crosses developed using S4 lines. The parental lines of Semar 1 were extracted from Population 28 (CIMMYT) and Malang Comp.9. Semar 2 was developed by using lines extracted from Population 31 (CIMMYT), Acer (Malang Comp.) and Bogor Pool 1. Evaluation of Semar 1 at 13 locations in E. Java showed that it yielded 27% more than the OPV Arjuna, 11% higher than the OPV Rama and as high as CPI-1 hybrid (**Table 4**). Semar 1 is later in maturity than the OPV Arjuna, but it is earlier than CPI-1. The yield of Semar 2 was 17% higher than that of OPV Arjuna and 9% lower than that of CPI-1 (**Table 5**). The maturity of var. Arjuna is 90 days and that of Semar 2 is similar, both being earlier than CPI-1. The difficulties in developing a hybrid using S4 lines is the maintenance of the parental lines.

Recently, MARIF also introduced lines from CIMMYT. These lines were crossed with several lines developed by MARIF. However, CIMMYT's lines are later in maturity than MARIF's lines.

Table 2. Released hybrid maize cultivars in Indonesia (1983-1992).

Hybrid	Type of hybrid	Institution 1/	Year released	Mean Yield (t/ha)	Mean Maturity (days)
C-1	TC	Cargill	1983	5.8	100
C-2	TWC	Cargill	1989	6.4	100
C-3	TWC	Cargill	1992	6.4	98
P-1	TWC	Pioneer	1985	5.6	100
P-2	TWC	Pioneer	1986	6.3	100
P-3	DC	Pioneer	1992	6.4	98
CPI-1	TC	CPI	1985	6.2	97
CIP-2	TWC	CPI	1992	6.2	97
IPB-4	SC	BAU	1985	6.6	105
Semar-1	TWC	MARIF	1992	6.4	96
Semar-2	TWC	MARIF	1992	6.0	90

1/ CPI = Charoen Pokhand Indonesia
BAU = Bogor Agric. Univ.
MARIF = Malang Res. Inst. for Food Crops.

Four Malang Synthetics have been developed: two early maturing, K1 and K2, and two late maturing J1 and J2. Malang Synthetic K1 was developed from lines which posses good general combining ability with Suwan 2. Malang Synthetic K2 is constitued by lines derived from Suwan 2 which combine well with inbred GM15. These two synthetics are being improved through reciprocal recurrent selection. Malang Synthetic J1 was developed using lines with good combining ability with GM15 while J2 has lines that have good combining ability with inbred GM 19. Inbreds GM 15 and GM 19 were parent lines of Semar 1. These two synthetics are also being improved through reciprocal recurrent selection. S1 lines were crossed with the tester parent (K1 with K2, J1 with J2 and their reciprocals). S1 lines were planted in a disease nursery to evaluate their resistance to downy mildew, polysora rust and maydis, leaf blight. Resistant plants will be selfed and advanced to S2. Intercross of selected lines will be done by using S2 lines.

Table 3. Grain yield of three maize hybrids and var. Arjuna on irrigated land in three sites in E. Java. 1986-1987.

Variety	Grain yield (t/ha) 1/ Muneng DS	Muneng WS	Kediri DS	Kediri WS	Genteng DS	Genteng WS	Mean	% over check
C-1	5.69	6.04	6.73	3.55	5.12	4.70	5.31	23
P-2	5.82	6.16	9.21	4.04	6.16	5.39	6.13	42
CP-1	5.47	6.10	8.15	3.35	6.75	5.70	5.92	37
Arjuna (ck)	4.42	4.27	5.60	2.72	4.86	4.00	4.31	
BNT .05	0.71	0.85	1.49	1.17	0.96	0.80		

1/ DS = Dry season; WS = Wet season.
Source : Slamet *et al.* (1988).

Table 4. Grain yield of Semar 1 and open pollinated checks on irrigated and rainfed land at 13 environments in E. Java. 1991, 1992.

Variety	Yield (t/ha) [1/] Irrigated DS 91	Irrigated WS 91-92	Rainfed DS 91	Rainfed WS 91-92	Mean
Arjuna	5.045	5.706	4.326	5.286	5.090
Rama	5.774	6.051	5.837	5.467	5.782
CPI-1	5.764	7.175	7.044	6.242	6.556
Semar-1	6.383	6.778	6.217	6.375	6.438
% Arjuna [2/]	127	119	144	121	127
% Rama [2/]	111	112	107	117	111
% CPI-1	111	94	88	102	99

[1/] DS = Dry season; WS = Wet season
[2/] Yield of Semar 1 compared to checks.
Source : Dahlan *et al.* (1993).

Table 5. Grain yield of Semar 2 and open pollinated checks on irrigated and rainfed land at 13 environments in E. Java. 1991 and 1992.

Variety	Yield (t/ha) [1/] Irrigated DS 91	Irrigated WS 91-92	Rainfed DS 91	Rainfed WS 91-92	Mean
Arjuna	5.045	5.706	4.326	5.286	5.090
CPI-1	6.845	7.582	5.592	6.092	6.528
Semar-2	6.271	6.691	4.955	5.925	5.960
% Arjuna [2/]	124	117	115	112	117
% CPI-1 [2/]	92	88	89	97	91

[1/] DS = Dry season; WS = Wet season
[2/] Yield of Semar 2 compared to checks.
Source : Dahlan *et al.* (1993).

A trial comparing F1 hybrids with their F2's was conducted in an area where farmers routinely use F2 seed for maize production. F2 seed of CPI-1 and Pioneer-2 were provided by farmers. They had been selected from F1 plants for the next planting season. F2 seed of Semar 1 and 2 was collected from 15 m^2 plots. The results showed that the yield reduction was less than 10%, except for Semar 1 (**Table 6**). The F2 of CPI-1 and Pioneer 2 yielded higher than var. Arjuna. This explains why many farmers use F2 hybrid seeds for maize production.

Hybrid seed production.

Hybrid maize seed is being produced by Pioneer Seed Co., Bright Indonesia Seed Industry (BISI), and the State Seed Corp. Sang Hyang Seri (SHS). SHS produces Cargill hybrid seed and BISI produces CPI hybrid seed. All these seed growers operate in E. Java. During the last three years, the total seed production has reached approximately 2000 t/year (**Table 7**). This means that the maximum maize area planted with hybrid seed is nearly 100,000 ha or 3.5% of the total

Table 6. Grain yield reduction of F2 seed in four maize hybrids at Kediri, E. Java. 1993 Dry.

Variety	Yield (t/ha)		% reduction
	F1	F2	
Semar-1	6.89	5.70	17.3
Semar-2	6.36	5.73	9.9
CPI-1	7.36	6.80	7.6
Pioneer-2	7.28	6.68	8.2
Arjuna	5.69		
BNT	0.42		

maize area. In 1989 the total hybrid seed production covered approximately 900 ha. The reduction in area devoted to seed production is mostly due to the fact that the government stopped the subsidy for hybrid seed.

Table 7. Hybrid seed production area in E. Java.

Year	Total area	Total seed yield
1989-1990	920 ha	-
1990-1991	547 ha	-
1991-1992	438 ha	1466
1992-1993	533 ha	1935

Hybrid varieties: Cargill C-1 and C-2
Pioneer P-2
CPI-1

Source : East Java Seed Certification Service, Surabaya.

The hybrid seed produced by seed growers is certified by the Seed Control and Certification Service to ensure the identity and purity of the variety.

In 1993, the price of hybrid maize is Rp. 3500/kg (1 US$ = Rps. 2070) for hybrids and Rp.1000-1500 for open pollinated varieties. The price of maize grain ranged from Rp. 200-400/kg in 1993. Hybrid seeds are sold in 1 or 5 kg bags.

Seed growers cooperate with farmers in seed production. The seed production area is concentrated near Kediri, Blitar, and Malang, in E. Java.

Maize production intensification.

Nearly 31% of the maize growing area is considered as highly productive. In this area, hybrid maize will give high yields and become highly profitable. The government has promoted the use of hybrid maize in this area. In 1984-1985, the government provided a subsidy (Rp. 500/kg) for Cargill's seed and the price at farmer level was Rp. 1000 instead of Rp. 1500/kg. However the adoption of hybrid maize was very slow. In 1985, 1986, and 1987, the maize areas planted with hybrids were 14,402, 46,085 and 32,901 ha respectively. Approximately 63% of the maize hybrid growing areas were located in E. Java, which is one of the important maize production centers. The maize area harvested in this province is about 1 m ha, and it produces about 40% of the country's maize production (Table 8). Maize hybrid area in this province is about 8 to 11%. However, the hybrid areas include those where advanced generation hybrids were planted (F2 to F4). Farmers are aware that the yield of F2-F4 generations is lower than the yield of F1 seed, but they have been selecting ears from good performing plants and using these as sources of new seed for the next season. The reduction of CPI-1 hybrid made in experimental plots was only 7.6% (Table 6). Observations in farmer's fields indicated that the yield of the F2 of CPI-1 hybrid was 4.62 t/ha, while the F1 yielded 6.25 t/ha, with a reduction of 26% (farmer's information) (Table 9). Although the F2-F4 yields lower than the F1, their yield is still higher than that of the local variety.

Table 8. Area and yield of hybrid and open pollinated varieties of maize in E. Java. 1987-1991.

Year	Hybrid		Open pollinated		Total area (ha)	Yield (t/ha)
	Area (ha)	% of total	Area (ha)	% of total		
1987	51,951	4.9	1,015,127	95.1	1,067,078	2.32
1988	115,360	9.4	1,114,407	90.6	1,229,767	2.04
1989	131,935	10.9	1,075,703	89.1	1,207,638	2.57
1990	114,995	9.8	1,058,486	91.2	1,173,481	2.30
1991	91,616	8.3	1,012,637	91.7	1,104,253	2.63

Source : East Java Agric. Extension Service.

Table 9. Cost:production benefit of maize hybrid using F1 and F2 hybrid seed. Kediri 92 Dry.

Item	F1	F2
Cost production (Rps.):		
Land cultivation	69,000	24,000
Seed	87,500	0
Planting	48,000	36,000
Fertilizer	243,500	198,000
Weeding, irrigation, etc.	144,000	117,000
Harvesting & Processing	75,000	96,000
Total cost	667,000	471,000
Yield (t/ha)	6,25	4,62
Income (Rps)	1,562,000	1,155,000
Benefit (Rps)	895,000	684,000

1) Sample of 10 farmers fields
1 US$ = Rps.2,070
Grain price Rps. 2,500/kg

The level of fertilizer in some areas such as Kediri, E. Java was almost double the recommended rate. The price of urea is low (Rp. 260/kg). The cost of production using F1 hybrid maize seed was Rp. 667,000/ha and Rp. 471,000 when using F2-F4 seed. In the later case, farmers were using their own seed and a lower fertilizer level. Farmers get more benefit using F1 seed than advanced generation seed.

The problems of low adoption of hybrid maize are:

a. To save cost of seed, almost 70% of farmers use their advanced generation seed.

b. Farmers usually grow maize at high plant densities, therefore they need more seed. This would make the crop costly since they have to buy new seed.

c. The first released hybrids C-1 and CPI-1 were top crosses, and the yield reduction in F2 is

low.
d. The average farm size is small (0.5 ha), and the benefit of using maize hybrid seed is also small. Farmers do not want to invest in expensive seeds when gains are small.
e. Most maize is planted on rainfed upland where the crop is risky because of frequent occurance of drought. Therefore farmers do not want to risk more money buying expensive hybrid seed.
f. The benefit ratio maize/other crop is less than 1.0.
g. In some areas the rate of fertilizer application is low. Planting a hybrid variety increases the cost of production with higher investment in seed and fertilizer.

References

Bastari, T. 1988. Program pengembangan jagung. Dalam Subandi *et al.* (eds.): Jagung. Puslitbangtan, Bogor: 21-32.

Dahlan, M., S. Slamet dan Mudjiono. 1993. Maksimalisasi produksi jagung dengan menggunakan varietas hibrida. Makalah disam paikan pada Lokakarya Komunikasi Teknologi untuk Peningkatan Produksi Tanaman Pangan. Surabaya.

Slamet, S., M. Dahlan, and P. Soepangat. 1988. Hasil dan stabilitas varietas jagung pada lingkungan yang berbeda. Penelitian Palawija 3:1-11.

Sjofjan. 1956. Suatun tinjauan kitis dari cara-cara seleksi yang dipakai untuk jagung di Indonesia. Teknik Pertanian V: 40-80.

Subandi, I.B., Suprihatno, D.A. Sihombing, Soemardhi, and S. Sadjad. 1987. Research and development of hybrid variety for maize and rice in Indonesia.

Tinmer, C.P. 1987. The corn economy of Indonesia. Cornell Univ. Press, Ithaca.

Questions to the author:

FROM : Jaswant Singh

Q : 1) What was the main reason of drop in maize acreage from 1990-1991?

2) 1980 developing S2 x open pollinated 1990 again started selfing from Suwan 1, 2, 5 - Why this change from inbreeding program to varieties?

A : 1) In 1990 the rainy season started in September, therefore some of the maize areas were harvested in December. So the maize area in 1990 increased and in 1991 decreased.

2) In 1990 we started inbreeding for extracting lines from Suwan 1, 2 and 3. These activities are still part of the hybrid program.

MAIZE RESEARCH AND PRODUCTION IN LAOS.

Kanyavong Bounphavanh [1]

Abstract

Research activities on maize in Laos have been conducted in Hat Dok Kew Station in the seventies and the eighties. A maize improvement program conducted at this station has lead to the release of the varieties HDK3 and HDK4 in the early eighties. Although there is no written report about the selection scheme applied and the parent materials used in the process, the open pollinated variety HDK4 has become popular in some lowlands and show some interesting characteristics. HDK4 possesses good level of resistance to downy mildew, fairly good yield of 4-5 t/ha in optimum conditions and high level of inputs.

Collaboration with CIMMYT-Maize Program, was initiated through the international variety trials conducted at Naphok since 1984. These trials were comparing several improved populations adapted to lowland and temperate environments. Maize research activities have been directed towards the identification of improved varieties for animal feed in order to promote maize production as a row material for the Tha Ngon feed mill.

External assistance for maize research has been provided through bilateral cooperation programs with Israel, Hungary and Vietnam, and through multilateral cooperation programs such as the Mekong Committee, the UNDP/FAO Integrated Agricultural Development Project from 1984 to 1988 and the UNDP/ADB Planning of Agricultural Research Project from 1989 to 1991.

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1. Introduction.

Laos is a land-locked mountainous country situated in South-East Asia between 100-108 E longitude and 12-23 N latitude. It has an area of 236,800 Km^2 with 680,000 ha of arable land. In other words, only about 3% of the country's area is considered arable land. Altitude ranges between 100-2800 masl. The North is mostly highlands, whereas significant plains exist in the central region and in the South, especially in Savannakhet province. The most fertile soils are found close to the banks of the Mekong river, which runs the length of the country, and along its tributary the Nam Ngum river, and on the Boloven Plateau in the South. (Fig. 1)

Laos is influenced by a monsoon system which creates two seasons per year. From June-October there is a rainy season, and November through May is the dry season. Maize is produced for food and feed in the Lao PDR. The total area under maize production in 1991 was about 36,245 ha with an average yield of 2 t/ha. By contrast, the main crop, rice, was grown on a area of 628,253 ha with an average yield of 2.34 t/ha. Other production figures are listed in **Tables 1 and 2.**

2. Maize growing environment.

The majority of the soils used for maize cultivation in the main production area in provinces adjoining the Mekong river in northern, central, and southern Laos, are a combination of gleyic acrisols in the plain areas, and ferric acrisols and orthic acrisols in adjacent old terraces and adjoining upland areas. These soils are moderately acid with low levels of N, K, organic matter, a low CEC, and they have low to moderate levels of available P. Low levels of other nutrients are also suspected. (Fig. 2).

The climate of the main maize producing area is classified as tropical wet. Total annual rainfall in most areas is within the range 1400-1500 mm, with about 80% falling in the period July-September. The rainfall distribution is usually bimodal, with a dry period often occurring between mid-June and mid-July. (Fig. 3).

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Table 1. Lao national agricultural production. 1991.

Crop	Area (ha)	Yield (t/ha)	Production (t)
1. Rice	628,253	2.34	1,491,495
2. Maize	36,245	2.00	72,609
3. Soybean	6,015	0.87	5,209
4. Mungbean	3,469	0.65	2,257
5. Peanuts	5,965	1.02	6,070
6. Sugar-cane	6,761	29.70	111,649
7. Tobacco	10,481	4.84	50,732
8. Cotton	8,027	0.59	4,749
9. Coffee	28,256	0.35	22,840
10. Vegetables	6,492	10.12	65,707

3. Varieties and cropping systems.

There are several varieties grown in the country. Local pest-resistant varieties of white flint and waxy types are principally grown for food, and yellow flints for feed. Maize is usually grown with several different maturing varieties and many times intercropped with other field crops or perennials. Maize grown for food in the highlands supplements rice in the diet and compensates for rice shortages.

There is considerable genetic diversity in the cultivars grown by farmers.

There are different cropping systems which can be observed in different regions and at different altitudes. Cropping systems include:

- Maize for human consumption grown in small plots, often in mixed cropping with other food crops next to the village houses in the lowlands (waxy and sometimes sweet type),
- Food maize grown on the river banks, often during the dry season, in pure stand or in mixed cropping, using early cultivars of the waxy type for production of fresh cobs for sale at neighboring markets (common around Vientiane, Luang Prabang, etc.),
- Feed maize cultivated in pure stands on alluvial soils of the Vientiane plain for sale to the Tha Ngon animal feed mill. This type is dominated by the improved variety HDK 4,
- Highland maize grown for food or for animal feed under shifting cultivation in association with upland rice (harvested before rice). Some farmers have developed cropping techniques to grow different varieties of maize with different maturities without mixing them.

The main disease problem in the lowland regions is the high incidence of the downy mildew. The Asian corn borer is one of the most important insect pests.

4. Marketing and processing.

- More than 50% of the corn is produced for human food consumption. The main barriers to marketing are transportation, storage, processing, and food preparation. Most of the sweet corn production is marketed fresh and as baby corn sold in the villages. It is either boiled or roasted for home consumption.
- In Laos farmers use both the stalk and the grain for feeding their animals. The Tha Ngon Feedmill purchased a significant quantity of the grain from Muang Kasi and Vientiane prefecture.

Surplus production from the northern province is sold and consumed locally. The size of the potential export market is presently limited by tariffs and high transport costs.

5. Government policy.

With the introduction of the New Economic Mechanism promoting a more market-oriented agriculture, maize is considered as one of the potential domestic cash crops. Feed maize is being promoted for the agro-based industry development. Food maize is promoted as an alternative to rice in order to reach self-sufficiency in food production.

6. Constraints.

A. Socio-economic constraints

The main socio-economic constraints for the development of the maize-based production systems are:

1. Diversity in socio-economic conditions of maize growers.
2. Insufficient access to credit for intensive cropping.
3. Insufficient support services: research and extension.
4. Great ethnic diversity among maize growers.
5. Difficult access to many regions where farmers grow maize.

B. Agroecological and technical constraints

The main agroecological and technical constraints for he development of maize production are the following:

1. Inbreeding depression in local varieties due to a small population size of each different and isolated type.
2. High incidence of the downy mildew disease in lowlands.
3. High weed infestation in fields of the Vientiane plain.
4. Wide range of agroecological environments with various types of maize cropping systems.
5. Low fertility of upland soils.

7. Acquired knowledge.

Most research activities have been conducted under on-station conditions at Hat Dok Keo, Naphok, and to some extent at Pakcheng and Nabong. Emphasis has been on improved varieties of feed maize. The major achievements are the following:

a. **Varietal selection and improvement**: The variety HDK 4 has been created and promoted for the lowland farmers of the Vientiane plain for animal feed production. Several other varieties or populations from the international variety trials were identified as promising: Suwan-1, Pop.28, etc. These varieties were identified for high to medium input environments and according to their resistance to the downy mildew disease. Mass selection is being applied on HDK 4 to maintain a certain level of purity since it appeared to become less productive than Suwan-1.

b. **Improvement of cultural practices**: The cultural practices for HDK 4 and similar varieties are well known for the Vientiane plain and for both rainfed and irrigated conditions. Plant density is estimated to be optimum with 53,000 plants/ha. Planting is made by dibbling 3 seeds every 42 cm along rows spaced 90 cm apart and thinning at 2 plants per hole. Fertilizer rates for soils similar to Naphok's acrisols are 45/45-50-20 (NPK) kg/ha. Several fertilizer trials have been conducted on maize at Naphok showing important deficiencies in nitrogen and phosphorus in the soils of the Vientiane plain. Irrigation techniques have been developed for dry season irrigated maize.

c. **Improvement of plant protection**: Varietal resistance has been promoted against the downy mildew disease. Varieties are systematically evaluated and screened for their resistance to the downy mildew disease. The variety Suwan-1 has shown the best resistance to downy mildew, followed by HDK 4. Pesticide treatments have been developed for protection against the most common insect pests.

d. **Post-harvest technology**: Techniques for seed storage have been developed, but some aspects related to seed quality control can still be improved.

Some preliminary observations have been collected also on sweet corn varieties at Naphok and at Hat Dok Keo. Hat Dok Keo has set up a gene bank collection for maize. Naphok has developed the artificial hand pollination method for maintaining the purity of the selected varieties.

In summary, past research activities have placed emphasis on improvement of feed maize varieties grown with a high level of inputs. On-farm trials were never conducted on maize, and there were no research activities in the major maize producing areas (northern provinces). Research on maize used as human food was recently initiated in a small-scale manner.

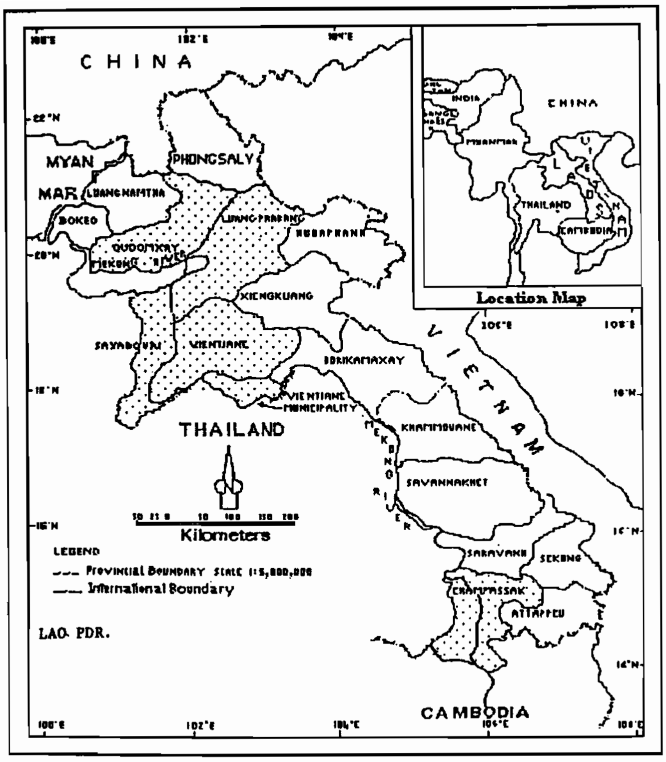

Fig. 1. Lao People's Democratic Republic.

Table 2. Area, production and yield data in different province in Lao PDR (1990-92).

	1990			1991			1992		
	Area (ha)	Prod. (mt)	Yield (t/ha)	Area (ha)	Prod. (mt)	Yield (t/ha)	Area (ha)	Prod. (mt)	Yield (t/ha)
1. Vientiane Mun.	300	600	2.00	2550	4972	1.95	2600	5148	1.98
2. Phongsaly	1650	4210	2.55	1667	4250	1.68	1684	4292	2.55
3. Luangnamtha	1000	2500	2.50	1010	2525	2.50	1020	2550	2.50
4. Oudomxay	4150	1525	3.50	5150	18025	3.50	5202	18207	3.50
5. Bokeo	450	1440	3.20	455	1454	3.20	460	1471	3.20
6. Luangprabang	3998	3486	0.86	4519	10805	2.39	4564	10908	2.39
7. Houaphanh	7563	6655	0.88	7638	6721	0.88	7714	6798	0.88
8. Sayaboury	1794	4851	2.70	1159	1985	1.71	1171	3079	2.63
9. Xiengkouang	3937	6139	1.56	3796	6203	1.56	4016	62565	1.56
10. Vientiane	2800	6430	2.30	2814	6472	2.30	2828	6505	2.03
11. Bolikhamxay	1750	2765	1.58	1759	2775	1.58	1768	2790	1.58
12. Khammouane	900	2025	2.25	905	2035	2.25	910	2046	2.25
13. Savannakhet	3435	5840	1.70	274	521	1.90	275	468	1.76
14. Saravanh	700	1820	2.60	704	1829	2.60	708	1840	2.60
15. Sekong	900	1080	1.20	972	1166	1.20	977	1172	1.20
16. Champasack	845	1603	1.90	193	251	1.30	194	369	1.90
17. Attapeu	498	597	1.20	500	620	1.24	503	594	1.18
TOTAL	36670	66566		36245	72609		36594	74491	

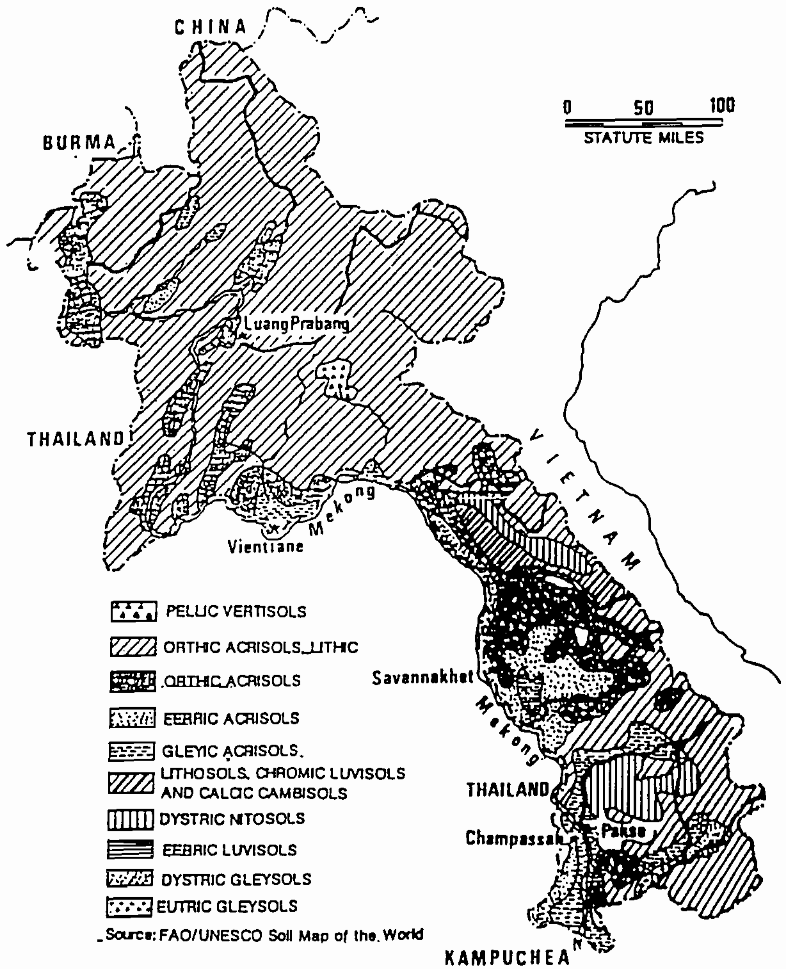

Fig. 2. Soils in Lao PDR.

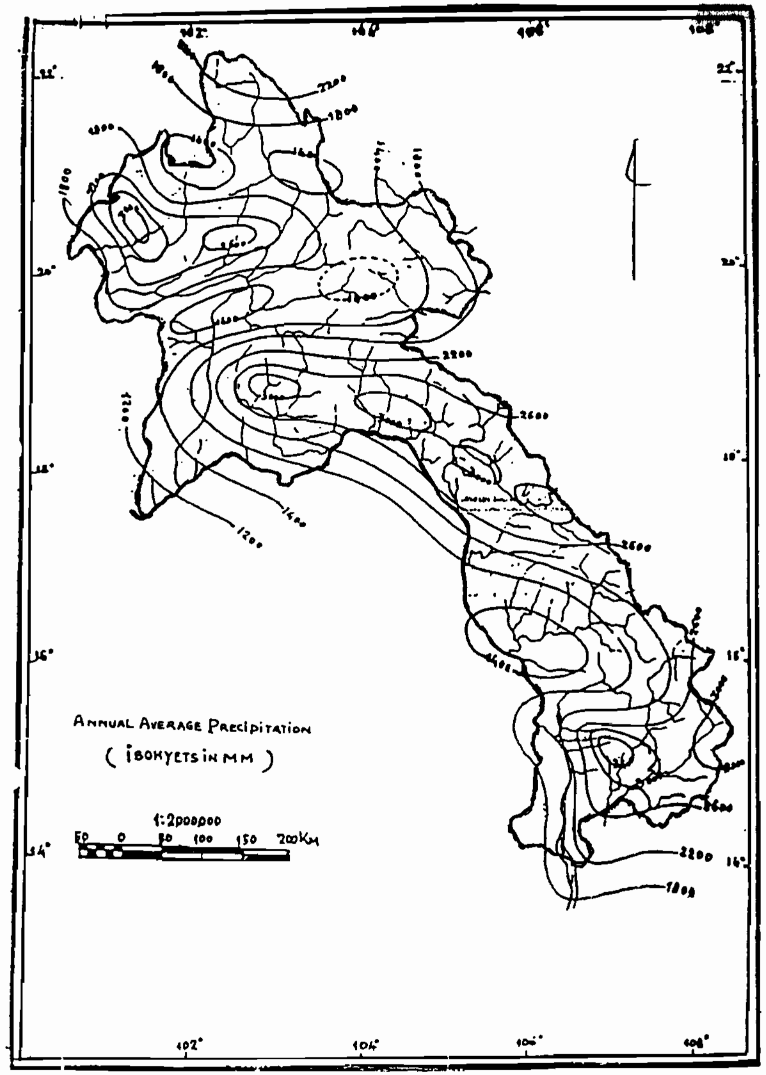

Fig. 3. Isohyets for annual rainfall distribution in the Lao PDR.

8 Price information:

Table 3. Shows variation in prices of various corn types and fertilizer.

	Year					
	1987	1988	1989	1990	1991	1992
Corn						
- Field corn (Kips/kg-grain)	35	45	60	62	65	70
- Sweet corn (Kips/ear)	15	15	20	30	50	50
- Baby corn (Kips/kg)	80	80	95	100	100	100
* Fertilizer prices						
- 15-15-15 (Kips/bag)	3500	6200	6500	9500	11000	12000
- 16-20-00 (Kips/bag)	3600	6500	7000	9200	9800	10000
- Urea 46% (Kips/bag)	3000	6000	6500	8800	9200	9500

In 1993; 1US$ = 700 Kips.

9. Research program (5 years):

Maize research will focus on open pollinated varieties for food, for dual purpose (food and feed), and for animal feed. Hybrid varieties are not suitable for Lao farmers.

Emphasis will be put on more on-farm research in the northern provinces (major maize producing areas).

Activities will include the following:

A. Varietal improvement (Selection and plant breeding):

The aim is to identify a range of different suitable open pollinated varieties (or populations) to be grown by farmers in different environments. Selection criteria will depend on the maize utilization. For food maize, criteria will be grain quality, early to medium maturity, and yield. For dual purpose maize (food and feed), criteria will be grain quality, yield, and healthy grain. For feed maize, criteria will be yield, healthy grain, and plant architecture. Resistance to downy mildew disease is an important criteria for all types to be grown in the lowlands. Activities will include:

a. Collection, characterization and evaluation of local varieties grown by farmers for all types of maize.
b. Establishment of a simple gene bank for the germplasm collection in collaboration with an international institution.
c. Introduction and evaluation of improved material from abroad.
d. Mass selection in HDK 4 and other promising material.
e. S1-S2 recurrent selection scheme if enough specialized manpower is available.
f. Screening of varieties for pest and disease resistance with emphasis on downy mildew (collaboration with Plant Protection).
g. On-station and on-farm replicated yield trials for the different types of maize.
h. Seed selection and basic seed production including breeder seed and foundation seeds.
i. Preparation of an annual catalog with the different types and varieties of maize evaluated by the researchers for use by the extension personnel. Food maize, feed maize, food and feed maize, duration, and all required data for cataloging.

B. Cultural practices (Agronomy and cropping systems):

The objective is to develop appropriate cropping techniques for the farmers according to different types and varieties, different cropping systems, and different agroecological conditions of the important regions. Main activities will include:

a. Diagnostic surveys in the major maize producing regions with prioritization of constraints for maize cultivation in the different cropping systems.

b. According to the findings of the surveys, study planting dates, plant densities, weed control, intercropping with various food crops, relay cropping, fertilizers, irrigation levels, etc.

c. Preparation of written recommendations for improved cultural practices according to the varieties, the agroecological conditions, and the cropping systems.

C. Post-harvest technology (Post production systems and seed technology):

The main objective is to improve the post-harvest operations in order to improve the quality of the final products, such as maize for human food, for animal feed, and maize for dual purpose. Activities will include:

a. Diagnostic surveys to identify the major constraints in post-harvest operations including storage, drying, shelling, etc.

b. Test alternative techniques if necessary.

c. Develop improved seed technology techniques.

d. Prepare written recommendations for improved post-harvest operations appropriate for the farmers.

D. Socio-economic studies:

The aim is to study the agro-socioeconomic aspects of maize production in the priority regions in order to provide guidance to the other activities of the program. Activities will include:

a. Conduct of surveys in priority regions to identify major constraints and potentials for maize development.

b. Prepare written recommendations to guide the other components of the program.

E. Priority areas:

The priority regions for maize research will be the provinces of Luang Prabang, Oudomsay, Sayabury, Vientiane, and Champasak, and also Vientiane prefecture.

Expected results

It is expected that research will give a better understanding of the maize situation at the farm level, some improved material for extension, maize for food, feed, and dual purpose, and an increased impact on lowland maize growers in the central region and upland growers in the northern region.

10. Recommendations:

a. The improvement of the varieties for food and for both food-and-feed, shall be pursued employing an on-farm research approach. For the varieties for food, whenever possible, and in order to counteract their inbreeding depression, a recombination procedure is recommended.

b. A national programme for seed conservation should be implemented in the area of maize for feed with a subsidy incentive for the construction of bamboo cribs.

c. A governmental commitment for research and an agreement with an international institution specialized in maize breeding, are also recommended.

d. In order to build up a research team for maize breeding, two pairs of nationals (one pair at a time) should be allowed to get some training at a specialized maize breeding institution. One of the first candidates should be the person recently nominated responsible for the Lao National Maize Breeding Programme.

Recommended practices for farmers

- Variety	:	HDK-4
- Fertilization	:	NPK:90-60-30 kgs/ha
- Planting date	:	April-June / October-December
- Spacing	:	80x25 cm
- Crop establishment	:	2-3 seeds/hill in furrows; thin to 1 plants per hill 2 weeks after emergence
- Water management	:	Irrigate whenever necessary
- Hand weeding	:	Twice

- Pest control : Spray monocrotophos EC 0.4 kg ai/ha to control stemborers (wet season only).
- Harvesting : 110-120 DAP
- Grain yield : 3-3.5 t/ha.

References

CIMMYT, 1986. CIMMYT International Maize Testing Program. 1985 Preliminary Report. Mexico.

CIMMYT, 1987. CIMMYT International Maize Testing Program. 1985 Final Report. Mexico.

CIMMYT, 1988. CIMMYT International Maize Testing Program. 1986 Final Report. Mexico.

CIMMYT, 1988. CIMMYT International Maize Testing Program. 1986 Preliminary Report. Mexico.

Con, N.T. 1986. Progress report of experiments of the landcrops at Hatdokkeo station for the period January to June 1986. TCDC Expert, Project LAO/82/011, Vientiane. 4 p.

Con, N.T. 1987. Report of experiments of the landcrops at Hatdokkeo Agric. Res. & Expt. Stat. during dry season 1986-1987. TCDC Expert, Project UNDP/FAO/LAO/82/011, Vientiane.

Con, N.T. 1987. Report of experiments of the landcrops at Hatdokkeo Agric. Res. & Expt. Stat., during period July-December 1987. TCDC Expert, Project LAO/82/011, Vientiane. 25 p.

Kanyavong B., Van Gansberghe D., 1987. Yield trial on selected maize varieties in Lao PDR. Pages 12-13 and 24, *In* Food Legumes & Coarse Grains Newsletter 3. FAO, Project RAS/82/002. Bogor, Indonesia.

Ministere des Relations Exterieures Cooperation et Development, Republique Francaise, 1984. Mais. P. 488-501. In Memento de l'agronomie la. Documentation Francaise, Paris.

Ministry of Agric. and Forestry. 1991. Natl. Agric. & Forestry Res. Master Plan, 1991. Detailed Priority Research Program Elements. NARC, Vientiane, Lao PDR.

Pego, S.E. 1987. Assessment and evaluation of the maize breeding programme in Lao PDR. Consultancy Report. Integrated Agricultural Development Project UNDP/FAO/LAO/82/011, FAO, Rome.

Saphangthong, S. and V. Phannourath. 1989. Agricultural research in thè Lao PDR. p.41-46. *In* the SUAN Secretariat (eds). Proceedings of the SUAN-EAPI exploratory on Lao agroecosytems. Khon Kaen University, Khon Kaen, Thailand.

Questions to the author:

FROM : G. Granados

Q : We also recognize that to develop the maize crop in Laos, there is an urgent need to have staff trained in maize improvement. We (CIMMYT) have offered several times scholarships to Laos for training in our HQ in Mexico, but our offer has not been accepted by the Government, what can we do?

A : I think now our Government understands more how to develop the maize program in Lao PDR. You try again to contact our ministry of Agriculture and Forestry, P.O. Box 811,Vientiane, Lao PDR. To Mr. Sithaheng Ratsaphonh, Vice Minister.

BREEDING AND AGRONOMIC RESEARCH ON GRAIN CORN IN MALAYSIA - A COUNTRY REPORT

Leong Chee Onn [1], Abd. Wahab ABD. Hamid [2], Ramli Mohd Nor [3]

Abstract

This paper outlines the status of breeding and agronomic research on grain corn in Malaysia. Even though there is as yet no significant production of the commodity, research is given priority due to the economic importance of the crop, as reflected in the annual import of over a million tons. Breeding research covered varietal screening and evaluation through development of composites and synthetics, as well as the development of inbreds in hybrid breeding. It is expected that hybrids between inbreds from different locally adapted populations could produce higher heterotic level. Agronomic research has evolved from merely yield increasing practices through manipulation of nutrient levels to supportive research meant for large scale production of the commodity. Yield maximization as well as cost reduction practices are reported, together with a technology package for mechanized production.

I. Introduction

Malaysia imports over a million tons of grain corn annually to meet its domestic demands. It is estimated that by 1995 the country will need 1.783 m t of corn and corn-related products worth over US$285 m (MARDI 1992). Corn is used mainly as a feed formulation in the livestock and poultry industries. Despite the huge demand, there is practically no maize production. In 1989, out of a total of 8,453 ha planted to corn, only 86 ha or 1% was taken up by grain corn, with sweetcorn and vegetable corn accounting for the other 99% (MARDI, 1992). This minimal production of grain corn is attributed to low yields and high production costs, as well as the ready availability of more attractive crop alternatives. However, due to the economic importance of the crop and the lack of suitable substitutes, research on grain corn continues to be carried out with future cultivation to be based on large scale mechanized production in order to reduce production costs and increase yields. It has been estimated that there are about 40,000 ha of available and suitable land for corn cultivation in the country (Leong *et al.*, 1991).

II. Grain corn research

In Malaysia, research on grain corn is carried out mainly by the Malaysian Agriculture Research and Development Institute (MARDI) and to a lesser extent by the Universities. Within MARDI, grain corn comes under the Horticulture Research Division and it is one of the three field crops that has been accorded research priority. As far as grain corn research is concerned, there is some collaboration with CIMMYT through its Asian Regional Maize Program as well as the International Potash Institute (IPI) through its Maximum Yield Research Program.

A. Breeding

Prior to the formation of MARDI, corn research was carried out by the Department of Agriculture where breeding work was mainly confined to varietal screening and evaluation.
In 1972, MARDI continued maize improvement research where open-pollinated varieties were developed through either mass selection, modified half-sib selection, or S1 family selection methods.

The adoption of the open pollinated cultivar Metro was very successful, which was rapidly disseminated to farmers. This was followed by the release of a new variety MC1 (MARDI Composite

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#1) and a series of varietal trials in 1978 and early 80's. Varieties that stood out included Suwan 1 C7, Across 7824 and Across 7728 with mean yields of between 3.1 to 4.3 t/ha. This research has continued till the present day with the inclusion of inbred formation and combining ability tests.

1. *Varietal trials*

Varietal trials have been the focal point of the local breeding program. Results of the multilocational trials showed that several varieties are high yielding and suitable for planting locally. The yield performance of these varieties showed no statistical differences (**Table 1**). Some of these varieties, i.e Suwan 3 C2 and Bertam 8701 (half-sib population of Suwan 1) have been endorsed for local cultivation.

Table 1. Performance of adapted varieties at MARDI, Seberang Perai 1991-1992.

	Days to		Height		Lodging		Disease rating	Husk cover	Ear Aspect	Yield (t/ha)
	Tassel	Silk	Plant	Ear	Root	Stalk				
Bertam 8805	48.67	51.67	194.4	98.5	8.00	5.33	3.33	2.00	1.67	6.04
Bertam 8602	46.67	49.67	189.6	96.0	3.33	6.67	3.67	2.00	1.00	6.81
Bertam 8701	47.67	51.00	204.8	101.7	8.33	6.67	2.33	2.67	1.67	6.99
Pop. 28	48.67	51.33	203.1	106.3	9.00	8.00	3.67	1.67	1.33	5.71
Suwan 3 C2	47.33	49.00	191.7	118.2	6.33	6.00	2.67	2.00	1.33	5.73
Nakorn Sawan-1	47.00	49.00	223.5	117.6	8.33	13.00	3.00	2.00	1.67	6.63
Overall mean	47.67	50.28	201.2	106.4	7.22	7.61	3.11	2.06	1.39	6.32
S.E./obs.	0.84	1.43	9.56	15.57	3.93	3.16	0.51	0.51	0.54	0.55
CV (%)	1.76	2.85	4.75	14.64	54.38	41.5	16.25	24.60	38.70	8.65

Elite varieties of other countries were also evaluated. However, none of them performed better than the above varieties (**Table 2**). Some varieties were found to be high yielding, but too tall e.g. Rama, which also showed serious leaf disease problems (e.g. Jinjuk and Suwon, 1979).

2. *Varietal improvement and development of hybrids*

Mass selection was the earliest and most frequently used method of varietal improvement. Modified half-sib selection was carried out to obtain maize varieties maturing in 120 days to fit in the second planting season of specific localities. Reciprocal recurrent selection was being carried out in the breeding program to improve Suwan 3 and Bertam 8805, and also for Suwan 1 and Bertam 8602. Parallel to the development of inbreds in hybrid breeding was the development of inbreds up to S4 for recombination to form synthetic varieties.

Trials using F1 hybrids showed that there was a yield advantage (**Table 3**). However, the advantages obtained were small and insignificant compared to the best composite varieties. Inbreds from locally adapted populations are being developed. It is expected that hybrids between inbreds from different adapted populations can produce a higher heterotic level, thereby making the use of hybrids feasible and the cultivation of maize more viable.

B. **Agronomy**

The early emphasis in agronomic grain corn research was on increasing yield mainly through manipulation of nutrient levels to suit local conditions. Later, the priority was shifted towards supporting large scale production when it became clear that due to rising labor cost and lack of readily available farm labor, the future mode of production was to be through mechanization with estate or mini-estate type management. Agronomic research placed greater emphasis on its adaptability towards larger scale production.

Table 2. Corn varietal evaluation. MARDI, Seberang Perai, 1992.

Varietay	Plt/hgt (cm)	Ear/hgt (cm)	Grain yield (kg/ha)
USMARC 2088	212	115	6016
USMARC 1288	169	112	6093
Bertam 8701	217	105	7192
Bertam 8602	158	103	4855
Bertam 8805	189	96	7513
Suwan 3	201	86	8148
IBP Var. 5	188	88	6193
Suwan 79	201	86	5712
Pop. 28 Bk 89 BF	203	82	7152
Rama	222	80	7815
Jinjuk	191	75	4850
USM Var. 2	185	65	5938
Mean	194.6	92.1	6467
CV (%)	11.4	17.7	16.5

1. *Early fertilizer trials*

From 1977-1981 MARDI carried out a series of fertilizer trials covering the states of Kedah, Perak, Seberang Perai, Selangor, Negeri Sembilan, Pahang, Terengganu, and Kelantan

Table 3. Performance of International Yellow Hybrid Maize. MARDI, Serberang Perai, 1992.

Variety	Days to silking	Plant hgt. (cm)	Cob hgt. (cm)	Yield (kg/ha)
8329-15	51	214.7	116.5	6012
8425-8	52	225.8	120.9	7230
8505-13	52	222.3	116.0	6078
8522-2	54	242.0	124.2	7212
8644-27	53	211.7	110.8	7225
8644-31	52	213.9	114.0	6670
8644-32	51	210.4	110.7	6328
Across 85 TZ SR-Y	34	230.7	125.8	6490
Bertam 8805	51	213.9	110.1	6650
Bertam 8701	52	229.2	118.0	6752
Mean	52.2	221.5	116.7	6665
S.E./observation	1.41	72	6.0	862
CV (%)	2.70	3.2	5.2	12.9

(Foster, 1989). A yield range of 0.8-5.4 t/ha was reported with liming recommended for soils having extractable aluminum levels exceeding 0.5 meq/100 gr soil. In a corn-legume rotational experiment at MARDI, Seberang Perai (1987), it was shown that grain corn under continuous cultivation on the same area would eventually lead to yield deterioration which could be arrested by rotating with a legume. After 3 seasons, the yield of grain corn stagnated at 4.4 t/ha, while those rotated with mungbean or soybean yielded 5.2 and 5.4 t/ha, respectively (Anon., 1990).

2. *Maximum yield research*

The concept of maximum yield research involved raising the experimental yield level of grain corn from 6 t/ha to over 9 t/ha under local conditions through identification and manipulation of yield limiting factors as well as their interactions. Past research indicated that variety, spacing, and nutrient played dominant roles in determining yield. Accordingly, these factors were studied in an experiment over five consecutive seasons (Leong, 1989).

The results were as shown in (**Table 4**). This indicated a gradual increase in the average yield over time from 6.2 t/ha in the first season to 8.2 t/ha by the fifth season. A maximum yield of 10.1 t/ha (average over 3 replications) was achieved by the fifth season.

The nutrient concentrations of the plant tissue at tasseling and harvest were used to determine significant correlations (**Table 5**).

This indicated a positive correlation of plant and ear heights with K values in the stem at harvest for Suwan 1 and a negative correlation with leaf Mg content. Leaf K value also has a positive effect on ear length. For hybrids, there were strong correlations between stem K values at harvest and plant and cob heights with leaf Mg content again sharing a negative relationship with plant height. These correlations were used for model building through stepwise regression:

(1) Suwan 1 - ear length

$Y = 12.5719 + 17518*\text{leaf K} + 0.005179*\text{leaf Fe} - 0.2691*\text{leaf Zn} + 0.4761*\text{stem K}$

(2) Hybrid C1 - yield

$Y = 5.6824 + 0.0060*\text{leaf Fe}-67010*\text{stem Mg}$

3. *Supportive research for large scale production*

The future trend for maize cultivation will be large scale mechanized production. A fundamental aspect in viable mechanized production would be its cost. In the final stages, studies such as land preparation sequences were carried out to reduce costs without affecting yield.

In 1992, an experiment on various combinations of land preparation was carried out at MARDI, Seberang Perai to compare 3 against 2 tillage operations as well as ploughing depths. The average yields are shown in **Table 6**.

The data indicated that a reduction in land preparation tillage operations from 3 to 2 not only did not affect yield adversely but actually increased it by 0.46 t/ha. However, there were no yield differences between the two tillage depths of 40 and 50 cm, indicating that a 40 cm depth was sufficient. The highest yield of 6.23 t/ha was achieved by a 2 tillage operation of a 40 cm depth with plough followed by rotovation. This meant that using the plough-rotovation sequence increased yields by 15% and reduced land preparation cost by 32%.

4. *Pilot projects on large scale production*

Several large scale pilot projects have been carried out on a research basis (ranging from 20-40 ha) to identify actual field production problems as well as to complete the technology package needed for future production. The results are shown in **Table 7**.

Data recorded indicated there is a yield range from 1.36 to 3.99 t/ha over seasons and location. The wide yield variation has been attributed to inadequate drainage during heavy precipitation, drought leading to water stress, and high postharvest losses (Ramli and Leong, 1990).

5. *Technology package*

The production research carried out has resulted in the development of a technology package for large scale mechanized production of grain corn (Leong *et al.*, 1993) as follows:

Table 4. MYR grain maize yields over 5 seasons 1988-1990 (t/ha).

Treatment 1/	Season 1	2	3	4	5	Std. deviation
V1S1F1	5.73	5.46	6.27	5.46	6.11	0.37
V1S1MF1	7.13	5.06	5.54	5.14	7.28	1.09
V1S1F2	5.96	5.44	6.15	5.42	6.72	0.54
V1S1MF2	6.05	4.89	5.49	4.80	7.55	1.12
V1S2F1	6.22	5.39	7.09	5.76	7.02	0.75
V1S2MF1	6.93	5.72	7.01	7.02	7.77	0.74
V1S2F2	6.15	6.15	7.70	6.76	7.41	0.71
V1S2MF2	6.68	7.15	8.35	7.50	7.88	0.64
V2S1F1	6.14	5.80	7.07	6.67	6.94	0.54
V2S1MF1	6.09	6.95	6.96	7.92	10.14	1.55
V2S1F2	5.75	7.24	7.47	6.96	9.45	1.34
V2S1MF2	5.91	7.77	7.69	7.68	9.95	1.43
V2S2F1	5.95	7.66	7.94	6.81	8.06	0.89
V2S2MF1	5.61	7.08	8.81	8.11	9.18	1.44
V2S2F2	6.45	8.40	9.00	8.34	9.30	1.11
V2S2MF2	6.00	7.70	7.84	8.00	9.73	1.32
	6.17	6.49	7.27	6.77	8.16	

1/ V1 = Suwan 1   S1 = 15 x 75cm F1 = 120:60:60   M = Manure at
V2 = Hybrid C1   S2 = 25 x 75cm F2 = 360:180:180   45 t/ha

Table 5. Significant correlations between nutrient concentrations and plant parameters (at 1% level of significance).

Hybrid C1 Plt. nutrient	Plt. parameter	Correlation coefficient	Suwan 1 Plt. nutrient	Plt. parameter	Correlation coefficient
Leaf K1 1/	Ear length	0.55	Leaf Fe1	Yield	0.62
Leaf Mg2 2/	Plant height	-0.58	Stem N1	Ear length	0.55
Leaf Mn2	Grain row	0.61	Stem K1	" hgt	0.55
Stem K2	Plant height	0.69	Leaf P2	" length	0.56
Stem K2	Ear height	0.55	Leaf Mg2	Plt hht	-0.74
			Stem N2	Ear hgt	0.58
			Stem K2	" hgt	0.69
			Leaf Mg2	" hgt	-0.62
			Stem K2	Plt hgt	0.71

1/ : tasseling
2/ : harvest

Table 6. Average yields for tillage experiment in MARDI (1992).

Treatment 1/		Mean yield (t/ha)
DP + DP + R	3 tillage operations	5.28
DO + DP + DH		5.19
MP + DP + R		5.89
MP + DP + DH		5.31
DP + R	2 tillage operations	6.23
DP + DH		5.93
DM + R		5.91
MP + DH		5.38

S.E = 1.1555
1/DP = disc plough; DH = disc harrow; R = rotovation; MP = mouldboard plough.

Table 7. Marketed yields from various corn pilot projects 1986-1991 (t/ha).

	Season				
	1	2	3	4	5
MARDI Seberang Perai	2.58	1.36	-	-	-
Pdg Tembusu	3.50	2.84	2.96	1.99	3.10
United Plantation	3.99	2.50	-	-	-
Ladang Lambor	2.60	3.99	2.54	3.20	3.70

First season
- one round disc ploughing followed by one round of rotovation
- mechanized simultaneous planting and basal fertilization
- mechanized spraying of preemergent atrazine at 3 lt/ha
- monitoring of pests through IPM
- mechanized harvesting with combine harvester
- grain drying to 12-15% moisture content within 48 hr of harvest
- one round disc ploughing

Second season
- same as above but with the added operation of planting mungbean after harvesting of corn as green manure.

C. Conclusions

Priority in grain corn research in Malaysia is given to breeding, particularly in the development of inbred lines for hybrid formation. For grain corn to be competitive with other commodities, the yield needs to be increased to a high and consistent level. Present research in breeding is targeted towards that objective. Once the relevant cultivars have been identified, further yield increases can be effected through research in the agronomic aspects of production, as well as in reduction of losses through IPM and efficient postharvest handling techniques.

References

Anonymous. 1990. Grain maize production and research in Malaysia - A review. Bahagian Hortikultur Serdang, mimeo.

Foster, H.L. 1989. Final report on the cereal/legume nutrition project Aug. 1977-July 1981. MARDI, K. Lumpur.

Leong, C.O. 1989. Proc. Symp. on maximum yield research. Nov. 16-18, 1989. New Delhi, India: 196-203.

Leong, C.O., M.N. Ramli, M.N., Setarfarzi, A. A. Rashid, A.M. Abd. Aziz, D. A. Hassan, N.J. Mahamad, S. Ahmad, M. Wan Zahari, R.S. Raja Shukor, K.K. Yau, S. Praim, and M.N. Adnan. 1993. Experiences in commercial grain maize production. Proc. Workshop in underexploited crops. MARDI Serdang: 25-37.

Leong, C.O., N.J. Mahamad, and M.N. Ramli. 1991. Potential of soybean and grain maize production under irrigated environment in P. Malaysia. Proc. Natl. Conf. Irrigated Agric. Johor Bahru. Nov. 14-16, 1991.

MARDI. 1992. A production package for grain maize cultivation based on the Ladang Lambor Project 1991, 54 p. Ed. Leong, C.O., Serdang. Bahagain Hortikultur, MARDI (mimeo).

Ramli, M.N. and C.O. Leong. 1990. Yield gap of grain maize in Malaysia. Reg. Workshop on increasing soybean yields in Asia. Phitsanulok, Thailand. Aug. 21-24, 1990.

Questions to the author:

FROM : J. Singh

Q : What is the seed cost of varieties, and hybrids? (In your slide chemical + seed costs were 35% of total cultivation costs. This seems to be too high. Should seed cost be kept separate?

A : The cost of grain corn composite seeds (Suwan 1) in Malaysia is US$0.48 per kilogram. Hybrid seeds will cost five times that. Chemicals + seeds which contributed to about 35% of total operational cost includes chemical compound fertilizers which are costly at US$360/mt. The seed component accounted for less than 5% of the "chemicals + seeds" cost.

FROM : P. Silpisornkosol

Q : 1) How many private seed corn companies operate in your country? Name the companies please.

2) When do you test hybrid? What hybrid you are talking about?

A : 1) There are no private international corn seed companies operating officially in Malaysia. There are some local seed companies which, among other seeds, market sweet corn seeds.

2) Some international corn seed companies have in the past provided some seeds for testing by MARDI, particularly Pioneer and Cargill.

FROM : R. S. Paroda

Q : According to your presentation, composites and hybrids are giving similar yields. For future of maize, Malaysia must explore potential of single cross hybrids. What is your strategy for technological advancements and how much self-sufficiency of maize Malaysia intends to achieve in near future? Perhaps more aggressive approach in future is needed than at present. Please comment.

A : Single cross hybrids will be given priority in our hybrid maize program. Malaysia does not aspire to be entirely self-sufficient in corn in the near future, and for a start we would be satisfied with a 5-10% sufficiency level. For attainment of higher consistent yields in hybrids, we need to link up with international agencies like CIMMYT, network program under FAO, as well as international corn seed companies, besides developing our own hybrid breeding program.

HYBRID CORN DEVELOPMENT IN MYANMAR

San Htun [1/]

Abstract

Research on hybrid corn was initiated in 1984 and many tropical inbreds have been introduced since 1989-90. The International Inst. of Tropical Agriculture (IITA), Nigeria and Internatl. Maize and Wheat Improvmt. Center (CIMMYT) Mexico provided materials and inbred lines for production of hybrid corn in Myanmar.

At present, Myanmar has multiplied inbred lines and produced a single cross hybrid. From 1993-94 to 1996-97, the area under hybrid corn will be increased from 60 to 3600 ha and the total production will be 7000 t.

Introduction

In the Union of Myanmar, maize is the second most important cereal crop. Most cultivated varieties are open pollinated varieties. It has been well documented that hybrid corn yields two to three times more than the open pollinated varieties. In 1989-90 hybrid corn seeds were introduced from abroad and hybrid corn yield trials were conducted in Pyinmana and Lewe.At these two locations the average yield obtained by farmers planting hybrid seed was 85 to 92 baskets/acre (equal 5100-5460 kg/ha, at 1 basket = 25 kg, and 1 acre = 0.405 ha).

Maize production in Myanmar

Total maize area and production from 1982-1992 is described in **Table 1**.

Background research

A hybrid corn development program in Myanmar was initiated in 1984 at Tatkon Central Farm. Population improvement, varietal development and hybrid development, programs were carried out as parallel programs. Over 200 established inbred lines, many of them of US Corn Belt origin, were introduced from the former Soviet Union. These inbreds were tested for their performance and adaptability and combining ability studies were made using some of the selected lines. The program was successful only in developing some commercial synthetic varieties.

An extensive inbreeding program using genetically diverse CIMMYT germplasm was established in 1986. In 1993, a list of the source varieties and their different generations of inbreeding was complied.

In 1987, two hybrid corn yield adaptation trials, including open pedigree hybrids, were obtained from IITA, Nigeria. In 1988 two more sets of hybrid adaptation trials were obtained from the same Institute. Based on the performance and yield data obtained from the two years, two superior hybrids were identified. Their parental lines were requested from IITA and the F1 seed was generated in Myanmar. In 1989 and 1990, these were included in the multilocation elite variety yield trial.

In many trials, these hybrids showed consistent yields 25-35% over the best open pollinated variety.

Program for cultivation of single cross corn hybrids.

1) Introduction of the selected inbred lines from IITA, Nigeria. 2) Single cross hybrid seed is produced at the Central Agric. Res. Dept., Yezin.

[1/] Deputy Supervisor. Myanmar Agric. Service, Union of Myanmar.

Table 1. Total area under maize and production in Myanmar. 1982-1992.

Year	Planted area (ha)	Harvested area (ha)	Yield (kg/ha)	Production (t)
1982-83	170920	136010	1770	232577
1983-84	207910	180940	1668	301807
1984-85	228767	186316	1584	295124
1985-86	199319	171000	1704	291384
1986-87	222524	159248	1746	278047
1987-88	159964	134837	1614	217627
1988-89	137961	120957	1554	187967
1989-90	133289	122740	1536	188528
1990-91	140771	125197	1524	190800
1991-92	140232	124163	1500	186244

Maternal inbred lines.

The inbred Tzi 18 is the maternal parent used in hybrids Yezin No. 1 and No.2. It is short statured and intermediate in maturity. Due to poor pollination, its yield was 15-20 baskets/acre (= 900-1200 kg/ha).

Paternal inbred line of Yezin No.1.

The inbred TZi-25 was used as male parent of the hybrid Yezin No.1. Plants are 150 cm high and have intermediate maturity.

Paternal inbred line of Yezin No.2.

The inbred TZi-28 was used as male parent of the hybrid Yezin No.2. Plants are 135 cm high and are early maturing. Both TZi 18 and TZi 28 have a potential yield of 20-25 baskets/acre (=1200-1500 kg/ha).

On-farm demonstration trials.

Since the 1990-91 rainy season, hybrid corn varieties have been compared for their performance and yield with other high yielding varieties in Pyinmana (**Table** 2) and Lewe.

Table 2. Results of corn trials planted at Pyinmana. 1992-1993 and 1993-1994.

Character	1992-93				1993-94	
	Shwe Wa-1	Suwan-3	Yezin-1	Yezin-2	Yezin-1	Yezin-2
50% tasseling (days)	59	58	44	50	42	40
Plant hgt (cm)	200	182	182	180	185	210
Ear hgt (cm)	97.5	90	85	72.5	97	102
Days to harvest	100	99	95	100	95	100
Yield (kg/ha)	3480	4920	6180	6060	5460	6180
% best check	-	-	126	123	111	126

Future of hybrid corn program

1. **Hybrid corn research.**

Hybrid corn research and development programs include the following activities:

a. Inbred line development.
b. Combining ability testing.
c. Inbred line seed increase.
d. Production of F1 seed.

The Agric. Res. Div. of the Ministry of Agric. is the institution responsible for the development of inbred lines and their increase. The seed increase program of inbred lines with good combining ability is described below:

Year	Region	Area planted (ha)	Production
1992-93	Yezin	0.4	1200
1993-94	Yezin	0.8	2400
1994-95	Yezin	1.6	4800
1995-96	Yezin	2.0	6000

2. **Hybrid seed production program.**

The crossing blocks including the staggered planting of male and female lines in 1:3 ratio, are established at Tatkon and Chaung Ma Gyi Seed Farms, under the Seed Div. of the Ministry of Agric. Detasseling of the female rows is done manually. The hybrid seeds production program for 1992-93 to 1995-96 is as follows:

Year	Region	Area planted (ha)	Total product (t)	Seed production (ha)
1992-93	Yezin	1.2	1.5	60
1993-94	Tatkon	2.0	25.0	1000
1994-95	Tatkon	2.0	25.0	1000
	Chang Ma Gyi	2.0	25.0	1000
1995-96	Tatkon	2.0	25.0	1000
	Chang Ma Gyi	2.4	30.0	1200
	Lun Kyaw	2.8	35.0	1400

3. **Hybrid corn substitution program.**

Hybrid corn is mainly targeted for those areas in Myanmar where farmers obtain a yield plateau with the open pollinated varieties and where agronomic constraints are no longer a yield limiting factor. To replace OPVs with hybrid corn on successive steps in two townships, Lewe and Pyinmana, selected areas are planted to hybrids as follows:

Year	Township	Area planted (ha)	Total production (t)
1993-94	Pyinmana	30	122.5
	Lewe	30	122.5
1994-95	Pyinmana	500	192.5
	Lewe	500	192.5
1995-96	Pyinmana	1000	385.0
	Lewe	1000	385.0
1996-97	Pyinmana	1800	700.0
	Lewe	1800	700.0

Constraints

Constraints in hybrid corn research.

a. Limitation in the availability of breeding materials, including inbred lines.
b. Lack of adequate trained personnel.

Constraints in farmers adoption of hybrids.

a. Lack of fertilizer inputs.

Conclusion.

Based on Government plans, there is an emphasis in increasing total maize production in the country, to meet the increasing demand for local consumption both as human food and livestock feed, as well as to have larger quantities available for exports. It is assumed hybrid corn will contribute in increasing yields to the required levels.

Questions to the author:

FROM : R. S. Paroda
Q : In spite of slight increase in area, the production has not increased in last one decade. On the contrary, the yield/ha has declined. What are the reasons for this and how to improve the situation in future?
A : 1) Lack of corn HYVs in all of corn cultivation areas.
2) Lack of sufficient chemical fertilizers in those areas.
In future 1) We substitute with hybrid corn varieties such as Yezin No. 1 and Suwan 3 and Shwe Wa (1).
2) Sufficient amounts of fertilizer for special planning areas which contract farming with the government.
3) Extension agencies will help in mechanization such as cob threshers and tractors for the main corn region.

AN OVERVIEW OF MAIZE RESEARCH AND PRODUCTION IN NEPAL

M. M. Palikhe [1/]

Maize is the most important cereal crop in Nepal. It is the principal staple cereal diet in the of over 55% of the people who live in the hilly regions. Based on the total cultivated area and production, maize ranks first in the hills and second after rice in the tarai. Maize occupies about28.5% of the total cultivated area of Nepal, or approximately 757,700 ha, with a national average yield of 1,625 kg/ha (DFAMS, ASD, 1991). It is grown throughout the country both as monocrop and intercropped with finger millet, soybean, etc.

Of the total area under maize, 58,550 ha (7.73%) are grown in the high hills with an average production of 1,497 kg/ha; 537,320 ha (70.91%) are planted in the mid-hills with an average production of 1,569 kg/ha and 161,830 ha (21.36%) in the tarai with a mean of 1,765 kg/ha (DFAMS, Agric. Stat. Div., 1991).

In 1991/92, the total area planted to maize and total production increased by approximately 59 and 64% respectively compared to 1981/82 (**Table 1**).

Table 1. Maize area, production, and average yield in Nepal.

Year	Area ('000 ha)	Production ('000 t)	Average yield (kg/ha)
1981/82	475.5	751.5	1581
1982/83	510.8	718.2	1405
1983/84	503.8	761.1	1511
1984/85	578.7	819.9	1417
1985/86	614.7	873.8	1421
1986/87	626.7	868.4	1366
1987/88	673.8	901.5	1338
1988/89	721.9	1071.6	1484
1989/90	751.2	1201.0	1599
1990/91	757.7	1230.9	1625

The low yields and slow increases in yield observed throughout may be attributed to unpredictable monsoon rains, poor soil fertility in the hills due to soil erosion, drought during the growing period, excessive rain delaying weeding, no practice of controlling insects and diseases, slow dissemination of improved varieties, unwillingness to use fertilizer, and low purchasing power of the hill people.

In the hills, over 90% of the maize produced is consumed as *roti* (flat bread), *dhido* (thick porridge), *chyakhala* (grits cooked like rice), roasted popped maize kernels, and as roasted green ears. The demand for maize as a major raw material for animal feed has increased.

Nepalese farmers prefer maize varieties with hard-flint kernels. The kernel color preference varies from white flints in the West and East to yellow flints in the central regions. The feed industry prefers yellow maize. Farmers prefer early maturing varieties with tight husk

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cover, short plant stature, and satisfactory yield response to low fertility conditions. Maize is grown in the marginal areas. This also offers the biggest challenge to research to breed varieties with suitable yield suited to these conditions. To meet these challenges, the Maize Research Program has developed broadly adapted improved populations with adequate genetic variability suited to a reasonable range of agroclimatic environments of the country.

The Nepal Agric. Res. Council, as an independent agriculture organization, has been developed to broaden and strengthen the agricultural research activities as a national priority, including extension linkages and cooperation with international and national research centers.

Since 1988/89 yield per hectare has shown an increasing trend. Area has increased by 59.35%, production by 63.79%, and productivity by 2.78% compared to 1981/82.

Research highlights:

1. **Varietal improvement.**

The major achievement of Nepal's maize improvement program since 1965 has been the development of populations and release of a dozen composite maize varieties suited to different agroecological regions. These varieties have been maintained for general cultivation to meet the varietal demand of the farmers (**Table** 2).

Most of the released varieties have been selected from exotic germplasm and from crosses of local with exotic materials introduced by the different organizations in the varietal testing programs. The evaluation of local and exotic materials to assess their merits for a long term breeding program has become one of the main objective of the Varietal Improvement Program.

The exotic germplasm, namely Amarillo de Cuba, Cubano Flint, and Francisco Flint were introduced in Nepal prior to 1965. These varieties proved to be high yielding, but were not acceptable to farmers due to their late maturity, denty grain type, and tall plant height. During 1965, some varietal crosses and composite varieties obtained through the Inter-Asian Corn Program based in India were tested for their adaptation to various environments throughout the country. Out of the material tested, three promising exotic varieties called Composite J1, Antigua 2D x Guatemala, and Antigua Gp.2 x Guatemala were released under the names Rampur Yellow for terai and inner terai, Khumal Yellow for mid hills (1 500 m) and Kakani Yellow for high hills (2 000 m) respectively (**Table** 2).

In order to strengthen and broaden maize research in Nepal, in 1972 the National Maize Research Program (NMRP) was established as a commodity program for systematic maize breeding at Rampur. Upon the establishment of the Maize Res. Program, close links were established with CIMMYT, Mexico and other international organizations to improve and broaden exotic and local germplasm. These efforts resulted in the development of a dozen maize varieties for general cultivation on the basis of varietal traits and yield data received from varietal trials.

Even though the varieties listed in **Table** 2 were high yielding, they were not acceptable due to undesirable traits such as high percentage of cobs with open tips, late maturity, semident kernels, and tall plant height. But these problems have been significantly reduced through continuous half-sib modified ear-to-row and mass selection improvement methods.

The varieties Janaki Makai (Rampur 7434), Makalu-2 (Amarillo del Bajio) and Arun-2 (UNCAC 242 x Phil. DMR x Amarillo 59 (Temperate x Tropical) were developed from CIMMYT materials and released for the terai, inner terai, and hills. The early maturing variety Arun-2 has gained popularity among farmers because it fits well into the cropping system maize:rice:wheat, and in mixed cropping yields above 2 t/ha. The newly introduced Pool 9A from CIMMYT has a high yield potential in the high hills but it has late maturity.

The following populations maintained by NMRP have been released:

Arun-1: Half-sib families of white flint early maturity, subtropical material adapted to low and mid altitude for mixed or sequential cropping systems.

Rampur-1: Hal-sib families of white flint, full-season, subtropical germplasm adapted to low altitude (<1,000 m) and terai areas.

Manakamana-2: Half-sib families of orange yellow flint, full season, subtropical germplasm adapted to mid altutde areas (mid hills).

Arun-4: Half-sib families of yellow flint, short season, subtropical germplasm adapted to low and mid altitude for mixed and sequential cropping systems.

Table 2. Agronomical features of recommended varieties.

Varieties	Av. yield (t/ha)	Maturity days	Pl. ht (cm)	Grain color	Recommended	
					Year	Area
Rampur yellow (Composite J-1)	3-4	105	220	Yellow	1966	Terai & foot hills
Khumal Yellow (Antiqua Gp.2D x Guatemala)	3-4.5	130	220	Orange	1966	Mid-hills
Kakani Yellow (Antigua Gp 2 x Guatemala)	3-4	180	230	Orange	1966	High hills
Hetauda Comp. (Exotic x local landraces)	3-4	120	220	Yellow	1972	Terai, foot hills

2. **Agronomic management**

An improved variety per se is not sufficient for producing high yields unless it is grown under proper cultural practices. Agronomic research is a necessary component to develop a package of recommendations to increase productivity. The agronomic studies emphasized to date are in the areas of planting date, optimum population density for varieties from the different maturity groups, intercropping, crop sequences, fertilizer requirements, tillage practices, effect of planting in furrow against planting in flat, and crop water requirements.

NMRP could not standardize its techniques and recommended available general agronomic practices due to many constraints including the lack of genetically broad based varieties, variation in the climatic conditions, soil types, fertilizer uses, drought, soil erosion, marginal land crop, insect pests and diseases, unpredictable monsoon rains, economic constraints of hill people, and the poorly organized market for farmers to dispose of the product at a reasonable price.

NMRP has conducted many trials relevant to the problems present at the different locations (Agric. Res. Stations (**Table 3**) and farmer's fields) to develop production practices that are economically and ecologically feasible to farmers. The agronomical production practices usually followed by farmers in maize cultivation differ from lower to high elevations. With this view, the National Agric. Res. Council has the mandate to conduct in future location specific (regional problem oriented-research) trials at different farms and station (**Table 3**).

The results of some of the agronomy trials with emphasis on germplasm conducted in the different locations are tabulated in **Tables 4, 5, 6 and 7**. The results are inconsistent between the various locations due to one or several of the factors already described.

The general recommendation made by NMRP on fertilizer level is 90:45:45 kg/N, P_2O_5 and K_2O for winter crop and 45:30:30 kg/ha N, P_2O_5 and K_2O for monsoon crop. The row to row and plant to plant distances are 75 cm and 25 cm, respectively. The spraying of both herbicides Atrazine and Lasso at the rate of 1.5 kg a.i. in 800 lt of water before emergence has shown satisfactory results. The use of herbicides by farmers is nil. Weeds are controlled either by hand-hoeing or less commonly, with ox-drawn wooden cultivator/plough in terai.

The farmyard manure (FYM) collected by the farmers is extensively applied in spring/summer maize cultivation. In general, the use of inorganic fertilizers in high and mid-hills is very low to negligible. Hence, fertilizer recommendations need to be developed for specific cropping patterns and land types. The present tendency toward a blanket general recommendation on

Table 3. Multilocational testing sites in Nepal.

Res.Stat.	Elevation (masl)	Annual rainfall (mm)
Rampur	228	2000
Khumaltar	1360	1200
Parwanipur	115	1750
Lumle	1520	5600
Pakhribas	1770	800
Khairenitar	525	3000
Surkhet	500	-
Nepalganj	181	1300
Doti	1360	900
Jumla	2387	600
Kavre	1700	-
Kakani	2121	2600
Tarahara	233	1700
Janakpur	93	1600

fertilizer dosages fails to take into consideration the different traditional methods of soil fertility management praticed by the farmers.

Table 4. Grain yield (t/ha) of maize varieties evaluated at low altitude. Rampur, Surkhet, Nepalganj.

Varieties	1987	1988	1989	1990	Mean
Rampur 1	2.04	2.50	3.87	3.88	3.07
Rampur 2	2.16	3.57	-	3.93	3.22
Rampur composite	2.24	3.05	4.29	-	3.19
Arun 1	1.97	2.46	3.44	3.73	2.90
Arun 4	2.03	3.14	3.94	3.82	3.23
Arun 2	1.87	2.76	3.73	3.73	3.02
Farmers' local	1.01	2.59	2.66	2.85	2.28

The response to nitrogen fertilizer in maize is very high. Split applications of nitrogen, half as basal and the remaining half as a side dressing at the knee-high stage of maize have shown the highest yield potential. The use of 30-40 kg N/ha as side dressing at the knee-high stage with sufficient quantity of FYM/compost as basal applications is useful to maize for rainfed conditions.

The yield response of the improved varieties with the same agronomic production practices (improved/farmer) is comparatively higher than local varieties in farmer's fields.

Table 5. Grain yields (t/ha) of maize varieties evaluated at low altitude. Summer 1990.

Varieties	Chitwan	Surkhet	Nepalganj	Mean
Rampur 1	1.74	2.20	2.66	2.20
Rampur Comp.	2.08	2.08	3.63	2.60
Arun 1	1.99	1.67	2.81	2.16
Arun 4	2.15	2.05	3.81	2.67
Arun 2	1.91	1.72	3.73	2.45
Farmers' local	2.11	1.91	2.38	2.13
F test (at 0.05% level of signif.)	NS	**	**	
CV %	15.5	22.41	7.25	
LSD (0.05) t/ha	-	0.395	0.227	

Table 6. Grain yields (t/ha) of varieties evaluated at mid to high altitude. Khumaltar, Lumle, Kavre and Pakhribas.

Varieties	1987	1988	1989	1990	Mean
Manakamana 1	3.27	4.11	4.47	4.72	4.14
Manakamana 2	3.96	4.52	4.65	5.67	4.70
Khumal Yellow	3.85	4.12	3.92	3.31	3.80
Ganesh 2	-	4.33	4.34	4.61	4.43
Farmer's local	2.76	4.19	3.77	4.38	3.77

Table 7. Yield performance (t/ha) of maize varieties evaluated in hill research stations.

Varieties	Lumle	Pakhribas	
		1990	1991
Kakani Yellow	5.24	-	-
Ganesh	4.57	4.57	5.35
Arun 1	3.67	4.30	4.59
Arun 2	3.51	3.59	4.01
Arun 4	3.23	3.91	4.11
Manakamana 1	3.94	2.10	5.00
Manakamana 2	3.28	4.05	5.10
Khumal Yellow	3.06	3.67	3.95
Rampur 2	3.55	-	-
Rampur Comp.	2.92	-	-
Pool 9A	4.37	4.88	5.93
Local	3.58	2.03	5.78

3. **Plant protection:**

a. **Diseases**

The major diseases of maize in Nepal are:

Ear rot
Stalk rot
Downy mildew
Common rust
Turcicum and maydis leaf blights
Leptosphaeria leaf blight.

The recommended varieties Rampur Composite, Sarlahi Seto, Rampur 2, and Arun 2 are relatively resistant to downy mildew and have been recommended to farmers. None of the recommended varieties have been found resistant to ear rot, stalk rot, and leaf blights. The Kakani local and Palung local (white and yellow) have shown some degree of field tolerance to ear rots.

b. **Insect pests**

In general, a large number of pests have been found causing significant damage to the maize crop both in field and storage conditions. The most destructive field and storage insects are:

i. **Field insects:**

Cutworm (*Agrotis* spp.)
Maize stem borer (*Chilo partellus*)
Armyworm (*Mythima separate*)
Field cricket (*Brachytrupes portentsus*)

ii. **Storage insects:**

Maize weevil (*Sitophilus zeamaise*)
Rice weevil (*Sitophilus oryzae*)

None of the maize varieties so far developed are resistant to any field and storage insects. These insects are controlled satisfactorily by using insecticides. The whorl application of Sevin 4% granules or Furadan 3% granules are very effective to control field and storage insect pests.

Seed production

The Maize Research Program is responsible for producing and maintaining the foundation seed of the maize varieties with coordination of different farms/stations (**Table 3**). The foundation seed is supplied to the Agric. Input Corp. (AIC) for production of certified seed. The certified seed is produced by contact farmers under the Agric. Developmt. Bank and under technical assistance from the AIC Seed Division and MRP staff. The private seed companies existing in Nepal are not well equipped to handle maize seed business.

Seed produced by contract farmers is bought by the AIC at a premium over the grain market price based on a favorable seed inspection report and other related criteria. In general, the farmers use their own or locally produced seed. The use of hybrids in area adjoining to the Indian border has been reported.

4. **Future strategies:**

In the near future the Nepalese Maize Program needs to direct its research towards the following aspects:

1. Development of high yielding varieties with pest tolerance/resistance and environmentally stable genotypes for hills.
2. Priority to develop stress tolerant varieties.
3. To develop location specific, problem-oriented research and production practices appropriate to the farmers economically and environmentally.
4. Continue to link with international research organizations to get appropriate research technologies.
5. To assess locally available and exotic germplasm suited to further use in developing broad-based and high yielding varieties.
6. Study optimum seed rates for adequate plant densities by different sowing methods.

7. To observe new potential varieties in low and high levels of fertilizer with/without organic source of nutrients.

8. To continue a systematic survey and monitoring on loss assessment due to insect pests and diseases and their control measures.

Table 8. Response to levels of FYM/compost combined with inorganic fertilizer on yields of maize: millet intercropped. Lumle, 1991.

Variety 1. Maize-Kakani Yellow 75 x 25 cms.
2. Millet Okhale - 1 planted in 10 x 10 cm at KHS of maize.
KHS = Knee-height stage of maize.

Treatments	Yield t/ha at 12% MC Maize	Yield t/ha at 12% MC Millet	Combined yield/ha	Rank
5 t/ha FYM/compost only	2.58	2.27	4.86	14
5 t/ha FYM + 30 kg N side dressed at knee height stage (KHS) of maize	3.18	2.20	5.38	10
5 t/ha FYM + 30 KG N/ha basal and 30 kg N/ha side dressed at KHS	2.54	1.89	4.43	17
10 t/ha FYM/compost only	3.05	2.10	5.16	11
10 t/ha FYM/compost + 30 kg N/ha side dressed at KHS	2.64	2.10	4.79	16
10 t/ha FYM + 30 kg N/ha basal + 30 kg N/ha side dressed at KHS	3.76	2.18	5.94	6
15 t/ha compost/FYM only	3.39	2.42	5.82	7
15 t/ha FYM/compost + 30 kg N/ha side dressed at KHS	2.90	2.11	5.02	13
15 t/ha FYM/compost + 30 kg N/ha basal + 30 N/ha side dressed at KHS	4.27	2.24	6.52	2
20 t/ha FYM/compost only	2.89	1.90	4.80	15
20 t/ha FYM/compost + 30 kg N/ha side dressed at KHS	3.35	2.39	5.74	8
20 t/ha FYM/compost + 30 kg N/ha basal + 30 kg N/ha side dressed at KHS	4.17	2.16	6.34	3
5 t/ha FYM/compost + 60:30:30 kg NPK/ha (30:30:30: basal and 30 kg N at KHS	4.35	2.57	6.92	1
10 t/ha FYM + 60:30:30 kg NPK/ha (30:30:30 basal and 30 Kg N at KHS)	3.91	2.05	5.97	5
15 t/ha FYM + 60:30:30 kg NPK/ha (30:30:30 basal and 30 kg N at KHS)	3.21	2.40	5.62	9
20 t/ha FYM + 60:30:30 kg NPK/ha (30:30:30 basal and 30 kg N at KHS)	3.97	2.25	6.43	4
60:30:30 kg NPK/ha 30:30:30 basal and 30 kg N at KHS)	3.02	2.00	5.03	12
Control (No FYM, no chemical fertilizer)	1.65	2.09	3.75	18

Questions to the author:

FROM : S. Kumar

Q : What is the major problem pest encountered for maize in Nepal, and what is the most successful control measure recommended?

A : Most destructive insects are:

Field insects: Cut worm (*Agrotis* spp)
Maize Stem Borer (*Chilo partellus*)
Army worm (*Mythima separate*)
Field cricket (*Brachytrupes portentsus*)

Storage insects: Maize weevil (*Sitophilus zeamais*)
Rice weevil (*Sitophilus oryzae*)

For field insects: We are using liquid insecticides and Granular insecticides (whorl application) for field cricket. For field cricket, we applied poison baits just after maize germination. Liquid insecticides - *Metasystox, Metacid*, granular - *Furadan* 3% *G*, Sevin 5%.

For storage insects: We treat seed with insecticide (dust) available in the market to store seed for next sowing.

HYBRID MAIZE DEVELOPMENT IN PAKISTAN

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Abstract

In Pakistan, maize is used for animal feed and for human consumption. At present, yields are low due to extensive use of local varieties, traditional tillage practices, and low inputs. Preference is for early semiflint varieties that can tolerate high densities and low inputs. Originally US hybrids were tested in 1951-1968 but did not succeed due to late maturity, dented yellow grain, and problems associated with seed production and high cost of seed. In general, high yielding hybrids continue to have these same limitations and hence the low adaption of hybrids in the country. For successful hybrid utilization and expansion of area, hybrids are required to have early maturity, flint semiflint kernels, resistant to foliar diseases and stalk rots, and easily and cheaply produced. Main limitation of utilization of hybrid seed in Pakistan is the seed availability. It is recommended that the development and establishment of a seed industry should be following scientific lines.

Maize is potentially one of the highest yielding cereals and is of great importance to the rural farming community of Pakistan. It is produced over a wide range of agroecological zones, for a variety of purposes, and within both market and subsistence oriented farming systems. Maize is gaining an increasingly important position due to recent changes in Government policy regarding expansion in the textile industry, poultry feed, maize products, etc. Besides, maize is also used as human food in many maize based farming systems of Pakistan. An increasing trend for its demand has been observed for the last several years. To meet this challenge, we can not expect a major shift in cropping patterns or expansion in the area. Therefore, there is a need to improve maize production vertically rather than horizontally. No doubt, there has been some progress in the use of improved synthetics or open-pollinated varieties, but seed production has always remained a serious problem in the way of yield improvement per hectare on the whole. One of the major reasons being the disinterest of private seed companies in the seed multiplication of open-pollinated varieties.

Presently, maize yield per unit area is low primarily due to the use of local varieties, traditional tillage practices, and use of low inputs. Growers generally prefer early maturing or semiflint cultivars/hybrids that can tolerate high plant density, with response to low input utilization, poor weed control, and which can still give good grain and stalk yield. More importantly, a cultivar or hybrid is accepted by farmers only when it properly fits in their cropping pattern and can tolerate environmental stresses in which that cultivar is grown. Therefore, the breeder needs to remember that he is operating in a stressful environment and hence should develop widely adapted hybrid cultivars that must match the growing conditions of subsistence farmers.

Some exotic hybrids such as US 13, Indiana 909, and US 523, were tested during 1958-68 and earlier, but had limited adoption in Pakistan due to the following reasons (Saleem, *et al.*, 1993):

1) They were late maturing and could not fit into the prevailing cropping pattern. 2) They possessed dent grains while growers prefer flint types. 3) US 13 hybrid and some other ones

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were unacceptable in some parts due to yellow grain color. 4) F1 production was a tedious job and farmers were not willing to purchase fresh seed every year at high cost.

More recently, some multinational seed companies, the local seed company, Rafhan Maize Products Co. and Provincial Research Institutes are involved in the development and distribution of hybrid maize seed. Hybrid seed is planted in a limited area (54,000-56,000 ha) by contract growers in the Punjab Province in the spring season. All hybrid seed is provided by Rafhan Maize Products Co. (Khan, 1993). During the main growing season (kharif) only 20 tons of hybrid seed are provided by all multinational seed companies combined. The limited use of hybrid seed in Pakistan is attributed to the following factors:

a. All exotic hybrids are of full-season maturity, about a month later than what farmer's would prefer to grow.

b. Almost all hybrid seed is imported. This activity increases the price of hybrid seed beyond the purchasing power of a common maize grower.

c. Imported hybrids are developed from full-season inbreds, which can not be successfully produced in the subtropical environment of Pakistan. Parents of hybrids, therefore, can not be maintained easily or grown without risk.

d. Most foreign hybrids are bred specifically for favorable growing conditions, but Pakistani growers have experienced disappointments when these hybrids were grown under suboptimal conditions or when stresses occurred during the growing season.

e. Because imported seed remains for a long time in shipment, its quality often deterio rates.

f. Little incentives are provided by the Government to private seed companies.

For the above reasons, there is a need for short duration hybrids, well adapted to local conditions, and whose seed could be cheaply and easily produced. Hybrids developed from elite local populations could be the only suitable source of hybrid seed.

In the past, no serious attempts were made to locally develop and produce short duration F1 hybrids for commercial cultivation. The hybrid breeding program could not be established on a sound footing due to lack of financial resources and technical manpower, sound seed production and distribution system, and many other related problems. Maize hybrids under relatively good management can give higher yields than open-pollinated varieties with much better uniformity of maturity, plant height, and disease resistance.

The hybrid maize breeding program was initiated with the following objectives:

1. To develop short duration F1 hybrids (85-90 days) for areas with intensive cropping pattern and where late planting Virginia tobacco is grown.
2. To select high yielding and stable hybrids, resistant to leaf blights and stalk rots.

Development of inbred lines.

Research on inbred line development from four adapted and elite populations was started in 1984. With the availability of two seasons per year, selfing and selection was twice as fast as having only one season per year. A standard pedigree selection procedure was used where S2 plants were tested for general combining ability. Many S2 lines were discarded at this early stage. Considerable work has been reported on the development of short duration maize hybrids by numerous workers. Inoue and Okabe (1982) in a study on a method of breeding inbred lines of maize reported visual selection to be very effective for vigor, ear morphology, disease, and insect tolerance and lodging if inbred populations were derived from primary open-pollinated varieties. Oyervides, *et al.* (1985), reported that US Corn Belt populations could be a source of useful alleles for yield, early maturity, and short plant height for tropical or subtropical areas. Cross (1979) reported a new breeding technique for selecting early high yielding maize by use of the marker gene Rnj (purple aleurone gene), which indicates the rate and/or duration of grain filling.

On the basis of their combining ability from each group, selected inbred lines were crossed to check their performance in hybrid combinations. Hybrids were tested in single cross, three-way, and double cross combinations. Some good single cross hybrids were also crossed to adapted improved open-pollinated varieties as double topcrosses. Selected hybrids were extensively tested in multilocation trials for several years.

Results on performance of some hybrids are presented in **Tables 1 to 5**. In all trials, hybrids PSH 817 and PSH 107 proved to be outstanding in terms of yield, early maturity, and disease resistance. In almost all trials, the performance of these two hybrids remained stable with consistent ranking. They significantly outyielded many other hybrids and improved open-pollinated checks. These hybrids were earlier in maturity with better levels of disease resistance, and were recommended for official approval by the government for commercial production. Both hybrids can be grown in spring as well as in the main kharif or summer seasons.

Table 1. Cereal Crop Res. Inst. (CCRI) maize hybrid yield trial. Pirsabak, 1992 Spring.

Entry	Grain yield (kg/ha)	50% silk (days)	Plts./ha	Ears/ha	Stalk rot (%)
PHS 817	9657	85	70,666	68,666	3
PSH 217	9390	87	74,666	67,333	5
PSH 107	9116	87	68,000	68,333	6
PSH 157	9067	85	72,666	65,000	5
PSH 2912	8960	86	72,333	67,333	3
PSH 1229	8960	86	69,666	64,333	4
PSH 307	8850	86	75,333	69,000	5
.	.	.	.	.	.
Sarhad (Y)	8187	90	69,000	64,667	10
(Check-1)					
.	.	.	.	.	.
Kisan	7710	84	69,666	65,333	6
.	.	.	.	.	.

LSD (0.05) = 934
C.V. (%) = 7.89

Seed production.

One of the main reasons for the low yields of maize in Pakistan is the nonavailability of improved seed. Unless government provides incentives to private seed growers, multinational seed companies, provincial institutions and individuals involved in seed production, yield improvement in farmers' fields seems unlikely. Presently there are many types of taxes on seed imports. The seed industry in maize producing provinces must be established on scientific lines.

References

Cross, H.Z. 1979. A new breeding technique for selecting early high yield corns. N. Dakota Farm Res. 37: 27. Dept. Agron. N. Dak. Univ. Fargo, USA.

Inoue, Y., Okabe, T. 1982. Studies on a method of breeding inbred lines of maize (*Zea maize* L.). Res. Bul. Hokkaido Natl. Agric. Expt. Sta. No. 133. Japan.

Oyerrides-Garcia M., A. R. Hallauer, and H. Cortez-Mendoza. 1985. Evaluation of improved maize populations in Mexico and the US Cornbelt. Crop Sci. 25: 25.

Saleem, M. and H. Rahman. 1993. Methods of breeding cross pollinated crops. *In* Elements of Plant Breeding. Elena Bashir ed.

A. Rahman Khan. 1993. General Manager, Cargill Pakistan Seed (Ltd). Personal communication.

Table 2. CCRI maize hybrid yield trial. Swat 1992.

Entry	Grain yield (kg/ha)	75% silk (days)	Plts./ha	Ears/ha
PSH-157	9990	61	54,333	51,000
PSH-107	9853	61	55,000	48,667
PSH-817	9648	61	54,333	49,333
PSH-217	9290	61	55,333	49,667
PSH-2912	9138	61	50,000	48,000
PSH-1229	8488	61	51,667	45,667
PSH-307	8105	61	48,333	42,667
PSH-1512	7798	61	52,333	45,667
Sd. (Y) Check-1	7103	62	52,667	44,333
Kisan Check-2	7093	61	43,667	40,667
LSD (0.05):	1390			
C.V. (%):	11.08			

Table 3. CCRI maize hybrid yield trial. Serai Naurang, 1992.

Entry	Grain yield (kg/ha)	50% silk (days)	Plts./ha	Ears/ha
PSH-107	4372	51	86,166	50,499
PSH-217	4303	50	76,833	56,166
PSH-817	4157	48	71,499	53,666
PSH-1229	4142	50	91,991	63,666
PSH-2912	4013	49	93,999	67,666
PSH-1512	3938	50	68,333	55,166
Kisan	3863	47	56,499	50,000
PSH-307	3817	50	91,991	68,499
Sarhad Y	3738	49	68,393	48,833
PSH-157	3675	51	75,333	52,333
LSD (0.05):	1390			
C.V. (%):	11.08			

Table 4. CCRI hybrid maize yield trials across five locations. Northwest Frontier Province, Kharif, 1992.

	Grain yield (kg/ha)					
Variety	Swat	Mansehra	Pirsabak	S.Naurang	D.I.Khan	Mean
PSH-107	9853	6133	3763	4372	6667	6158
PSH-817	9648	6667	3494	4157	5733	5940
PSH-157	9900	5433	3457	3675	6000	5693
PSH-217	9290	4567	2823	4305	6567	5510
PSH-307	8105	5067	3133	3817	6933	5411
PSH-1229	8488	4933	2843	4142	6300	5341
PSH-1512	7796	5600	4400	3938	4867	5320
PSH-2912	9138	4267	3653	4013	5033	5221
Kisan (Check-2)	7093	5400	2583	3863	4833	4754
Sarhad Y (Check-1	7103	3767	3050	3738	5200	4572
LSD (0.05):	1390	1456	N.S.	-	1329	
C.V. (%):	11.08	19.29	16.0	22.34	15.76	

Table 5. National cooperative maize yield trial (short season) in four locations. Kharif, 1989.

Variety	Grain yield (kg/ha)				
	CCRI	Swat	Mansehra	S.Naurang	Mean
PSH 817	5597	7550	5296	4036	5619
P 3747	3830	9460	5430	2121	5210
P 31827	3890	9333	5340	1923	5121
PSH 107	3393	8110	4650	4100	5063
YEV 1081	4393	7503	4140	3466	4875
YEV 1085	4667	7313	4646	2676	4825
PSEV 4085	5017	7070	3596	2580	4565
Local check	4070	6963	4193	2750	4501
Gaughar	3610	6607	3686	2756	4164
LSD (0.05):	1276	1501	1322	680	
C.V. (%)	20.48	13.2	19.9	15.9	

Questions to the author:

FROM : S. J. Patil

Q : Can you prioritize the reasons for a wide gap between the experimental yield and the national average?

A : 1) Seed production of improved cultivars is number one problem, i.e., viable seed industry must be established.

2) Agric. Extension Service should be mobilized and take the appropriate technology to the small farmers.

3) Availability of credit be made available to small farmers on easy terms, and so on.

HYBRID MAIZE BREEDING AND AGRONOMIC PRODUCTION RESEARCH AND DEVELOPMENT IN THE PHILIPPINES

E. R. Bautista and V. C. Perdido [1/]

Abstract

Maize (*Zea mays* L.) is one of the important cereal crops in the Philippines whose origin traces back to its introduction from Mexico during the 16th Century. Through the years, it was traditionally grown by the farmers who adopted and adapted it, becoming the staple food of about 25% of the present population. It is also a major ingredient of animal feeds in the expanding livestock industry. Only a small amount of grain is used as seed and raw material for industrial purposes.

In 1992, about 3.323 m ha were planted to maize with a total production of 4.56 m ton of grain with a national average yield of 1.37 t/ha. Significant increase in productivity over the last decade was attributed to the availability and use of appropriate production technologies like high yielding maize seeds of improved open-pollinated varieties (OPVs) and hybrids, and the increased fertilizer usage as a result of government's subsidized input program.

Hybrid maize research is a recent innovation in the Philippine agriculture. Early attempts on hybrid development started at the Univ. of Philippines College of Agriculture (UPCA) at Los Banos in 1949. Thirty years later, this kind of research was resumed and developed into a strong component of maize R & D in both public breeding institutions and in private seed companies. Since 1977 about 40 hybrids have been released for commercial production. Most of them are three-way crosses developed by private seed companies. The highest yield of hybrids obtained by outstanding farmers reached 7.3 to 13 t/ha. With the availability of high production technologies and the support of the government for agricultural development, maize production targets for self sufficiency will hopefully be reached in the next five years.

I. Introduction

Present-day corn or maize in the Philippines originated as an introduction from Mexico through the famous Galleon Trade operated by the Spanish merchants in the 16th Century. Since then, the crop called "mais" by the Filipinos, spread and was traditionally grown all over the country until it became one of the major commodities with a distinct research and development (R & D) mandate in the present national research network system in agriculture. This paper presents an overview of hybrid maize breeding and agronomic production R & D in the Philippines.

Importance of maize

Through the years, maize has always been second to rice in grain utilization and in land usage. It is the staple food of almost 25% of the population, but the number may even reach up to 70% in major maize growing areas. It is the major feed ingredient contributing 20-50% of hog rations and 50-75% of the rations for poultry feed. A meager volume is used as seed and supplies the raw materials to sustain industries in the manufacture of maize byproducts.

Maize production trends

The area planted to maize varies with every cropping year as presented in **Table 1** and **Figs. 1, 2 and 3.** Distribution of corn areas in the country is shown in **Table 2.** Also in the last ten years the national average yield per hectare has increased from 1.0 to 1.37 t/ha. In a span of ten years, the area planted to maize slightly declined from 3.383 m ha in 1982 to 3.323 m ha in 1992. Partly, such growth in yield was attributed to the use of recommended production

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[1/] Maize Breeders, Univ. of Southern Mindanao and Dept. of Agriculture, respectively.

technologies like the improved open-pollinated varieties (OPVs) and hybrids, and the application of fertilizer as a result of the government's subsidized input program. Moreover, the decline in area in 1992 stemmed from the shift of maize farmers to other cash crops such as asparagus, upland rice, banana, pineapple, sugarcane, soybean, and cassava in Mindanao and the conversion of farmlands into industrial estates in Luzon and the Visayas.

Table 1. Maize production, area, and yield in the Philippines, 1982-1992.

Year	Area (000 ha)	Production (000 t)	Yield (t/ha)
1982	3,383	3,404	1.00
1984	3,227	3,250	1.00
1986	3,595	4,091	1.14
1988	3,745	4,428	1.18
1991	3,589	4,655	1.30
1992	3,323	4,560	1.37

Source : Bureau of Agric. Statistics.

Table 2. Corn production in the Philippines. 1990-1992.

Region	1990		1991		1992	
	Area (000 ha)	Prodtn (t/ha)	Area (000 ha)	Prodtn (t/ha)	Area (000 ha)	Prodtn (t/ha)
Philippines	3819	1.27	3589	1.30	3323	1.37
Car	22	1.14	21	1.00	22	1.41
Ilocos	79	1.11	84	1.15	68	0.96
C. Valley	347	1.59	305	1.53	328	1.98
C. Luzon	13	1.31	12	1.58	12	1.42
S. Tagalog	237	0.93	230	0.92	215	0.91
Bicol	194	0.77	190	0.79	175	0.78
W. Visayas	63	0.54	70	0.59	67	0.82
C. Visayas	551	0.54	458	0.52	405	0.50
E. Visayas	231	0.95	216	1.00	150	0.96
W. Mindanao	308	0.85	275	0.89	244	0.88
N. Mindanao	315	1.36	235	1.41	319	1.64
S. Mindanao	792	1.64	752	1.66	710	1.65
C. Mindanao	666	1.90	652	1.91	608	1.90

Source: Animal Husb. and Agric. J. (Vol. 27, No. 2, 1993).

Hybrids, improved OPV's, and traditional varieties are extensively grown, each contributing an aggregate share to the overall production output. Maize hybrids which produce an average yield of 4-5 t/ha occupy about 311,000 ha or 8% of the total area. Improved OPVs giving an average yield of 2 t/ha are planted in 200,000 ha or roughly 7% of the available production area. The remaining 85% of the 3.29 m ha are planted with traditional varieties, and F2 and F3 of hybrids. However in Isabela (northern Philippines), hybrid utilization is quite high reaching more than 40% of the total maize acreage (**Table 3**). As a consequence, even with the availability of highly productive technologies, the country's average production performance has barely risen from the 1.0 t/ha level, the lowest in Asia. With these developments, maize supply is still insufficient to meet the domestic demands for food, feeds, and other industrial needs.

II. **Hybrid maize research**

Background information.

The introduction of hybrid maize into Philippine agriculture is fairly recent. Although maize varietal improvement began with the founding of UPCA in 1909, initial work on hybrid development was initiated in 1945. Emphasis was on the production and testing of crosses between local varieties; subsequently, in 1949 extraction of inbred lines began. The first double-cross hybrids were developed and released in the early 60's. Slow progress in hybrid maize development was caused by the failure to achieve maximum expression of hybrid vigor due to the use of provincial strains which were generally related to each other.

Table 3. Maize area and production in the province of Isabela (northern Philippines) 1990-1992.

Seed class	1990 Area (ha)	1990 Production (t/ha)	1991 Area (ha)	1991 Production (t/ha)	1992 Area (ha)
Hybrid Yellow	41392	4.27	73020	3.18	63040
OPV Yellow	18939	2.23	5308	2.98	6025
OPV White	1723	1.05	2876	2.19	3634
% Hybrid over OPV	66.7	-	89.9	-	86.7

Note: Areas planted to traditional varieties were not included.

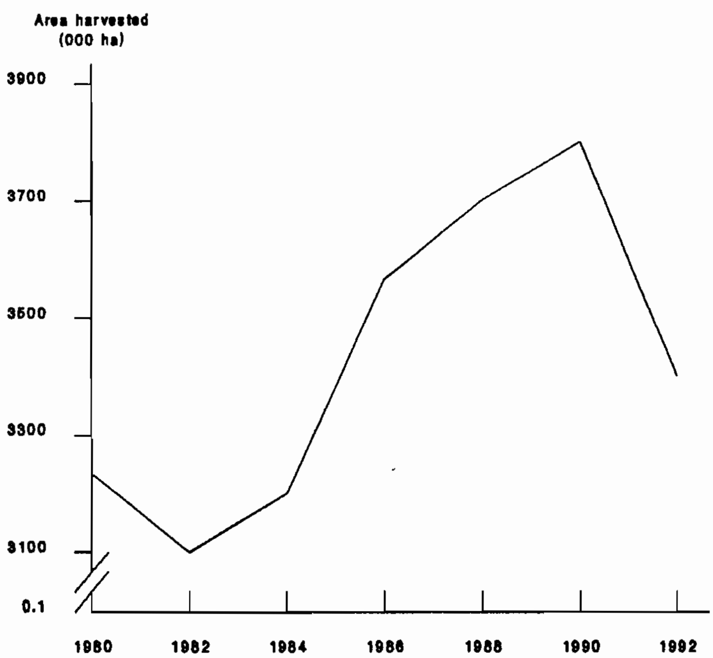

Fig. 1. Total corn area harvested in Philippines. 1980-1992.

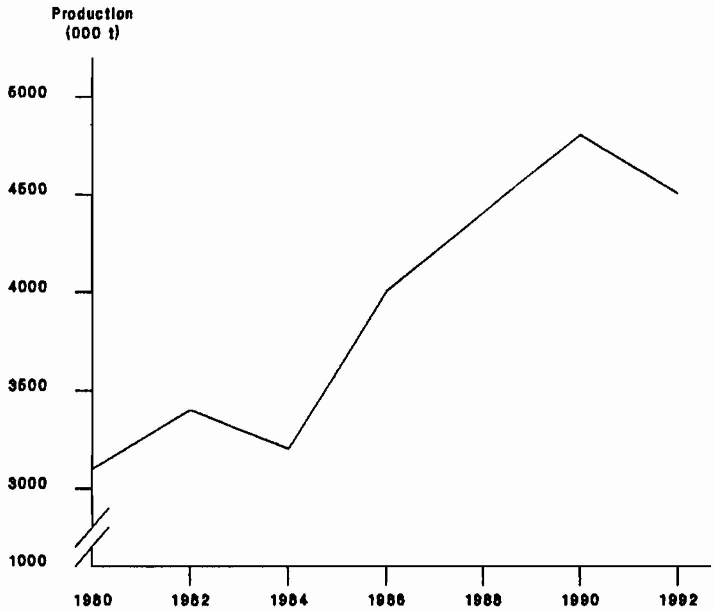

Fig. 2. Total corn production (000 t) in Philippines. 1980-1992.

Until the mid-1960s, all maize improvement work was done at UPCA. Maize R & D was reoriented towards the development of high-yielding OPVs. Several OPVs were released but were found to be susceptible to downy mildew. This prompted maize investigators at UPCA and later at the Mindanao Inst. of Technol. (MIT) to work on the development of downy mildew resistant (DMR) materials through massive hybridization of local DMR varieties, USA and European maize germplasm, and the improvement of local selections. As a result, several DMR composites were released.

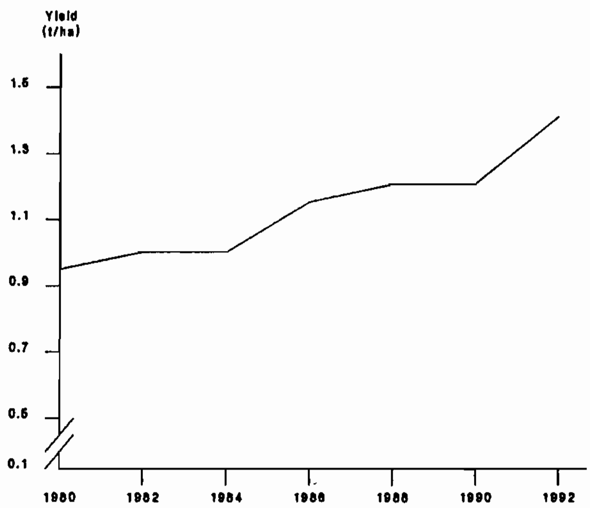

Fig. 3. Variations in the average corn yield in Philippines. 1980 to 1992.

Maize varietal improvement continued in the early 70s using the composite breeding approach. Population development and improvement were started through full-sib selection of DMR composites. Inbred line extraction and hybrid development were resumed. Research and development on hybrid seed were initiated by the private sector which resulted in the release of the first hybrid maize variety in 1977, however, the hybrid was not commercialized.

In the 1980s, maize breeding programs became more comprehensive in nature. Population development and improvement were greatly emphasized which subsequently became the source for the extraction of inbred lines in the development of future maize hybrids and synthetics. Initial attempts on varietal hybrid development were started by the breeders at the Inst. of Plant Breeding (IPB) at Los Banos on account of the high heterotic values they were getting from their maize population hybridization efforts. At the end of the decade, other public institutions/agencies participated and became actively involved in maize improvement with breeding objectives quite distinct from those at UPCA. As a result of such efforts, a number of hybrids and OPV's were released and commercialized during this period.

Beginning in 1990, the growing awareness the remarkable performance of hybrid maize and its significant potential impact on the total production had motivated leading breeding institutions of the country to consider the development of hybrids as an important component of their maize R & D programs. At IPB, for instance, undertaking hybrid maize research was considered necessary as a back-up to the private sector efforts. At present, the program has a number of good combining yellow and white lines which could be used as parents of commercial hybrids. To date, the institute has released three hybrids for commercial production.

Similar efforts are also moving forward at the Univ. of Southern Mindanao Agric. Res. Center (USMARC) using heterotic lines from CIMMYT. Development of three-way cross hybrids and synthetics is presently underway and the finished materials are expected to be in the National Cooperative Test (NCT) for Corn in 1994 for dry season evaluation.

Finally, there are five public institutions which are actively engaged in maize varietal improvement: the Inst. of Plant Breeding at Los Banos, Univ. of Mindanao (USM), Central Mindanao Univ. (CMU), Dept. of Agric. - Cagayan Valley Integrated Agric. Res. Center (DA-CVIARC) and Visayas State College of Agric. (VISCA). Only IPB, USM and DA-CVIARC conduct hybrid maize research as a component of their respective maize R & D, utilizing germplasm from CIMMYT, IITA, Univ. of Hawaii, commercial hybrids, and other local germplasm. At present, in the private sector, several hybrid seed companies conduct maize research and development, including Pioneer Overseas Co., Cargill Seeds, Inc., Asia Hybrids, ICI-JARDINE Davis, Corn World, Ciba Geigy, and DeKalb (Pfizer Genetics).

Historical events in the maize breeding activities in Philippines:

Appendix A. History of corn breeding in Philippines.

Year		Events
1914-1940	=	Early corn improvement years; activities were selections and evaluation of local materials. Most accessions were lost during the war.
1945-1951	=	Post-war rehabilitation years; corn breeding was geared towards production and testing of crosses among provincial strains by thesis students: progress was low.
1952-1954	=	Cooperative improvement years by the Bureau of Plant Industry (BPI), Bureau of Agric. Extension (BAExt), and the Univ. of the Philippines at Los Banos-College of Agric. (UPLB-CA). Plans on cooperative work on production, improvement, and distribution of hybrids were drawn up and formalized, UPCA to produce inbreds for single crosses.
1961	=	Yields of released hybrids were 30% higher than the native varieties but not well accepted by farmers (not very high yields). There were problems in seed production and distribution.

1963	= Varieties were obtained from Maize Program of Rockefeller Foundation. Imported varieties outyielded recommended hybrids by 15-20%. Collaboration among corn researchers in Asia increased with the development of the Inter Asian Corn Program; breeding programs were reoriented towards development of improved OPV's.
	= Technologies became available to increase corn production in farmers' fields; Intensified Corn Production Program was laid out.
	= Downy mildew diseases built up. Intensified breeding to develop downy mildew resistant (DMR) varieties.
1964	= Identify germplasm sources and procedures for increasing gene frequency for DMR.
1968	= Maize hybridization program between native DMR and exotic germplasm.
1971	= Philippine Government approved and funded DM research with provision of extended training and production. This was centered at CMU, and MIT (now USM).
1973	= Population improvement with multiple breeding objectives and utilization of DMR germplasm.
1980	= Private hybrid seed companies became active in hybrid maize business; from the official institutions, inbred line development and maintenance was done only at IPB-UPLB.
1988-1991	= Extensive hybrid research program started at different government breeding institutions.
1992	= Philippine Seedboard released the first hybrid from the IPB-UPLB for commercial production.
	= Several private seed companies (local and international) became interested in developing maize hybrids in the Philippines.

Breeding strategy and objectives

Hybrid maize R & D is pursued simultaneously with the development of synthetics through standard inbreeding and combining ability evaluation techniques. A strong population improvement program which supports the development of OPVs is also a source for inbred line development. At USM, both yellow and white high combining lines are being received from CIMMYT. Before these materials are entered into the diallel hybridization process, they are first evaluated for adaptability in small plots and likewise, for purposes of seed increase. In the work on synthetics, agronomically desirable S2s from DMR populations are crossed in all possible combinations limiting the number of families to groups of 6, 8 or 10. The syn 0 or F1 generation is subjected to random mating in isolation to produce the Syn 2 variety. Subsequent selections made from this material allows for the maintenance and the improvement of the variety. Whenever possible, inbreeding is carried up to S3 after which the line is maintained through mass sibbing.

The major objectives of hybrid maize research are relatively similar to those formulated in the development of OPVs. Currently, the breeding objectives in the government sector are geared towards the following:

1. Development of single crosses and modified single cross hybrids.
2. Development of inbreds from temperate and tropical crosses.
3. Development of inbreds and hybrids resistant/tolerant to biotic and abiotic stresses with emphasis on downy mildew, stalk rot, drought, and acid soils.
4. Development of early maturing hybrids with flinty kernels.
5. Use of molecular markers such as RFLP's and RAPD's for inbred conversion and line identification.
6. Exploration of other germplasm sources especially those from international institutions developing inbred lines for national programs such as CIMMYT and others.

Development of S1 and S2 lines from DMR maize populations

In collaboration with CIMMYT-Asian Regional Maize Program (ARMP) based in Thailand, USM has been conducting extensive screening for maize resistance to the Philippine downy mildew, *Peronosclerospora philippinensis* Weston. S1 and S2 families derived from four DMR pools consisting of tropical early and late white/yellow materials are being screened separately under Thailand and Philippine conditions. According to the data available, Philippine screened materials show remarkably higher natural DM resistance than the same materials screened in Thailand. Percent DM infection at USM ranges from 0 to 100. Those families which show a high level of DMR with superior agronomic attributes are being used in the formation of synthetics and OPVs and/or bulked as progenitors for the development of experimental varieties. The following USM developed and released OPVs are originally CIMMYT-ARMP germplasm based. USM Var 1 (Pop.78-DMR), USM Var 2 (Sta. Rosa 8073), USM Var 3 (Pop. 28-DMR), USM Var 4 (Pop. 75-DMR) and USM Var 10 (Pop. 72). In the same way, the released materials from DA-DVIARC are derived from CIMMYT populations. These varieties are categorized as "semi-synthetics" since they were developed from balanced-bulks of seeds from ears harvested from agronomically superior plants within selected families.

With regards to the maximum potential of hybrids, results of maximum yield research studies on maize conducted by Pamplona *et al.* (1988) at USMARC, showed that hybrids differed significantly in their response to varying rates of fertilizer, population densities, and irrigation. Using P3228 and YCH 55, the lowest yield of 10.36 t/ha was obtained in plants fertilized with 150-60-60 kg NPK. Yield was further increased to 10.79 and 10.67 t/ha when fertilizer was increased to 250-150-150 and 500-300-300 kg NPK/ha, respectively. Likewise, increasing population density from 70,000 to 90,000 plants/ha increased yield from 8.46% to 11.30 t/ha. Irrigated plants produced 10.88 t/ha, which was 0.55 t/ha higher than non-irrigated plants. No significant interaction effects were observed in any of the different treatment combinations involving the four variables.

In a related development, outstanding farmers using hybrids attained yield records ranging from 7.3 to 13.00 t/ha under actual farm circumstances, similar to those obtained at experiment stations.

Variety testing and release

Under Philippine regulations, a maize cultivar is released for commercial grain production if it has passed a series of agronomic performance tests. The last of these is the multilocation National Cooperative Test (NCT) conducted for at least two seasons in 12 experiment stations strategically located throughout the country. On the basis of the results, the Corn and Sorghum Technical Working Group (CSTWG) recommends the outstanding varieties to the Philippine Seed Board for approval. On-farm data, if available, are considered to complement data from the experiment stations.

Between 1982 and 1992, about 30 hybrid maize cultivars were released for commercial production against 12 OPVs approved. A majority of the released hybrids had yellow-flint endosperm. Half of the OPVs were either yellow or white with flinty endosperm. Some OPVs showed comparable yields with the hybrids and their maturity was within the desired range. The most recent maize varieties/hybrids released from 1990 to 1992 are presented in **Table 4.**

Management and handling of developed materials

Most hybrid seed companies operating in the Philippines have their own marketing branch so that they can directly sell their products. The Philippine Government acknowledges the active participation of the private sector not only in the development of high yielding hybrids but also in the promotion and adoption of their hybrids, through their extension efforts and demonstration trials.

In the government sector, where lack of capabilities hinders the promotion and widescale production and distribution of seeds, coupled with inefficient processing facilities to handle large volumes of seed, developed hybrids and inbreds would become a public variety since everybody has access to the parental materials at a cost and with due acknowledgement of the breeding institution. Likewise, for seed producers, especially the established and capable agricultural cooperatives who wish to venture into hybrid seed production, they could have access to the parental seed at the breeding institution on a per hectare basis.

Table 4. Maize hybrids/varieties released by the Philippine Seed Board. 1992-1993.

PSB Var	Grain yield (t/ha)	Maturity (days) Wet	Maturity (days) Dry	Breeder
Hybrid:				
XCW 11	5.59	90	101	Corn World
XCW 15	5.75	91	101	"
XCW 16	5.94	100	99	"
XCW 18	6.78	97	99	"
CPX 22	6.28	92	97	Cargill Seeds, Inc.
CPX 3122	6.58	88	93	"
AH 190	6.33	95	98	Asian Hybrid, Phil. Inc.
MX 8190	6.33	98	98	"
MX 8336	7.54	91	99	"
Y 1352 G	6.65	97	98	Pioneer Overseas Co.
P 3246	6.75	92	98	"
IPB 919	6.15	95	101	IPB-UPLB
IPB 921	6.80	95	101	"
IPB 329	6.66	92	101	"
CTH 501	6.63	92	97	Cargill Seeds, Inc.
OPVs:				
IES 8906	5.75	92	95	DA-DVIARC
USM Var 5	6.37	93	98	USMARC
USM Var 10	6.21	92	96	USMARC

Source: National Cooperative Testing Program on Corn, 1993. Mean of 2 seasons from 13 testing sites in the country.

Status and prospect of the maize hybrid program in Philippines

Yield levels of existing hybrids obtained from experiment stations, demonstration farms, and land of advanced farmers could reach more than 6.0 t/ha under high level inputs. This shows the potential of hybrid corn in the prime lands of the country.

As for breeding programs, the country has a number of maize breeders, sufficient germplasm, and resources to carry out the program. There are also several private seed companies working on the development of hybrid maize appropriate for the various environments.

Problems and constraints

The most important constraints in maize technology are identified to be deeply rooted inthe production and the marketing phases. At the production level, the main problems are related to the type of maize planted by the farmer as well as site-specific problems. The four major problems stressed by corn growers as a group are as follows: 1) low price during the peak harvest period, 2) lack of post-harvest facilities, 3) limited financing available for production. 4) drought.

Beyond those problems, the hybrid maize growers ranked as important the high costs of hybrid seeds, fertilizer, and pesticide, and low yields under drought conditions. Growers of non-hybrids only added the problem of strong winds causing lodging during windy periods.

A summary of the problems, under what conditions they occur, and the implications is given below to help clarify the farm level situation. For the hybrid companies, the following problems are emphasized:

1. The small size of the hybrid seed market compared to the output capabilities of these companies.
2. The increasingly high costs of research, seed multiplication, and distribution in such a small seed market.
3. Inconsistent government policies affecting the maize sector such as irregular imports of grain maize.

The effects of the above problems lead to the high cost of maize production in the Philippines. Based on recent costs of inputs and market price, the cost of producing a kilo of maize is P 2.08, 2.8 and 3.46 when using hybrids, OPV's, and traditional varieties, respectively. (1 US = 28 Pesos). This situation encourages importation of maize from countries like Thailand with a relatively lower cost of production.

III. Agronomic production research on maize

Over the last twelve years, the National Agric. Resources Res. and Developt. Network (NARRDN) has generated and accumulated significant information regarding technologies related to maize production. The most recent technologies generated from 1990 up to the present are:

A. Development of high-yielding maize varieties.

As mentioned earlier, a number of high-yielding hybrids and OPVs have been recently released for commercial production in the country. The hybrids are all three way crosses with yellow endosperm, while the OPVs are either white or yellow with yield performances comparable to the hybrids.

Problem	**Situation**	**Implications**
Low farm price of maize	Mainly in peak harvest months (July-Aug.)	Difficult to cover cash costs and earn adequate income if cultivating only maize.
Inadequate drying facilities	1-2 months of peak harvest during the rainy season (Aug.-Nov.)	"Wet" maize had lower recovery rate during mechanical shelling, spoils when stored, has high aflatoxin level, and leads to mixing with good quality seeds to avoid loss.
Unexprected dry spells	During planting period	Delays planting and extends harvest into low price period and/or unfavorable weather which means reduced yields.
	During growth period	Severely reduces yields of non-drought resistant hybrids. Costs of land preparation and inputs cannot be recovered.
High costs of seed	Only for hybrids (P 920 - P 1200/bag)	Limits number of growers and increases exposure to cash losses. Encourages dependence on traders for financial support.
Limited financing for production	Poorer farmer trying to grow hybrid varieties and/or farmer alienated by local traders.	Lower yield than expected from hybrid varieties. Increases exposure of farmers to serious debt problems (cannot share risks if crop fails).

Heavy incidence of diseases and insects	Mainly for hybrid	Increases cash costs for pest control. Reinforces need to cultivate in appropriate season and least risky locations.

B. **Pest Management.**

Among the strategies designed to control maize borer (*Ostrinia furnacalis* Guenee) damage, resistant cultivars are still the technology most economical and easily adopted by maize growers. Researchers from IPB led by Legacion and Salazar (1990) have supplied significant information on the development of maize varieties or hybrids with resistance to the maize borer:

1. Many corn cultivars found to be resistant to pretasseling maize borer attack were susceptible to post-tasseling attack.
2. Antigua Group 1 is a reliable source of resistance to pretasseling maize borer attack.
3. Heavy fertilization favors corn borer damage.
4. Maize borer infestation is worse during the wet season, especially when planted late.
5. Insecticide treated plots have greater borer damage than untreated plots. This may be due to the killing of biological enemies of maize.
6. DIMBOA, a biochemical substance found in young maize seedlings, is positively corre lated with pretasseling maize borer damage.
7. Plants with erect leaves tend to show less borer damage.
8. Yield loss due to maize borer could run up to 95%.

For the control of storage pests of maize, chloropyrifosmethyl and deltamethrin are found to be effective and safe. Pesticide residue in maize stored for nine months in sacks sprayed with a solution of 14 cc chloropyrifos and formulated products remained unchanged for 30 days but increased in the second and third months. This indicates pesticide absorption from the sacks. The residue in corn grains increased while the residue in the sack decreased. Washing caused 78-100% reduction of residue in treated maize stored for six months, although detectable amounts were noted at the third washing. This study concludes that washing reduces chemical residues. Cooking can do the same for some chemicals but not all. It may even enhance the toxicity of some residues.

Several technologies of controlling maize borer through the integrated pest management (IPM) approach had also been generated earlier in the Philippines. These include the detasseling technique, the use of microbial insecticide, and biological control with *Trichogramma* species. Recently, its was found that the establishment of *T. evanescens* (Westw.) in maize growing areas was possible and could effectively minimize the damage of Asian maize borer. The technology developed by the Department of Agriculture - Regional Crop Protection Center (DA-RCPC) includes three-time releases of 50 cards containing *T. evanescens* Westw. in a hectare at a distance of 14 m x 14 m between cards. Close monitoring of maize borer infestation and *T. evanescens* parasitization throughout the cropping season is recommended. When releases were done, 30-80% parasitization of maize borer egg masses were observed. The parasitoids were able to establish in three different maize areas thus controling the pest population to an acceptable level.

Some technological options designed to control maize borer and other insect of maize are in **Table 5.**

A strategy on pest management for maize production for specific maize growing areas like Bukidnon was developed by Josue and co-workers at CMU. The technology includes the following:

1. Land preparation. Disc-plow the land, then disc-harrow twice. Another alternative is to disc-harrow twice as the only form of land preparation.
2. Varietal selection. Select an OPV with known resistance to downy mildew and other major diseases.
3. If the variety is susceptible to downy mildew, control of the disease can be obtained by using Apron 35 SD (= Ridomil) as a seed treatment. Mix 6 g of fungicide with 10 ml water to form a slurry. Mix this with 1 kg seeds in a suitable container.
4. Seed treatment for the control of soil-borne insects. Treat seeds with Malathion

Premium Grade (emulsifiable concentrate) at the rate of 10 ml/liter of water, applied as spray on seeds. Dry the seeds immediately if these are to be stored before using.

5. Control of major weed species (*R. exaltata, I. triloba* etc.). Follow recommended land preparation. At 12-15 days after emergence, do off-barring. Hill up at 25-30 DAE and do interrow hand weeding.
6. Fertilizer rates. Apply 90-60-0 kg NPK/ha or six bags of 16-20-0 at planting time. Sidedress two bags of 45-0-0 after weeding during the wet season. However, during dry season, apply the recommended amount of fertilizer basally and only once.

Table 5. Cost of some technological options in effectively controlling maize borer and other insects pest of maize.

Technology	Cost (Pesos)
A. Traditional recommendation	1,450
a. Application of carbufuran at 30 DAP	
b. Insecticide spraying at 40 DAP	
c. Insecticide spraying at 55 DAP	
B. USM technology 1	850
a. Application of *Trichogramma* twice at 30 and 40 DAP	
b. Detasseling (75%) at 45 to 48 DAP	
C. USM technology 2	925
a. Application of *Trichogramma* once at 30 DAP	
b. Detasseling (75%) at 45 to 48 DAP	
c. Insecticide spraying at 55 DAP	

Source: CEMARRDEC Techno Fora 1992.

C. **Fertilizer management.**

Soils belonging to the Adtuyon Series have low pH and are considered unproductive for maize production. Most Bukidnon soils belong to this series but they become productive by adding lime and fertilizer to increase soil pH. Yield was increased in two experimental areas in Bukidnon. The procedure for technology application includes:

1. Soil characterization. The soil should belong to the Adtuyon clay or Adtuyon clay stony phase series.
2. Soil analysis. Collect soil samples before each planting season for analysis of pH, organic matter, extractable P, exchangeable Ca, Mg, and K contents.
3. Lime application. Apply 3 t/ha lime only during the first crop.
4. Land preparation. Follow conventional methods.
5. Corn variety. Use IPB Var 2 (OPV).
6. Fertilizer application. Apply 60-30-0 kg NPK/ha, half of N and all P at planting. Sidedress remaining N 25-30 days later.
7. Weed and insect control. Hand weed and hill up at 15 and 35 days after planting, respectively. Control insects by spraying insecticides whenever necessary.
8. Harvesting. Harvest at crop maturity.

The technology provides a mean yield of 4.46 t/ha and 4.40 t/ha during the wet (first cropping) and dry (second cropping), respectively. The first cropping gave a 1.64 return on investment (ROI) due to the cost of lime. The highest profit (3.69 ROI) was obtained the next season. Furthermore, soil pH values, organic matter content, and extractable P contents increase through time.

D. **Agricultural engineering.**

In support for the activities in maize production, an improved mobile corn sheller was developed by the National Post-Harvest Institute for Res. and Extension (NAPHIRE). Its efficiency is found to be comparable with the existing high capacity shellers in the country giving a ROI of 53.4% with a payback period of 1.8 years.

At USMARC, Sarmiento also developed a versatile low-cost planter with fertilizer applicator combined. The equipment, which can simultaneously make a furrow, plant seed, and cover seeds and fertilizer comes in single-row and double-row models. Specifications of the equipment are presented in **Table 6**.

Table 6. Specifications of versatile low-cost planters with fertilizer applicator combined.

Specifications	Single row	Double row
a. Weight (with seeds and fertilizer)	50 kg	80 kg
b. Total length	1.80 m	1.50 m
c. Seed placement depth	5 cm	5 cm
d. No. of seeds per hill	1-2 seeds	1.2 seeds
e. Distance between hills	25-30 cm	25-30 cm
f. No. of hrs. to finish 1 ha using 1 animal-man power	6-8 hrs	4-5 hrs
g. Seed delivery	16-20 kg/ha	16-20 kg/ha
h. Fertilizer delivery	2-3 bags/ha	2 bags/ha
i. Cost/unit	P4,500	P6,000

E. **Economics of producing OPVs and hybrids.**

The profitability of producing maize can be gauged from simple costs and return analysis. At USM, a comparative production costs and return analysis on a per hectare basis was done for a commercial hybrid maize, OPVs, and the best farmer's selection. Gross returns of the four varieties used ranged from P22,360/ha with a total cost of P9,395 to P11,218/ha, and net returns of P1,355 to P11,142/ha. The hybrid maize, P 3228, with P11,142 net return per hectare, was the highest. It was followed closely by USM Var 5 with P10,816. The lowest was the farmer's selection with P1,355.

However, ROI analysis showed USM Var 5 with 101% ROI as highest. The hybrid maize with the highest net returns was second with 99% ROI. IPB Var 1 and the best farmer's selection were lowest with 31% and 14% ROI, respectively.

Government support to the maize industry.

In spite of the significant strides the country has attained in maize production technology over the past years, currently, the volume of grain supply can hardly meet the increasing domestic demands for maize products. With the country's aim to be self-sufficient in 1998, an agricultural plan was conceived on May 1993 to boost productivity in key production areas where the major crops of the country are primarily raised on the basis of suitability as per land use and availability ofmarkets. Under this approach, the Dept. of Agric. has identified about 270,000 ha for maize to be covered by the Grains Production Enhancement Program. Moreover, the key maize grain areas located in 17 provinces will be increased to 700,000 ha in 1998 while cropping intensity will be maintained. Yields are programed to increase from an average of 3.5 t/ha per crop in 1993 to 5 t in 1998. To support the program, the following components are included: 1) certified seed subsidy, 2) efficient fertilizer use, 3) irrigation support, 4) production technology development and dissemination, 5) credit, 6) post-harvest facilities and technology support, 7) transport infrastructure support, and 8) marketing support. The versatile planter/fertilizer applicator in described in **Table 6.** To elicit the appropriate and required levels of awareness and acceptance of the program, a public information campaign is also included.

V. Conclusion

Hybrid maize research is becoming an important component of maize R & D in the Philippines. Commercial hybrids developed by private seed companies and public breeding institutions continue to show higher performance compared with their OPV counterparts. The performance of synthetics has yet to be evaluated in the on-going National Cooperative Test for Maize throughout the country. With comparable yields obtained from OPVs and hybrids, private seed companies will be exerting more aggressive effort in the development of superior hybrids.

On the other hand, the availability of several technologies in maize production assures maize growers of affordable technological options for productive farming. The aggressive and generous support coming from the government, international research centers like CIMMYT, and the collaboration among maize investigators in Asia would finally make the industry prosper as it has long been hopefully expected.

References

AAPP-DA and USAID. 1988. The corn marketing system: A rapid marketing appraisal in Southern Mindanao region. Bureau of Agric. Stat. 1992. Manila.

CMARRDEC Techno Fora 92. Summary proceedings of the first technology fora R and D Highlights. USM, Kabacan, Cotabato.

DA-CVIARC. 1992. Annual report for 1992. Unpublished.

Dept. of Agric. 1993. Isabela Province Provincial Profile.

Dept. of Agric. 1993. The medium-term agricultural development plan: Key production areas, targets, and programs.

FAO. 1993. Yearbook in Agriculture.

Logronio, M. and A.M. Salazar. 1993. A personal interview: Hybrid maize program at the Inst. of Plant Breeding, UPLB, College, Laguna.

PCARRD-DOST. 1988, 1990, 1991. R & D Highlights.

Philippine Seed Board. 1993. List of released corn hybrids and varieties for 1993.

Sarmiento, R.O. 1992. Versatile low-cost maize planter with Kabacan, Cotabato. Unpublished. USMARC, Kabacan, Cotabato.

Urbanes, P. 1993. Corn production drops 2% in 1993. Animal Husbandry and Agric. J. 27 (2).

Questions to the author:

FROM : Firdaus Kasim

Q : How does the seed production system (hybrid) work in the Philippines?

A : Hybrids produced by private seed companies are produced (within the country) and marketed under their management although seed certification standards must be analyzed by the government through the seed quality center laboratory of the Dept. of Agric.

AGRONOMIC PRODUCTION RESEARCH ON MAIZE IN SRI LANKA

A. Malima Perera [1/]

Abstract

Maize (*Zea mays* L.) is the second most important cereal crop in Sri Lanka. Its distribution in the country is mainly confined to the Dry Zone where annual rainfall is less than 1200 mm/yr. The rainfall distribution in the country shows a bimodal pattern with two growing seasons: a relatively wet season "Maha", from October to February and a comparatively dry season "Yala", from March to September.

About 85% of maize is grown under rainfed conditions and the largest amount is cultivated on a mixed cropping system by small-scale farmers. Traditional cultivars perform poorly when intensively cultivated under stabilized systems of highland farming. This paper traces the research conducted at the Regional Agric. Res. Center, Maha Illuppallama, Sri Lanka, to identify improved varieties which could be grown under intensive management including optimum plant densities, fertilizer use, and other improved cultural practices.

Results indicate that composite cultivars show the most promise when raised at a population of 50,000-60,000 plants/ha and at a fertilization level of 67-45-20 kg NPK per ha during the Maha season. In an attempt to increase the productivity of maize cultivation, a few intercropping methods have also been developed.

Introduction

Maize is the second most important cereal crop in Sri Lanka. Its distribution in the country is mainly confined to the Dry Zone (Fig. 1).

The rainfall distribution in the country shows a bimodal pattern with two main growing seasons: A relatively wet season (Maha) from October to February and a comparatively dry season (Yala) from March to September. The main climatic features of these two seasons are shown in Table 1.

Approximately 85% of maize is grown under rainfed conditions (Maha season). Two cropping systems are prevalent in maize cultivation, mixed cropping and monocrop.

Mixed cropping of maize is the most popular system in the country. During the dry spell prior to "maha" rains, farmers clear their lands and burn the stubble. Individual land holdings seldom exceed 1 ha. At the onset of the monsoon rains, maize is mix planted with one or two other crops, usually grain legumes, finger millet (*Eleusine coracana*), mustard (*Brassica nigra*) and vegetables. This system is responsible for about 85% of the total national production. The rest comes from monoculture systems both in private and government farms.

During the last eleven years the average yield in experiments at RARC (Maha Illuppallama) is 3380 kg/ha. The yields obtained by farmers are much lower than the yields recorded at the research center, ranging from 1100 to 1400 kg/ha.

The main reasons for the low yields are low plant densities and the limited use of high yielding varieties and fertilizer. Low profitability of maize, high risks associated with rainfed farming, and cost of farm resources such as labor are some of the causes for low adoption of improved management practices by maize growers. As already stated, 90% of the farmers use traditional varieties of maize which are tall, leafy, and late maturing. These local varieties generally attain a height of 280-290 cm, with 18-20 leaves per plant, and mature in 130-135 days. Late maturing varieties are adversely affected when rainfall season ends earlier than usual. But the fact that these varieties have persisted over the years suggests that rainfall

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Table 1. Climatic conditions in the two cropping seasons in Sri Lanka.

Season	Rainfall (mm)	Temp. C °		Photoperiod
		Maximum	Minimum	
Maha	900	29.8	21.5	12 hr 10 min
Yala	600	32.8	23.9	12 hr 50 min

usual. But the fact that these varieties have persisted over the years suggests that rainfall during the maha season has been generally sufficient to mature a crop of that duration when planted at a low density. Moreover, these tall, leafy varieties could probably tolerate weeds better than the short and early maturing types, which is an advantage in subsistence farming systems. However, they are not suitable for growing under improved management practices.

Area and production

Maize is cultivated in 18 districts entirely under rainfed conditions. Anuradhapura, Badulla, Ampara, and Moneragala districts are the main maize producing areas during the maha season. These areas are the so called "maize belt" of Sri Lanka (**Fig. 2**). Apart from these districts, Hambantota, Polonnaruwa, Batticaloa, and Matale districts contribute a smaller percentage to maize production. Among the leading producers, Badulla district has been the most stable. The higher elevation districts of Kandy and Nuwaraeliya contribute to the total production only during the yala season.

Seventy-six percent of the national maize acreage and 78% of the current national maize production are located in six districts of the maize belt.

Utilization and future market potential of maize

Human consumption.

Demand of maize for direct human consumption is low. The largest single market is for the 'Thriposha' program, which currently requires about 7,300 t of maize per year. Thriposha is a food supplement provided by the Ministry of Health to lactating mothers. A portion of the maize crop is also consumed as green cobs. This is an important food for the rural poor in a few locations, while it is a novelty food with wealthy citizens in urban areas. The demand for green cobs has increased in recent times and farmers get a higher income.

Research on consumer preferences for maize flour-based food show that maize flour can be mixed with rice flour at the ratio of 3:1 (DOA, 1989). If emphasis is placed on popularizing maize flour-based foods, demand for maize could be increased.

Animal feed industry.

The largest demand for maize is created by the animal feed industry. Demand for maize as a raw material in animal feeds is derived primarily from the demand for poultry feeds. Until recently, no serious attention was given to monitor the maize market facilities and as a result the product gets a very low price. At present, the government has fixed a floor price for maize at Rs. 7.00/kg (1 US$ = Rs. 48.90). Yet, the bulk of maize is purchased by middle man at the site at a lower price because farmers find it difficult to reach the government purchasing centers due to poor transportation facilities.

With the increase in population and a change in food habits, the demand for maize has increased rapidly over the years due to expansion in the national poultry and livestock industries. The annual projected maize requirement for layer mash, broiler mash, and direct human consumption are shown in **Fig. 3**. However, the production in the country is seasonal and a large quantity of maize is imported by the private sector for the feed industry. This is one of the reasons why the demand and price of maize are low.

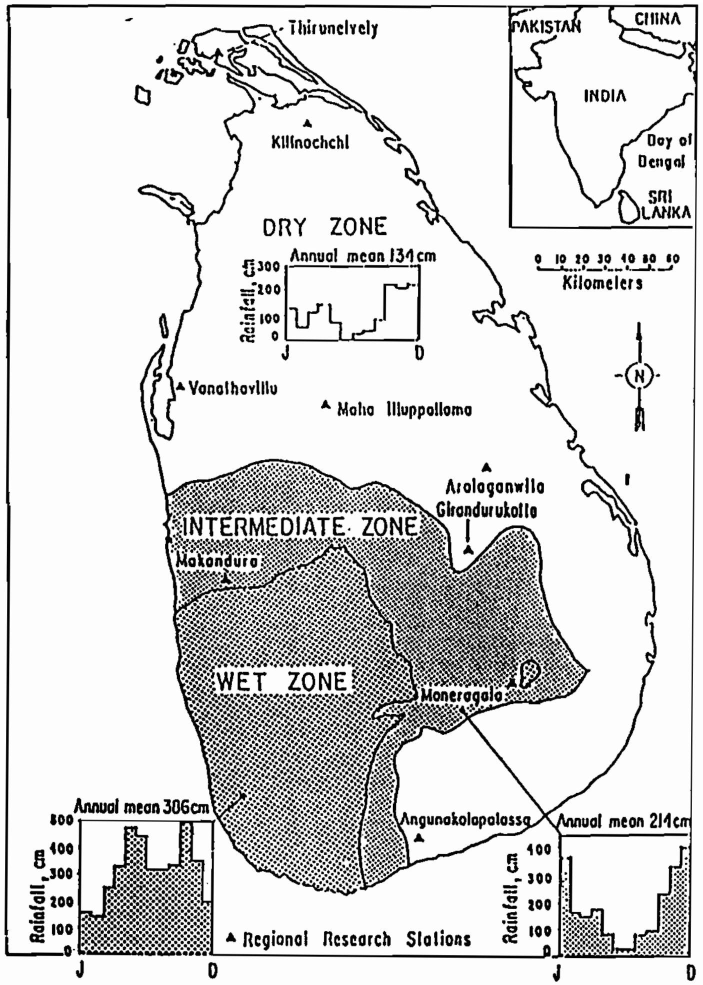

Fig. 1. Climatic zones of Sri Lanka.

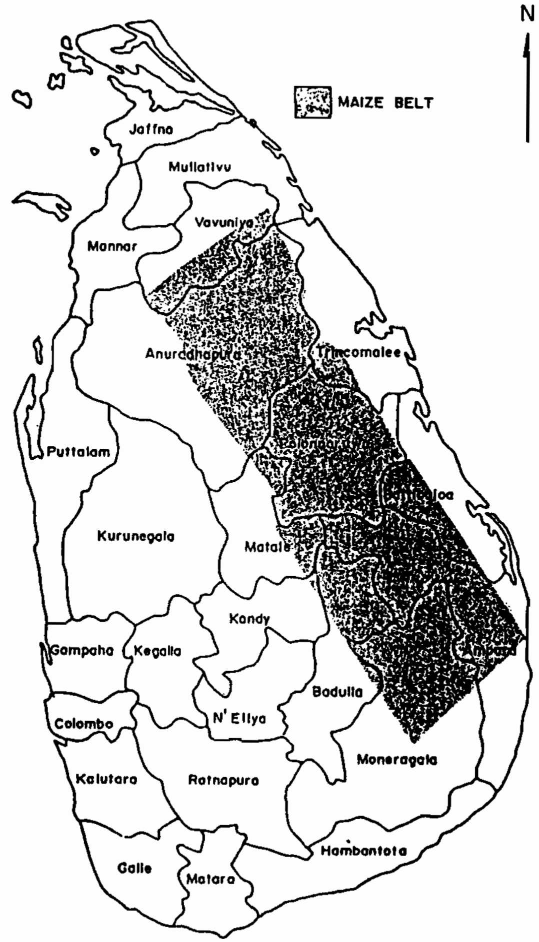

Fig. 2. Location of the "Maize Belt" of Sri Lanka.
Source: (After Ranaweera and Hafi).

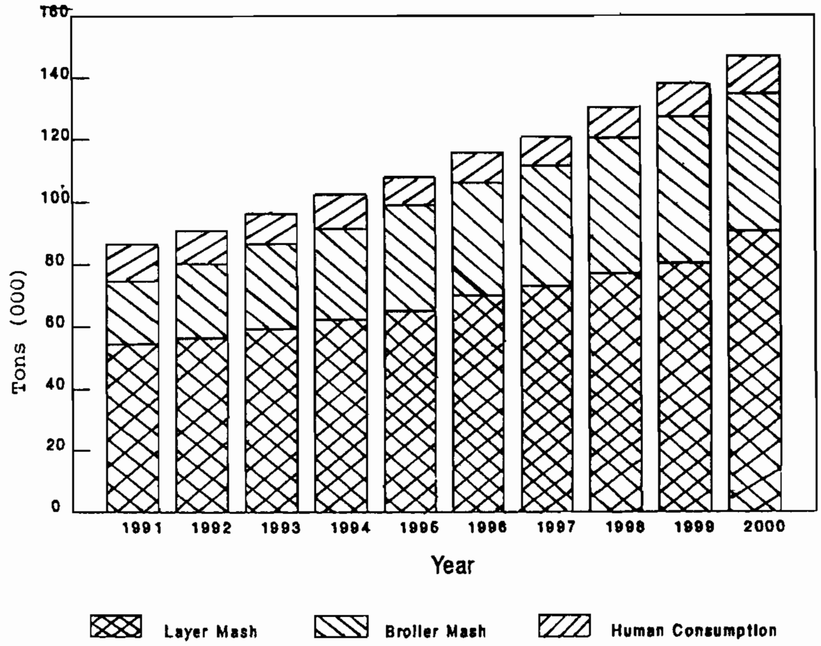

Fig. 3. Projected maize requirement.

Research and development activities on maize.

The need for improvement of maize cultivation in Sri Lanka was realized in the early 1950's and the Regional Agric. Res. Center, Maha Illuppallama was entrusted with the task of carrying out research pertaining to the breeding and development of agronomic practices for this crop. Four other Regional Research Centers namely Girandurukotte, Angunakolapellessa, Aralaganwila, and Monaragala also assist to carry out research programs.

The objective of the maize improvement program is to develop cultivars that are high yielding, with wider adaptation, shorter plant height, greater resistance to insects and diseases, and that fit into the rainfall pattern of the main maize growing regions.

Based on the research, the following recommendations have been made and were included as part of the improved package of practices for the farmers.

Varietal improvement.

Progress on the varietal improvement work up to 1958 was reported by Sithamparanathan (1958). In 1960, the open pollinated variety T-48 was released for cultivation. However, this variety did not become popular with the farmers. Since 1967 close links were established with the Inter-Asian Corn Improvement Program, Thailand and the International Maize and Wheat Improvement Center (CIMMYT). As a result, there was a regular flow of improved germplasm from these institutions into the local program.

Thai Comp. 1, a composite of 36 varieties mostly from Latin America and Cupurico x Flint Compuesto, an advanced generation varietal cross, was subjected to mass selection under local conditions for improvement of yield, adaptability, and other desirable characteristics. In 1977, an improved version of Thai Composite was released under the name Bhadra-1.

Composite 6 was selected from a population developed by combining selected progenies of the Thai Composite, Cupurico x Flint Compuesto, and **Poza Rica 7425**. This variety was released in 1990 under the name Ruwan.

The white seeded variety Across 7929 and the yellow Poza Rica 7931 were identified as promising late and early maturing varieties respectively, and have been given the Sri Lankan names of Muthu and Aruna, respectively. Characteristics of the maize varieties developed at Sri Lanka are described in **Table** 2.

Fertilizer studies.

Several fertilizer experiments were conducted to determine the optimum rates. Results of these experiments are reported elsewhere (Hindagala, *et al.*, 1971; Nagarajah, *et al.*, 1972). Fertilizer rates of 67-45-28 kg NPK/ha were found to be adequate for the main maize growing under rainfed conditions.

Various experiments have shown that highest yields could be obtained when nitrogen is applied in two splits at different growth stages. Application of 1/4th of the recommended rate of nitrogen (17 kg/ha) as basal and the balance at 4-5 weeks after seeding appears to be better than other split combinations.

Weed management.

Competition from weeds such as *Cyanodon dactilon* can reduce yield by about 30-40%. To a certain extent, farmers control weeds by hand weedings, but this is not done at appropriate times. Experiments on the number of weeding required for maize in Sri Lanka indicate that more than one weeding is required for good growth and high yields. It also appears that weeding has to be done 2 weeks after planting followed by another weeding at 4 weeks after planting which can be coupled with top dressing of fertilizer.

Table 2. Characteristics of varieties.

	Ruwan	Muthu	Aruna	Bhadra-1
Grain type	Flint to semiflint	Semi-dent	Semi-flint	Flint
Grain colour	Orange	White	Orange to yellow	Orange
Plt. hgt. (cm)	185-195	167-175	130-140	180-200
Ear hgt. (cm)	95-100	80-90	50-55	100-120
Days to 50% silk	58-60	58-60	48-50	58-60
Days to maturity	110-115	110-115	90-100	110-115
Lodging	Good resistance to root and stalk	Good resistance	Good resistance	Moderately susceptible
Yield (kg/ha)	4282	5366	4401	4280

Plant density.

Plant density is an important factor affecting yield. Plant density studies have shown that with adequate fertilizer and moisture, maize grown at a density of 50,000-60,000 plants/ha will produced optimum yields. The yield response to an increase in density is dependent on the fertility level of the soil, particularly nitrogen, as deficiency of this nutrient is common in tropical soils.

An experiment was carried out at the Regional Agric. Res. Center, Maha Illuppallama, to study the effect of plant density and nitrogen levels on the yield of maize. Based on these investigations, it was concluded that with adequate moisture and fertilizer a plant density of about 50,000-60,000 plants/ha would be best during the maha season. However, in dry areas where maize is grown at low fertility levels, it would be desirable to reduce the plant density in order to prevent barren plants and poor ear development. Traditional tall leafy varieties should also be grown at lower densities of approximately 37 000 plants/ha.

Agronomic investigations during yala season.

The climatic conditions in the dry zone during the yala season are different from those of the maha season. Yala season is characterized by low rainfall, high temperatures, and strong, dry winds.

In general, maize is not grown in the dry zone during the yala season. Results of an experiment carried out to study the performance of six varieties of maize grown under irrigation during yala 1976 are shown in **Table 3**. For the purpose of comparison, the same varieties grown under rainfed conditions during the previous maha season (1975/76) are also included in the same Table. There were differences in yield, plant height, and days to silk for all varieties during the two seasons. Mean grain yield of the varieties was reduced by 20% and plant height by 30% during the yala season as compared to the maha season. The varieties silked and matured earlier during the yala season. The reasons for these growth differences may be associated with high temperature during the yala season.

The maize stem borer *Chilo partellus* Swinhoe, is the most damaging single pest of maize. Occurrence of this pest is one of the major constraints in maize production during yala. Continuous data collected by the Entomological Division of the Agric. Res. Center, Maha Illuppallama shows a minimum population of stem borer during September to November and rising to a peak during February to April.

Chemical control experiments reveal that a single application of granular carbofuran or diazinon, or two sprays of these chemicals gave satisfactory control of *C. partellus*. The application of granules into the whorl of the plant appears to be more effective and residual than spray applications. At present chemicals offer the only means of control. Unfortunately, these are very expensive. If maize is considered as a crop for the yala season it may be necessary to develop varieties more tolerant or resistant to stem-borer and adverse weather conditions.

Table 3. Variation in agronomic characters of six maize varieties grown in maha 1975/76 and yala 1976, at Maha Illuppallama.

Varieties	Days to 50% silking		Plant height (cm)		Grain yield (kg/ha)	
	Maha	Yala	Maha	Yala	Maha	Yala
Thai Comp.	63	58	223	138	3165	2549
Cupurico x Flint Comp.	63	61	240	143	3165	2813
Salvador 8 x V250C A6, A21, PD (MS)6	64	62	232	149	3213	2535
Tuxpeno P.B.	64	62	212	142	3330	2296
Thai Opaque 2 Comp.	63	56	220	148	3213	2003
T 48 (check)	63	56	232	161	3008	2003
LSD (P = 0.05)					349	658
CV (%)					8.3	17.2

Studies on water requirement and irrigation have revealed that a 115 day maize crop needs to be supplied with 615 mm of water when it grows under irrigation during the drier period of the year. Furthermore, 112 kg N/ha appears to be the best level of N for the yala season.

Intercropping studies.

Though it is possible to grow maize under irrigation during yala season, it may not be competitive in terms of returns with other crops such as chilli and other vegetables that compete for the same resources. **Table 4** provides a summary of selected yala season crops with their net returns. At today's prices, maize is at about the level of soybean and cowpea in terms of total costs and gross returns per hectare.

Intercropping is an effective means of maximizing land use by small farmers who have limited land to increase their income. Thus, considering the feasibility of such advantages gained by a maize + legume intercropping system, the intercropping methods presented here have been formulated on the basis of research trials conducted at regional research stations and observation of farmers practices.

Maize + Soybean/Soybean + Maize.

a. Season

Maha : Rainfed
Yala : Irrigated

b. Spacing

For Maize + Soybean
Maize : 120 cm x 40 cm, 1 plant/hill
Soybean : 40 cm x 5 cm, 1 plant/hill
2 rows of soybean between maize rows.

For Soybean + Maize
Soybean : 40 cm x 5 cm, 1 plant/hill
Maize : 120 cm x 100 cm, 2 plants/hill

c. Time of planting

Maha i. Maize : At the set of maha rains.
ii. Soybean : Mid October to mid November.
Yala : April, both crops at the same time.

Maize + Cowpea

a. Season

Maha : Rainfed
Yala : Irrigated

b. Spacing

Maize : 120 cm x 40 cm, 1 plant/hill
Cowpea : 40 cm x 10 cm, 1 plant/hill
2 rows of soybean between maize rows.

c. Time of planting

Maha i. Maize : At the onset of maha rains.
ii. Cowpea : End of October to mid November
Yala : April, both crops at the same time.

Blackgram + Maize

a. Season

Maha : Rainfed
Yala : Irrigated

b. Spacing

Blackgram : 40 cm x 5 cm, 1 plant/hill
Maize : 120 cm x 100 cm, 1 plant/hill

c. Time of planting

Maha i. Blackgram : End of October to mid November.
ii. Maize : At the onset of maha rains.
Yala : April, both crops at the same time.

Maize + Groundnut

a. Season

Maha : Rainfed
Yala : Irrigated

b. Spacing

Maize : 135 x 25 cm, 1 plant/hill
Groundnut : 45 x 15 cm, 1 plant/hill
2 rows of groundnut between maize rows.

c. Time of planting

Maha : Mid to end of October, both crops at the same time.
Yala : April, both crops at the same time.

Maize + Greengram

a. Season

Maha : Rainfed
Yala : Irrigated

b. Spacing

Maize : 90 x 25 cm, 1 plant/hill
Greengram : 30 x 10 cm, 1 plant/hill
2 rows between maize rows.

c. Time of planting

Maha i. Maize : with the first rain
ii. Greengram : Mid to end of November.
Yala : April, both crops together.

Pumpkins + Maize

a. Season

Maha : Rainfed
Yala : Irrigated

b. Spacing

Pumpkins : 3 x 1 m, 2 plants/hill
Maize : 3 x 50 cm, 2 plants/hill

c. Time of planting

Maha : With the first rain.
Yala : April, both crops together.

Advanced technology transferred to farmers.

Extension service, video movies, leaflets, and mass communication media have been widely used to instruct and encourage farmers to grow maize and to apply new technologies.

Major areas identified to conduct future research on maize are:

a. Develop high yielding OPV's and hybrids.
b. Breeding for short plant height, early maturing varieties (75-80 days).
c. Select varieties for adverse environmental conditions.
d. Studies on postharvest technologies.

Table 4. Per hectare costs and returns of selected subsidiary food crops.

Crop	No. observations	Labour cost Rs/ha	Total cost Rs/ha	Yield kg/ha	Gross returns Rs/ha	Net returns Rs/ha	Net returns (rank)
Chili	5	8840	11155	650	24408	13253	2
Blackgram	2	4902	4832	560	7037	2205	5
Groundnut	3	6237	8399	1088	9909	1510	6
Red onion	1	18764	42809	10631	61235	18425	1
Soybean	5	3037	4193	933	6962	2769	4
Maize	8	3757	4157	1400	4889	732	7
Greengram	2	6246	7747	787	12310	4563	3
Cowpea	5	5634	6533	694	6742	209	8

Source: Adopted from cost of cultivation of agricultural crops maha 85/86, 86/87, 89/90.

Chili - Anuradhapura, Ampara, and Moneragala districts
Blackgram - Anuradhapura district
Groundnut - Moneragala district
Red onion - Batticaloa district
Soybean - Anuradhapura and Matale district

Maize - Anuradhapura, Matale, Batticaloa, Ampara, and Moneragala districts
Greengram - Anuradhapura district
Cowpea - Anuradhapura, Ampara, and Moneragala districts.

References

Agroecological regions of Sri Lanka. Compiled by Land and Water Use Division, Dept. of Agric., Sri Lanka.

Agricultural implementation program. A working document, Ministry of Agric. Developmt. and Res.,

Sri Lanka.
Ariyanayagam, R. P. 1967. Maize production in Ceylon. 4th Interasian Corn Improvmt. Workshop. Lyallpur, West Pakistan: 8-11.
CIMMYT Review. 1974. International Maize and Wheat Improvement Center. El Batan, Mexico. 51-52.
Hindagala, C.B.A. 1980. Varietal improvement and agronomic studies of maize (*Zea mays* L.) in the dry zone. Trop. Agric. 136: 119-134.
Muthukuda Arachchi, D.H. 1989. A report submitted to the Varietal Release Committee of the Department of Agriculture Sri Lanka on the performance of the new maize variety developed at Agriculture Research Center, Maha Illuppallama.
Sithamparanathan, J. 1958. Improvement of highland crops in the dry zone, Part I - Cereals and Millets. Trop. Agric. 114: 19-28.
Subasinghe, S.M.C. and J. Amerasena. Temporal distribution and chemical control of the maize stemborer, *Chilo partellus* Swinhoe. Trop. Agric.: 123-133.
Wickramasinghe, Yapa M., P.S. Pattie. 1992. Maize: Meeting future demand in Sri Lanka. Ministry of Agric. Developmt. and Res., Sri Lanka.

HYBRID MAIZE BREEDING AND AGRONOMIC PRODUCTION RESEARCH IN TAIWAN

Ching-Tien Tseng [1]

Abstract

In the cultivation environment of Taiwan, the spring corn crop frequently receives heavy precipitation, while seasonal winds prevail for the fall crop. The high annual average air temperature and the high relative humidity favor the occurrence of diseases and insect pests. Therefore, a vital part of programs to increase corn cultivation is the breeding of high-yielding corn varieties resistant to diseases, insect pests and lodging, and tolerant of high soil moisture. The most economically important diseases and insect pests which attack corn in Taiwan are downy mildew (*Peronosclerospora sacchari*), maize dwarf mosaic virus (MDMV), stalk rot (*Pythium aphanidermatum*) and the Asian corn borer (*Ostrinia furnacalis*). The selection for pest resistant germplasm used to breed hybrid corn can be conducted in the field or greenhouse using artificial infection methods. Selection for hybrids resistant to lodging and tolerant of high soil moisture can be carried out in paddy fields by flooding the soil. The gene frequency for quantitatively inherited traits such as yield and pest resistance in a population can be properly increased by recurrent selection breeding methods. Regional yield trials have to be held for at least two years in four crop seasons before a hybrid can be released. In facing the difficult climatic conditions and labor shortage in rural areas, the cultural techniques such as ridge culture, non-tillage, two-layer fertilizer application, improved cropping systems, and the integrated control of the Asian corn borer have been introduced in grain production. These cultural techniques had effectively increased the grain yield and reduced the production cost.

Introduction

As economic development progresses and the living standards have increased in the last decades, the people in Taiwan have gradually changed their dietary habits from carbohydrate to protein-rich food. Therefore, to provide enough protein-rich food for people's consumption since the 70's large amounts of corn are required to meet the rapid development of the livestock industry. Because only 8% of the annual corn consumption is supplied domestically, more than 4 Mt of corn grain have to be imported each year. Meanwhile, the decrease in rice consumption per capita has led to an over-production of rice, generating a great pressure on the government financial budget. In order to alleviate the pressure caused by rice over-production, in 1984 the government initiated a "six-year diversification program for rice production". Under this program, corn cultivation was substituted for rice production in paddy fields and grain was purchased by the government at a guaranteed price. Since then, the corn planting acreage increased annually and in 1990 reached 60,000 ha (Agric. Yearbook, 1991). To increase the farmer's profits and maintain their interest in corn cultivation, in the last decade much progress has been made on varietal improvement, cultivation practices, and plant protection. In 1990 the total corn production reached 284,000 t. Highlights in hybrid maize breeding for varietal improvements and agronomic production research in Taiwan from the 1950's to the the 1990's are presented in this paper.

A. Hybrid maize breeding

The corn cultivars released in Taiwan before the 1960's were all open-pollinated varieties. The first hybrid corn, the double cross hybrid No. 5, was developed in 1960. It has early maturity and it is susceptible to downy mildew (*P. sacchari*). Its grain yield is about 4.5 t/ha.

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It took almost 10 years to develop the disease resistant double cross hybrid Tainan No. 11. Tainan No. 11 was the first hybrid ever bred for downy mildew resistance in Taiwan. Its grain yield is similar to that of Tainan No.5. Tainan selection No.10 was bred for slope-land areas, it is tolerant to drought and maydis leaf blight, and its grain yield is about 4.5-5.0 t/ha. The above mentioned corn hybrids are all early-maturing varieties, their profits are not as high as that of rice, so these were cultivated in a limited area. By 1994, to effectively implement the government policy of "six-year diversification program for rice production", we need corn hybrids whose profits can compare with those of rice. However, the climatic conditions in Taiwan are not ideal for corn cultivation, since the annual average air temperature and planting time varies between major corn growing areas. The planting time for the spring crop is from mid-January in the South to early April in the North. For the fall crop, the crop is planted from mid-August in the North to mid-October in the South. The early growth stage of the spring crop coincides with the rainy season, when heavy precipitation results in waterlogging which usually retards plant growth. The latter part of the growing season for the fall crop is very windy, and the prevalent seasonal wind frequently causes plants to lodge, reducing grain yield by up to 20-40%. Geographically, Taiwan is located in the tropics and subtropics, where the warm weather and high humidity all through the year favor the occurrence of several diseases and insect pests, i.e. downy mildew *P. sacchari*, Maize dwarf mosaic virus (MDMV-B), stalk rot *Pythium aphanidermatum*, rust *Puccinia sorghi* and the Asian corn borer *Ostrinia furnacalis*. In these conditions, the maize breeding program should aim at developing hybrid corn cultivars with high yielding ability, medium - late maturity, disease and insect resistance, lodging and waterlogging tolerance, as well as being suitable for mechanical harvest.

In developing a resistant hybrid corn, breeders are interested in identifying the characters of resistance and the optimum stage of plant growth for selecting resistant segregates. In this part of the paper I will discuss techniques to screen for germplasm resistant to downy mildew, MDMV, stalk rot, the Asian corn borer, and strategies to breed hybrid corn which is suited to Taiwan's conditions.

1. Screening for resistance to downy mildew (*P. sacchari*).

Outbreaks of downy mildew (*P. sacchari*) generally occur at a temperature range of 18-22C, when heavy dew occurs in the early morning. The plants are infected from emergence up to when they are one month old. After one month, the plants are free from attack by downy mildew. The disease can be controlled by seed treatment with Ridomil (Chang, 1980), but breeding for a resistant hybrid is still considered to be one of the most economic and simple means of control. In developing resistant hybrids, resistant factors should be selected first. The selection procedures for downy mildew resistant factors are described as follows (Chang and Wu, 1976):

1. Search for sugarcane seedlings infected with downy mildew. Plant these seedlings in a separate plot to establish the downy mildew nursery. Since sugarcane is also a host plant of downy mildew, the diseased sugarcane seedlings will provide a source of inoculum to facilitate the selection for resistant germplasm.
2. Plant the corn seedlings in six rows, each 50 m long and 10 m apart.
3. Plant the corn germplasm to be screened in the spaces between the rows in early April or mid October.
4. Evaluate the screening materials one month after emergence. If a resistant inbred is identified, it can be multiplied and its seed collected. If resistant plants are identified in a segregating population, they can be selfed and the ears will be planted during the next cropping season until the resistant inbred is identified.

2. Screening for resistance to maize dwarf mosaic virus (MDMV).

Although MDMV can also infect johnson grass (*Sorghum halepense* (L.) Pers), sorghum (*Sorghum bicolor* Rio), and sugarcane (*Saccharum officinarum* L.), MDMV is spread mainly by aphid vectors (Chona and Seth, 1960; Sehgal, 1965; Tosic and Ford, 1974).

The corn plants can be infected by MDMV at any growing stage, but the earlier the plant is infected, the greater is the reduction in grain yield. Tseng (1980) noted that corn plants infected at the 3rd, 5th, 7th, 9th and 11th leaf stages showed a grain yield reduction of 25, 23, 18, 10 and 5%, respectively. At present, no effective chemical is available for curing infected plants. The most effective and economic method of protecting corn crops is to breed a hybrid resistant to MDMV. However, selecting for MDMV resistant inbreds is essential in breeding resistant hybrids. The MDMV resistant inbreds can be selected by the abrasion method, as follows:

1. Leaves infected with MDMV are collected from the susceptible variety Tainan No.5, which is grown in a greenhouse as a source of inoculum.
2. The leaves are sliced into pieces. One g sliced leaves are ground with 10cc 6N Na_3 SO_3 solution and the juice is collected.
3. The juice is filtered through a piece of gauze and placed in a beaker.
4. The filtrate is neutralized to pH 7.0 by adding 6N H_2SO_4 solution.
5. Cotton balls are soaked in the filtrate, and placed in 400 mesh carborundum.
6. The plants are artificially inoculated when they are at the 5th-6th leaf stage, by rubbing the middle leaves with the cotton balls.
7. Two weeks after inoculation germplasm is rated as highly resistant (0-20% infection), resistant (21-40%), having intermediate resistance (41-60%) or susceptible (61-100%), according to the percentage of infected plants.

3. **Screening for resistance to stalk rot (*P. aphanidermatum*).**

Stalk rot (*P. aphanidermanum*) can attack corn plants at any stage of development. The disease can easily become destructive when temperature and humidity remain high, (i.e. over 27°C and 86%, respectively) for 15-20 days (Dreschler, 1934). There is significant variation in resistance to stalk rot in different germplasm. Disease resistant germplasm can be identified by artificially inoculating corn plants at the second internode above the ground level when they reach the 5th-6th leaf stage. The inoculum used for infection is cultured in media made up of 200 ml V-8 juice, 10g $CaCo_3$, 20g agar, and 800 ml distilled water. Two weeks after inoculation, germplasm is rated as highly resistant (0-20% infection), resistant (21-40%), intermediate resistant (41-50%), and susceptible (51-100%), based on the percentage of infected plants.

4. **Screening for resistance to the Asian corn borer (*O. furnacalis*).**

It is impossible to evaluate germplasm for resistance to the Asian corn borer unless an artificial diet is available for the mass production of corn borer egg masses (Awadallah, 1983; Guthrie *et al*, 1965, 1970, 1987; Tseng, 1986). Asian corn borer can be mass produced in the laboratory using an agar-based meridic diet. The ingredients used in the diet are listed in **Table 1.**

Table 1. Ingredients used in meridic diet for the Asian corn borer.

Ingredient	Quantity	Ingredient	Quantity
Water	2340.0 ml	Ascorbic acid	21.6 g
Agar	50.4 g	Methyl p-hydroxybenzoate	3.0 g
Wheat bran	98.0 g	Sorbic acid	3.0 g
Dextrose	72.0 g	Aureomycin	625.0 mg
Casein	79.2 g	Propionic acid	12.0 ml
Cholesterol	5.8 g	Formaldehyde	1.0 ml
Wesson's salt	26.0 g	Streptomycin	110.0 mg
Vitamin complex	16.6 g		

Wesson's salt (g) = NaCl: 105.00 g; KCl: 120.00 g; KH_2PO_4: 310.0 g; $Ca_3(PO_4)_2$: 149.00 g; $CaCO_3$: 210.00 g; $MgSO_4$ $7H_2$ O; 90.00 g; $FePO_4,4H_2O$: 14.7 g; $MnSO_4$: 0.20 g; K_2Al_2 $(SO_4{}^2{}_{24}H^2O$: 0.09

g; $CuSO^4$ $(5H^2\ O)$: 0.39 g; NaF: 0.57 g; KI: 0.05 g.

Vitamin complex (g) = Vitamin A: 2.70 g; Vitamin D: 0.15 g; Vitamin E: 3.00 g; Vitamin C: 27.00 g; Inositol: 3.00 g; Choline Chloride: 45.00 g; Riboflavin: 0.60 g; Menadione: 1.55 g; P-Aminobenzoic acid: 3.00 g; Niacin: 2.70 g; Pyridoxine hydrochloride: 0.60 g; Thiamine hydrochloride: 0.60 g; Calcium pantothenate: 1.80 g; Biotin: 0.012 g; Folic acid: 0.054 g; B^{12}: 0.0018 g; Dextrose: 512.45 g.

In Southern Taiwan, there are usually six to eight generations of the Asian corn borer per year, with a population increase from late March until the end of October. Resistance in hybrid corn to the Asian corn borer should therefore be sustained through all stages of plant development. Resistance at the whorl and pollen-shedding stages is conditioned by different factors. High concentrations of DIMBOA [2, 4-dihydroxy-7-methoxy-(2H)-1, 4 benzoxazin-3 (4H)-one] have been proved to have a closer relationship with resistance to the Asian corn borer at the whorl stage than at the pollen-shedding stage (Klun and Robertson, 1969; Tseng, 1989). Thus, evaluation of corn germplasm resistant to the Asian corn borer at the whorl and pollen-shedding stages should be conducted separately, then the resistant factors at both stages combined in a single plant by breeding (Penny *et al*, 1967).

To screen germplasm resistant to the Asian corn borer at the whorl stage, egg masses are dropped into the plant whorls (30-35 days after germination. Satisfactory levels of infestation can be obtained by three applications (60 eggs per application) spaced two or three days apart. A 1-9 class rating scale was used to evaluate the amount of plant injury in corn for different levels of larval establishment and survival (Guthrie, 1960).

Class 1. No visible leaf injury, or a small amount of pin or fine shot-hole type of injury on a few leaves.
Class 2. Small number of shot-hole type lesions on a few leaves.
Class 3. Shot-hole injury common on several leaves.
Class 4. Several leaves with shot-hole and elongated lesions.
Class 5. Several leaves with elongated lesions.
Class 6. Several leaves with elongated lesions (2.5 cm).
Class 7. Long lesions common on about one half of the leaves.
Class 8. Long lesions common on about two thirds of the leaves.
Class 9. Most leaves have long lesions.

Genotypes created 1 and 2 are considered highly resistant, 3 and 4 resistant, 5 and 6 intermediate in resistance, and genotypes that rate 7 to 9 are considered susceptible.

To evaluate the resistance of corn plants to the Asian corn borer at the pollen-shedding stage, egg masses incubated until they are near hatching are pinned to the midrib of the leaves above and below the ear during anthesis. Fifty to sixty days after the first infestation, the number and size of cavities inside the stalk are counted. A cavity 2.5 cm long is counted as one cavity, a cavity 15 cm long is counted as six cavities and so on. The corn genotypes are then classified into highly resistant (0-20 cavities), resistant (21-40 cavities), intermediate resistance (41-60 cavities), and susceptible (over 61 cavities).

5. Strategies to breed hybrid corn varieties which are high-yielding, resistant to pests and lodging, and tolerant to high soil moisture.

1. Development of the basic population (CO).

For creating potential genetic variability in the CO population for a long-term breeding program, the parents selected to be recombined into one population should have superior resistance to stalk rot, MDMV, downy mildew, and the Asian corn borer (Klenke, *et al*, 1986; Davis & Crane, 1976). For the most favorable alleles to be present in a single segregate, the hybridization method of convergent crossing with modified backcrossing (Gallum, 1979) is used to form the CO population (Fig. 1).

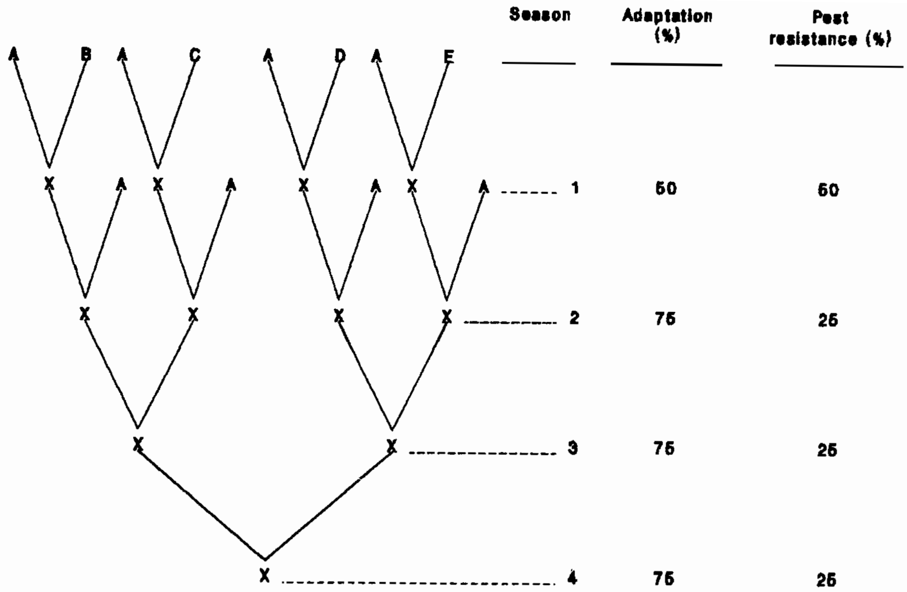

Fig. 1. Convergent crossing with modified backcrossing (Parent A represents an adapted variety with susceptibility to pests. Parents B, C, D and E represent lines resistant to stalk rot, MDMV, downy mildew and the Asian corn borer, respectively.

2. **Recurrent selection.**

The objective of a recurrent selection program is to increase the frequency of the favorable alleles in a population, while maintaining the genetic variability for the quantitatively inherited traits such as yield and resistance to pests and diseases (Davis and Crane, 1976, Klerke, *et al.*, 1986, Penny, *et al.*, 1967).

First cycle (C1) of breeding:

Season 1: Sow 2000 plants in the downy mildew nursery, pin the Asian dorn borer egg masses at the early whorl stage, inoculate with stalk rot and MDMV at the mid-whorl stage. Self the best 10% pest resistant plants and cross them to a tester.

Season 2: Evaluate 200 crosses in 3 replications for yield and pest resistance. Select the 10% of crosses which perform best.

Season 3: Plant the 20 S1 selections in paired rows to make all possible S1 combinations = 190 S1 x S1. Save 10 + seeds from each S1 combination to give a total of 2000 seeds for the C1 population.

Second cycle (C2) of breeding:

Seasons 4-6: Repeat the above procedures.

Third cycle (C3) of breeding:

Seasons 7-9: Repeat the above procedures. Self those plants which belong to the superior agronomic population.

3. **Making single crosses:**

Plant the selected inbreds which are pest resistant and have a high combining ability in paired rows, making all possible crosses between them during anthesis. Between 450 and 500 crosses can be developed each season.

4. **Local yield trial:**

Plant the new crosses in four replications. Every cross is planted in one 9 m row per replication, spacing of 75 cm between rows and 25 cm between hills within rows. At harvest, the top 5% high yielding and pest resistant crosses are selected.

5. **Evaluation of resistance to root lodging:**

The 5% of crosses which have the best yields and pest resistance are planted, with two replications (in Taiwan, this is done in a coastal town with a prevailing seasonal wind). Every cross is planted in a plot with four 9 m rows in each replication, 75 cm between rows and 25 cm between hills within rows. At the milking stage, the crosses are rated into five classes according to the degree to which plants in the whole plot are lodged. The following five-class rating scale is used (Thompson, 1972, 1982).

Class 1. No lodged plants.
Class 2. Half the plants in the plot lodged at 22°.
Class 3. Half the plants in the plot lodged at 45°.
Class 4. Half the plants in the plot lodged at 70°.
Class 5. At least half the plants in the plot have fallen on the ground.

At harvest, the five crosses which have the highest yields and the best resistance to pests and lodging are selected.

6. **Evaluation of tolerance to high soil moisture.**

The 5% of best high-yielding and pest resistant crosses are planted in paddy fields, with two replications. Each cross is planted in a plot with four 9 m rows in each replication, 75 cm between rows 25 cm between hills per row. When plants reach the 5th leaf stage, the plots are flooded with water for three days (Wenkert, *et al.*, 1981). At harvest, 5% of the crosses with the best yields, resistance to pests and tolerance of soil moisture are selected.

7. **Regional yield trials:**

The three crosses with the best performance as described above are then recommended for yield trials, to be planted in all major corn production areas throughout Taiwan (i.e. Miaoli, Taichung, Yunlin, Chiayi, Tainan, Kaohsiung, Taitung and Hualin counties) over two years. At the end of the two year yield trial, the cross with the best performance is recommended to the committee organized by the Department of Agriculture and Forestry of the Taiwan Provincial Government, for examination.

Agronomic production research:

As previously mentioned, the cultivation environment in Taiwan is not ideal for corn production. Also the arable land is limited and there is a shortage of laborers in the rural areas. In order to increase corn yields, these problems have to be solved. To cope with them, apart from varietal improvement, there should be an adoption of cultural practices which can lessen the losses caused by flooding, lodging, insect pests or reduce the production costs.

In this part of the paper, the cultural practices which have been developed for preventing the losses from unfavorable climatic conditions and increasing profits will be discussed.

1. **Ridged culture:**

To decrease the damage caused by flooding, ridged culture is usually adopted by the farmers in southern Taiwan. In this practice, two rows are planted on each ridge. The distance between rows is 70 cm, and between ridges is 150 cm (Fig. 2). The excessive standing water is drained out through the furrow between the ridges. By adopting this cultural method in the spring crop, 50-70% of the plants are saved from being damaged by flooding.

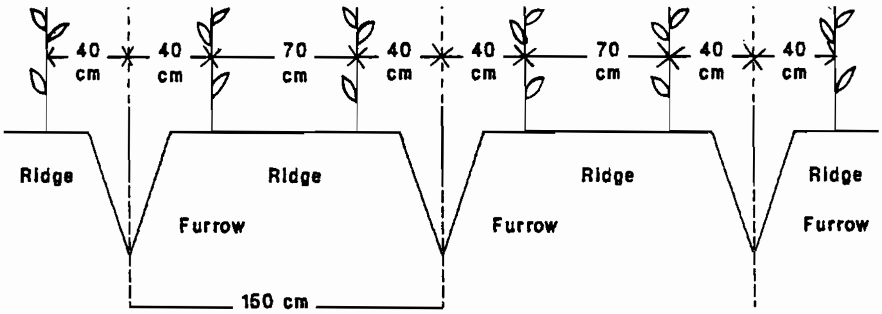

Fig. 2. Ridge culture

2. **Non-tillage cultivation:**

With the aim of reducing corn grain production costs, in eastern Taiwan non-tillage cultivation has been practiced after rice is harvested. Results from 2 year-experiments (1988-1990) revealed that corn yield and net income in non-tillage culture are higher than those in tillage by 11% and 31%, respectively (**Table 2**). This is due to the lower percent of lodging plants and less labor input in the former than those in the latter by 13% and 20%, respectively.

Table 2. Comparison of the differences in grain yield and net income between non-tillage and tillage cultivation in eastern Taiwan.

Cultural method	1989 Grain yield (kg/ha)	1989 Net income (US$/ha)	1990 Grain yield (kg/ha)	1990 Net income (US$/ha)	Ave. Grain yield (kg/ha)	Ave. Net income (US$/ha)	Index Grain yield (kg/ha)	Index Net income (US$/ha)
Nontillage	4,180 a	857 a	5,641 a	1,476 a	4,911 a	1,167 a	111	131
Tillage	3,860 a	511 b	4,911 b	1,267 b	4,386 b	889 b	100	100

Means in the same column followed by the same letter do not differ significantly at 0.05% probability level according to Duncan's Multiple Range Test (DMRT).

3. **Two-layer fertilizer application:**

The objectives of the two-layer fertilizer application are to simplify and reduce the labor for fertilizer application. A specially designed machine can sow and apply two-layer fertilizer on either side of a sowing furrow simultaneously (Lin, *et al.*, 1988). On one side of the furrow, fertilizer is placed at 5-10 cm depth to provide the nutrients for early growth stage, on other side of the furrow the fertilizer is placed at 25-30 cm depth to supply the nutrients for middle to later growing stages of plant development. The results from field experiments showed that the fertilizer applied in this way could facilitate the early growth and tasseling in the plant development and increase the grain yield by 10% as compared with that of conventional application (**Table 3**).

Table 3. Effect of two-layer fertilizer application on some agronomic characteristics and grain yield in spring crop. 1987.

	Location									
	Chian				Fengling				Ave.	
Treatment	Tassel (days)	Plt/hgt (cm)	Ear length (cm)	Grain yield (kg/ha)	Tassel (days)	Plt/hgt (cm)	Ear length (cm)	Grain yield (kg/ha)	Grain yield (kg/ha)	Yield index (%)
Two-layer application a/	52	203	16	3,461	52	206	16	3,891	3,676	110
Conventional application b/	55	192	15	3,141	55	200	15	3,556	3,349	100

a/ Compound fertilizer at 140-110-100 ($N-P_2O_5-K_2O$) kg/ha applied as basal dressing in two layers.
b/ Compound fertilizer at 72-96-96 ($N-P_2O_5-K_2O$) kg/ha applied as basal dressing and 70 kg/ha nitrogen fertilizer applied as topdressing to 50 cm high plants.

4. **Cropping system improvement:**

Multiple cropping is a traditional agricultural production system in Taiwan. Paddy rice is used to play an important role in maintaining sustainability in this system. In the last decade, due to the rapid decrease in rice consumption, new cropping systems have been developed for paddy fields. Results from 5-year experiments proved that the cropping patterns which could sustain soil fertility and offer a higher net income are: (R^1) Rice-Soybean-Corn, (R^2) Rice-Sesbania-Corn and (R^3) Sorghum-Soybean-Corn (**Table 5**).

In terms of average corn grain yield, R^1 gave the highest (7,198 kg/ha), whereas R^1 gave the lowest (5,471 kg/ha). This was probably due to the green manure included in R^2. Therefore, organic matter content was higher in R than in that of other systems (**Table 4**).

Table 4. Differences in corn yield between various cropping systems tested in southern Taiwan (1986-1990).

Code	Cropping systems	Grain yield (kg/ha)					Average (kg/ha)
		1986	1987	1988	1989	1990	
R1	Rice-Soybean-Corn	7,232	3,352b	6,472b	4,620b	5,677cd	5,471b
R2	Rice-Sesbania-Corn	8,483	4,943a	9,025a	5,205b	8,332a	7,198a
R3	Sorghum-Soybean-Corn	7,522	3,062b	6,306b	5,400ab	6,585bc	5,775b

Means in the same column followed by the same letter do not differ significantly at 0.05% probability level (DMRT).

Table 5. Differences in net income between various cropping systems tested in southern Taiwan (1986-1990).

Code	Cropping systems	Net Income (US$/ha) 1986	1987	1988	1989	1990	Average (US$/ha)
R1	Rice-Soybean-Corn	3,727	1,121	2,899	3,868	1,976	2,716 a
R2	Rice-Sesbania-Corn	3,836	1,511	2,829	2,480	2,690	2,669 ab
R3	Sorghum-Soybean-Corn	4,603	1,009	2,691	3,113	1,031	2,490 b

Means followed by the same letter do not differ significantly at 0.05% probability level (DMRT).

5. **Plant protection:**

The most important insect pest in corn grain production in Taiwan is the Asian corn borer *O. furnacalis* Guenee. In southern Taiwan, there are 6-8 generations of corn borer. The damage caused by this pest may be as high as 90%. In order to avoid corn borer damage, farmers usually have to apply chemicals 5 to 7 times during the growing season. In order to reduce both the user of insecticides and production costs, in 1984 the government implemented a biocontrol program using mass releases of *Trichogramma ostriniae* (a parasitoid of corn borer egg masses) (Chen and Chur, 1948) for reducing the corn borer damage. Under this program *T. ostriniae* was released in approximately 16,000 ha each year (Taiwan Govmt. Annual Rept. 1985-1988). In order to produce enough eggs of the parasitoid for practical use, three *T. ostriniae* propagation stations (Kung-Fu, Potzu and Woo-Shu-Lin) were established in the period of 1984-1986 (Tseng, 1990). In practice, *T. ostriniae* is released four times in each cropping season, at a rate of 75 egg cards/ha (300,000-360,000 egg parasitoids/ha), in an interval of 8 days. The egg cards are fixed to the underside of the leaves near the ears with a stapler. Three insecticide treatments are applied at the early whorl, late whorl, and pollen-shedding stages (**Fig.** 3). (Tseng and Wu, 1990). The results from field experiments showed that the mass releases of *T. ostriniae* increased the percentage of parasitism of egg masses by 8-20%, compared with areas where no releases of egg parasitoids were made (**Table 6**). This integrated control gave 11% higher grain yield than the conventional control (insecticide treatment applied from early whorl to pollen-shedding stages at an interval of 7-10 days) (**Table** 7).

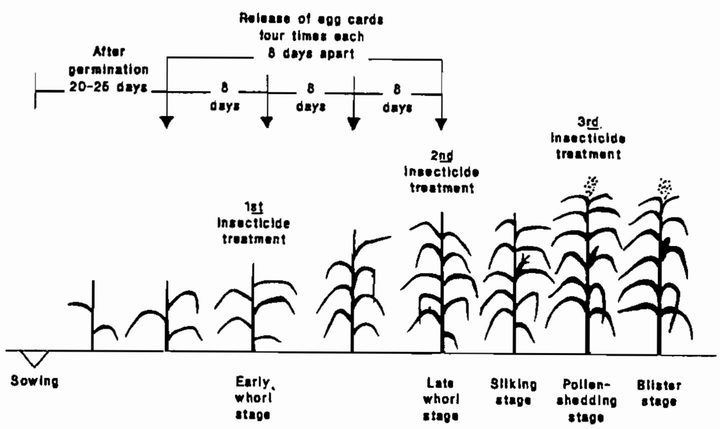

Fig.3. Steps adopted in the integrated control of the Asian corn borer on field corn.

Long term evaluation of mass releases of *T. ostriniae* show they have suppressed the corn borer population density from 7.2 male moths captured per virgin female trapped in 1985 to 4.5 male moths per trap in 1991, in Potzu, Chiayi area, Taiwan (Fig. 4 & 5).

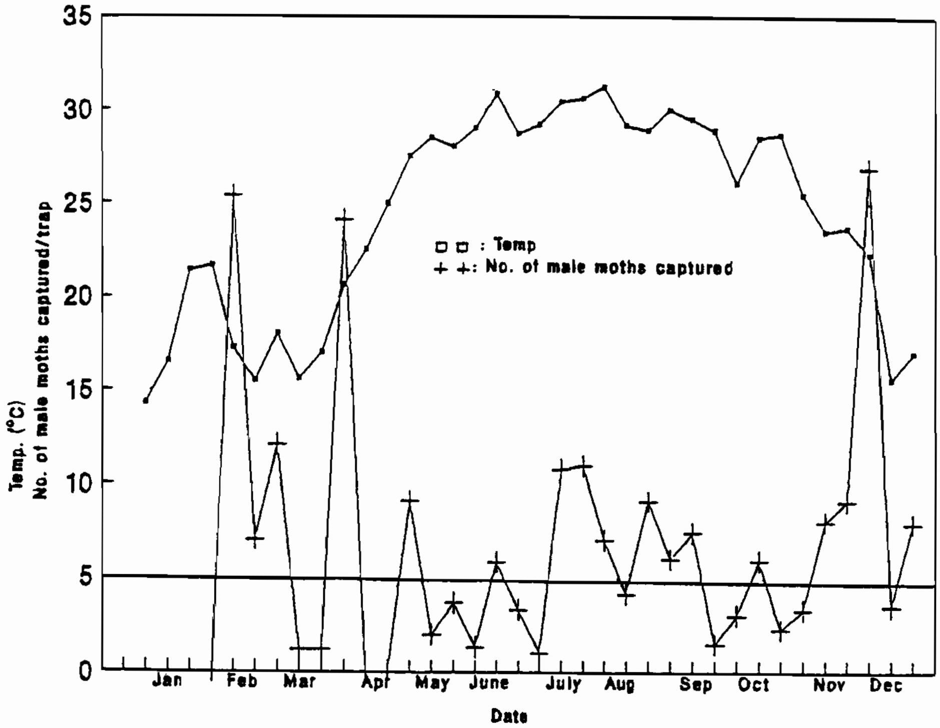

Fig. 4. Seasonal population fluctuation of the Asian corn borer in Chiayi Potzu are (1985)

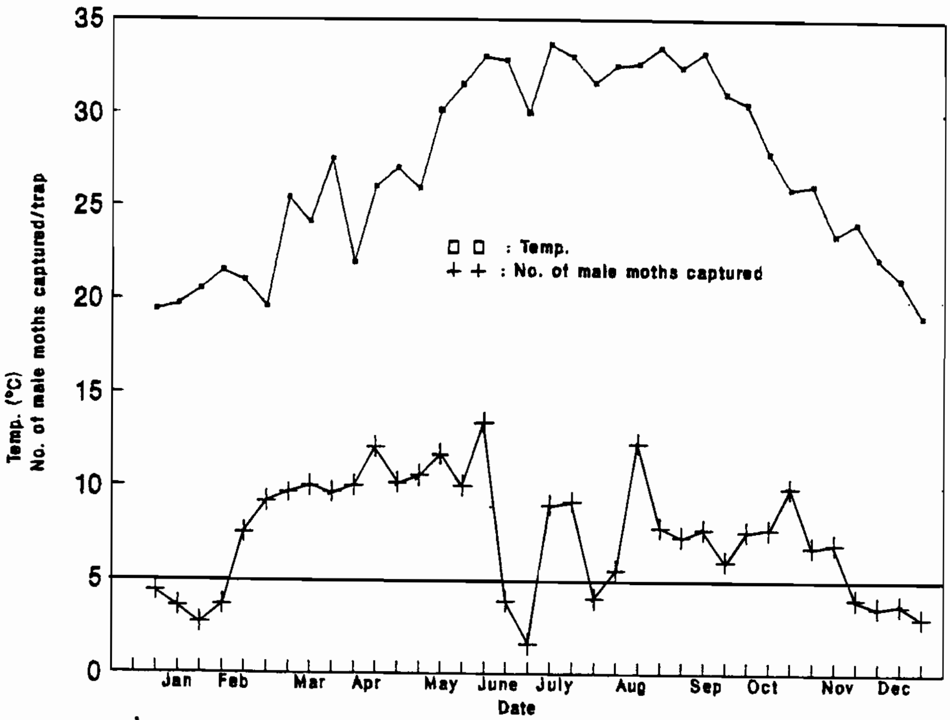

Fig. 5. Seasonal population fluctuation of the Asian corn borer in Chiayi Potzu area (1991)

Table 6. Density of corn borer egg masses, and percent parasitism of egg masses in field corn production areas with integrated or conventional control 1/

Control method	1985				1986				1987				1988	
	Spring crop		Fall crop		Spring crop		Fall crop		Spring crop		Fall crop		Spring crop	
	1/No. egg masses /plt	1/Egg parasitism (%)	No. egg masses /plt	Egg parasitism (%)	No. egg masses /plt	Egg parasitism (%)	No. egg masses /plt	Egg parasitism (%)	No. egg masses /plt	Egg parasitism (%)	No. egg masses /plt	Egg parasitism (%)	No. egg masses /plt	Egg parasitism (%)
Integrated 2/	2.7a	18.0a	1.3a	22.0a	1.5a	10.2a	4.0 b	14.0a	1.8a	12.1a	1.5a	13.4a	3.6a	26.3a
Conventional 3/	3.0a	5.0 b	1.8a	6.0 b	2.4a	2.0 b	7.8a	3.5 b	2.2a	1.5 b	2.2a	2.2 b	3.0a	6.5 b

1/ Within a column, means followed by same letter do not differ significantly at 0.05% probability level (DMRT).
2/ Four releases of T. ostriniae each 75 egg cards/ha combined with 3 insecticide treatments.
3/ Insecticide treatments applied from early whorl to pollen-shedding stage at an interval of 7-10 days.

Table 7. Grain yield of field corn with integrated or conventional control of corn borer 1/.

Control method	1985		1986		1987		1988		
	Spring crop (kg/ha)	Fall crop (kg/ha)	Spring crop (kg/ha)	Fall crop (kg/ha)	Spring crop (kg/ha)	Fall crop (kg/ha)	Spring crop (kg/ha)	Average (kg/ha)	Index (%)
Integrated 2/	3,708	4,503	3,869	4,561	4,085	4,396	4,557	4,240 b	111
Conventional 3/	3,405	4,087	3,543	3,867	3,854	3,890	4,078	3,818 a	100

1/ In the same column, means followed by the same letter do not differ significantly at 0.05% probability level (DMRT).
2/ Same as in Table 6.
3/ Same as in Table 6.

References

Awadallah, W.H. 1983. The development and use of varietal resistance and other nonchemical control methods to reduce yield losses due to stalk borers in maize. FG-E9-170 (EG-ARS-52). Final report.

Chen, K.P., and Chur L.S. 1948. The metods for artificially and massively releasing *Trichogramma australicum* Girault for controlling the sugar cane borers. Rept. of the Taiwan Sugar Res. Inst. 2: 21-36.

Chona, B. JL. and M.L. Seth. 1960. A mosaic disease of maize (*Zea mays* L.) in India. Indian J. Agric. Sci. 30: 25-32.

Chang, S.C., and Y.Z. Wu. 1976. Practical method for inoculation of downy mildew disease (*Sclerospora sacchari*) in corn. Rept. of the Corn Res. Center (Tainan Dist. Agric. Impromt. Stat., ROC on Taiwan) 11: 20-21.

Cheng, S.C. 1980. Effect of seed corn treated with Ridomil 25 WP and Apron 35 SD on the germination and control of downy mildew. Rept. of the Corn Res. Center (Tainan Dist. Agric. Improvmt. Stat., ROC on Taiwan) 14: 19-22.

Drechsler, C. 1934. *Pythium butleri* and *P. aphanidermatum.* Phytopathology 24: 7 (Abstr.)

Davis, S.M., and P.L. Crane. 1976. Recurrent selection for rind thickness in maize and its relationship with yield, lodging, and other plant characteristics. Crop Sci. 16: 53-55.

Dept. of Agric. and Forestry. 1991. Taiwan Provincial Government, ROC. Agric. Yearbook.

Fausey, N.R. and M.B. McDonald. 1985. Emergence of inbred and hybrid corn following flooding. Agron. J. 77: 51-56.

Guthrie, W.D., F.F. Dicke, and C.R. Neisweander. 1960. Leaf and sheath feeding resistance to the European corn borer in eight inbred lines of dent corn. Ohio Agric. Exp. Stn. Res. Bull. 860. 38 pp.

Guthrie, W.D., E.S. Raun, F.F. Dicke, G.R. Pesho and S.W. Carter. 1965. Laboratory production of European corn borer egg masses. Iowa State, J. Sci. 40: 65-83.

Guthrie, W.E., J.L. Huggans and S.M. Chatterji. 1970. Sheath and collar feeding resistance to the second-brood European corn borer in six inbred lines of dent corn. Iowa State. J. Sci. 44: 297-311.

Guthrie, W.D., W.A. Russell, G.L. Reed, A.R. Hallauer and D.F. Cox. 1978. Method of evaluating maize for sheath collar feeding resistance to the European corn borer. Maydica 23: 45-53.

Gallum, R.L. 1979. Breeding for resistance to insects in wheat. *In*: Biology and Breeding for Resistance to Arthropods and Pathogens in Agricultural Plants, M.K. Harris (Ed.). Texas Stn. Misc. Publ. MP-1451: 245-262.

Klun, J.A. and J.F. Robinson. 1969. Concentration of two 1, 4-benzoxazinones in dent corn at various stages of development of the plant and its relation to the European corn borer. J. Econ. Entomol. 62: 214-220.

Klenke, J.R., W.A. Russell and W.D. Guthrie. 1986. Recurrent selection for resistance to the European corn borer in a corn synthetic and correlated effects on agronomic traits. Crop Sci. 26: 864-868.

Lin, C.H., Y.C. Lu, C.H. Liu and C.I. Tsai. 1988. Development of a drill equipped with two-layer fertilizer applicator for maize and its effect on field test. Bull. Hualien DAIS. 4: 75-82.

Penny, L.H., G.E. Scott and W.D. Guthrie. 1967. Recurrent selection for European corn borer resistance in maize. Crop. Sci. 7: 407-409.

Sehgal, O.P. 1965. Host range, properties and purification of a virus isolated from dent corn in Missouri. Phytopathology 55: 1075-1076 (Abstr.)

Taiwan Provincial Govmt. Annual Rept. of the Integrated Control of the Asian Corn Borer. 1985, 1986, 1987, 1988. Dept. of Agric. and Forestry, Taiwan Provincial Government.

Thompson, D.L. 1972. Recurrent selection for lodging susceptibility and resistance in corn. Crop Sci. 12: 631-634.

Thompson, D.T. 1982. Grain yield of two synthetics of corn after seven cycles of selection for lodging resistance. Crop Sci. 22: 1207-1210.

Tosic, M. and R.E. Ford. 1974. Physical and serological properties of maize dwarf mosaic and sugarcane mosaic virus. Phytopathology 64: 312-317.

Tseng, C.M. 1980. Studies on corn mosaic virus in Taiwan. Rept. of Corn Res. Center (Tainan Dist. Agric. Improvmt. Stat., ROC, Taiwan) 14: 43-53.

Tseng, C.T. 1986. Effect of mold inhibitor combinations on growth and development of the Asian corn borer, *Ostrinia furnacalis*. Chinese J. Entomol. 6: 69-77.

Tseng, C.T. 1989. Concentration of DIMBOA in leaf tissue at various stages of corn plant in relation to resistance of host plant to the Asian corn borer. Plant Prot. Bull. (Taiwan, ROC) 31: 34-43.

Tseng, C.T., and Y.Z. Wu. 1990a. The integrated control of the Asian corn borer, *Ostriniae furnacalis* Guenee, on sweet corn. Plant Prot. Bull. 32: 177-182.
Wenkert, W., N.R. Fausey, and H.D. Watter. 1981. Flooding response in *Zea mays* L. Plant and Soil 62: 351-366.

Questions to the author:

FROM : G. Granados
Q : One of the better known sources of resistance to corn borers in tropical and subtropical maize is Antigua Gr.1, but Antigua germplasm is very susceptible to downy mildew. For this reason some people talk about a negative correlation between resistance to mildew and resistance to corn borer. Have you detected any kind of correlation between resistance to these 2 stress factors?
A : So far in our maize hybrid breeding program, there is not any evidence shown that the positive correlation between resistance to corn borer and downy mildew exists. However, this is an interesting question. We would like to look at more different sources of resistance to compare the correlation between these two stress factors.

FROM : P. Grudloyma
Q : Could you please tell me how long you flood the corn plant in the paddy field for screening to waterlogging resistance?
A : In our maize hybrid breeding program for screening waterlogging resistance the plots are to be flooded for 5to 6 days when plants are at 5th or 6th leaf stage.

DEVELOPMENT OF HYBRID CORN IN THAILAND

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Abstract

Since 1950, corn has been one of the most important economic crops of Thailand. In 1984, exports of corn grain reached a maximum value of 10,149 m Baht and exports of canned baby corn has also come to play an important role, earning 961 m Baht in 1991 (1 US$=25.2 Baht). However, the planted area has declined, and the fast growth of the feed industry demands greater supplies of corn grain.

High yielding hybrid corn and expansion of area by planting corn in paddy fields during the dry season where irrigation is available would make it possible to meet the national demand of the grain.

The first high yielding open pollinated variety (OPV), Phra-Phutthabat (PB), was released around 1961. It was replaced by two OPVs: Thai DMR 6 in 1972 and Suwan 1 in 1976. The other open pollinated varieties released were Suwan 2 (early maturity) in 1979, Rangsit 1 baby corn in 1981, Suwan 3 in 1987, Nakhorn Sawan 1 in 1989, and most recently, Suwan 5 in 1993.

All of these OPVs are good sources of germplasm for inbred line extraction and are used in both public and private hybrid corn breeding programs. So far, 44 Kasetsart inbred lines (Ki 1 to 44) have been released by the Corn Breeding Project of Kasetsart University (KU). The released hybrids are Kasetsart Single Cross 2301 (KSX 2301) or Suwan 2301, in 1982; Kasetsart Three-way Cross 2602 (KTX 2602) or Suwan 2602 in 1986; KTX 3101 or Suwan 3101, in 1991; and the Kasetsart Baby Corn Three-way Cross 3501 or KBTX 3501, in 1993. The hybrids expected to be released shortly are KOSX 3503, KSX 3504, NSX 9002, and NSX 9008.

These hybrids embody genetic improvements which make possible higher yields and better agronomic characteristics, such as greater resistance to root and stalk lodging, diseases, insects, barrenness and greater tolerance of drought and high plant densities.

The first recorded sale of hybrid corn seed was 40t in 1981. In 1993, an estimated 10,000 t of hybrid corn seed were sold in Thailand. The successful development of hybrid corn in Thailand has depended in part upon cooperation through the years of different agencies, including USAID, Rockefeller Foundation, CIMMYT and FAO, as well as of visiting scientists.

Introduction.

Corn *Zea mays* has become one of Thailand's leading economic crops over the past four decades, important both as an export product and as an animal feedstuff. Exports of corn grain have increased drastically from only 12,630 t valued at 10,479,000 Baht in 1950 to 3,982,440,000 t, worth 10,149,816,000 Baht in 1984. The 42 year (1950-1991) maximum (**Table 1**). Also important is baby corn. Exports of canned baby corn have risen from 67 t, worth 961,490,000 Baht in

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8/,9/ Nakhonsawan Field Crops Res. Center, DOA.
12/ Uniseeds Co.

in 1991 (**Table 2**). In addition, in 1992 exported fresh baby corn earned 47,000,000 Baht (**Table** 3).

Table 1. Corn production and exports of Thailand. 1950-1990.

Year	Planted area 1/ ('000 rai)	Production ('000 t)	Yield per rai 2/ (kg)	Exports ('000 t)	Value ('000 Baht)
1950	218	26.9	123	12.63	10,479
1952	281	44.8	159	25.16	27,925
1954	331	62.3	188	36.98	56,141
1956	514	114.8	223	81.49	96,133
1958	792	186.3	235	162.91	182,667
1959	1,249	317.2	254	236.78	249,512
Average	489	104.9	193	74.57	84,551
1960	1,785	543.9	305	514.74	550,734
1962	2,050	665.4	331	472.40	502,253
1964	3,449	935.0	271	1,115.04	1,345,676
1966	4,083	1,122.0	275	1,218.53	1,519,936
1968	4,193	1,508.0	360	1,480.84	1,556,138
1969	4,248	1,700.0	400	1,476.11	1,674,395
Average	3,216	1,026.8	317	948.98	1,089,857
1970	5,180	1,938.0	374	1,520.42	1,856,912
1972	6,231	1,315.0	211	1,932.40	1,980,214
1974	7,749	2,500.0	323	2,259.61	5,964,605
1976	8,029	2,675.0	333	2,388.18	5,598,073
1978	8,661	2,791.0	322	1,954.58	4,230,994
1979	9,529	2,863.0	300	1,988.15	5,567,355
Average	7,465	2,326.1	312	1,889.55	3,914,663
1980	8,960	2,998.0	335	2,715.33	7,200,830
1982	10,494	3,002.0	368	2,801.24	8,230,850
1984	11,355	4,226.0	389	3,981.44	10,149,816
1986	12,194	4,309.0	380	3,116.48	9,176,194
1988	11,471	4,675.0	419	1,208.76	3,809,929
1989	11,165	4,393.0	411	1,180.82	4,087,412
Average	10,930	3,832.0	376	2,446.24	7,074,620.3
1990	10,910	3,722.0	385	1,235.13	4,141,260
1991	9,219	3,793.0	434	1,232.13	3,913,280

Source : Center for Agric. Statistics, Office of Agric. Economics, Ministry of Agric. and Cooperatives.

1/ 1 ha = 6.25 rai; 1 rai = 1600 m

2/ 1 kg/ha = 6.25 kg/rai

Table 2. Quantity and value of Thailand's exports of canned baby corn, 1974-1992.

Year	Amount (t)	Value (m Baht)
1974	67.00	0.80
1976	234.50	3.60
1978	489.40	9.50
1980	916.50	21.40
1982	1,495.70	36.60
1984	4,468.30	101.10
1986	11,316.90	230.60
1988	25,615.90	489.90
1990	26,794.59	536.79
1992	36,761.19	826.12

Source: Dept. of Export Promotion, Ministry of Commerce.

Table 3. Quantity and value of Thai fresh baby corn exports. 1988-1991.

Year	Amount (t)	Value (m Baht)
1988	2,220	38.6
1990	1,787	43.5
1992	1,891	47.7

Source: Dept. of Business Economics, Ministry of Commerce.

The country's average area planted to corn has increased during the past four decades (**Table 1**); however, the average yield/rai of 317, 312 and 376 kg, respectively, for the past three decades, are not satisfactory. The demand for good quality grain by the rapidly growing feed industry has increased from 341,000 t in 1974, to 2,800,000 t in 1989 (**Table 4**). At present, some of the corn planted area is being given over to other crops, e.g., sugarcane and cassava. Chutkaew (1991) analyzed the supply of corn in Thailand and found that the amount of corn supplied in the North, central and northeast regions will change in the same direction as there is a change in corn price, amount of rainfall and time. Due to the excess of domestic demand over the supply, in 1992 Thailand had to import nearly 500,000 t of corn grain from the People's Republic of China.

Thus, there is an urgent need for research and development work on high yielding varieties, especially hybrids with resistance to pests and broad adaptability. One possibility for such varieties is planting them in paddy fields where irrigation is available (Chutkaew 1990, 1992). In this case, breeders must identify superior germplasm sources that may be combined to produce new higher yielding varieties, possess good agronomic characters and are stable in different environments.

The successful utilization of improved maize germplasm in Thailand may be outlined as follows (Chutkaew, 1989):

1. An open pollinated Guatemala variety (Tequisate Golden Yellow Flint) was introduced by the Department of Agriculture (DOA) in 1951. Its yield potential and agronomic characters were improved by maize breeders of the DOA, and a superior cultivar was then distributed to farmers as the Phraphutthabat variety (PB). This variety was extensively used until 1972 when it was replaced due to its susceptibility to downy mildew disease.
2. Thai DMR 6 was released in 1972.
3. Suwan 1 was released in 1976 (Chutkaew, 1982, 1986).

Table 4. Domestic consumption and export of corn. 1974-1989. ('000 t).

	Domestic consumption		Export	
	Amount	Index	Amount	Index
1974	341.00	100	2,190.31	100
1976	538.00	158	2,388.18	209
1978	706.00	207	1,954.58	89
1980	854.00	250	2,175.33	99
1982	968.00	284	2,893.93	132
1984	1,000.00	293	3,144.61	144
1986	1,230.00	361	4,013.24	183
1988	2,400.00	704	1,214.50	55
1989	2,800.00	821	1,182.10	54

Source: 1/ Center for Agric. Statistics Office of Agric. Economics, Ministry of Agric. and Cooperatives (1974-87). Thai Maize and Produce Traders Assoc. (1988-89).
2/ Customs Dept., Ministry of Finance.

4. Suwan 2, an early maturity cultivar, was released in 1979.

5. Suwan 2301 or Kasetsart Single Cross 2301 (KSX 2301), a cross of Ki3 x Ki11, was released to farmers in 1982.

6. Kasetsart inored lines Ki1 to Ki19 were released to the public in 1982.

7. Rangsit 1 baby corn, developed by the DOA, was also released in 1982 (Chutkaew *et al.*, 1983).

8. Ki 20 was released in 1984, and Ki21 and Ki22 in 1986.

9. Suwan 2602, or Kasetsart Three-way Cross 2602 (KTX 2602), a cross of Suwan 2301 x Ki20, was approved by KU and the DOA in 1986 (Chutkaew *et al.*, 1985a, 1985b) (Table 5).

Table 5. Mean grain yield of Suwan 2602 tested in 47 experiments planted at different locations and seasons during 2 years. 1983 and 1984.

Variety	Yield (kg/rai)					Mean		% of check
	KU 1/	KU 2/	DA 3/	KU 4/	KU 5/	Kg/rai	kg/ha	
Suwan 2301	1093	613	932	772	771	893	5581	111
Suwan 2602	1295	810	985	804	849	995	6219	123
Suwan 1(S)C8-F3 (check)	1096	703	936	660	707	808	5048	100

1/ Average of 11 trials for Suwan 2301 and Suwan 2602, 5 trials for Suwan 1(S)C8-F3, KU Corn Breeding Project, 1983-1984.
2/ Average of 1 trial, KU Corn Project No.3, 1984 late season.
3/ Average of 7 locations, DOA, 1984.
4/ Average of 9 locations at agricultural colleges, KU On-Farm Trial Project, 1983-1984.
5/ Average of 9 locations KU On-Farm Trial Project, 1983-1984.
N.B. There were several entries in each trial. For convenience, only two hybrids are compared with the check Suwan 1(S)C8.

10. Suwan 3 (Kasetsart Synthetic 4 Cycle 2 or KS 4(S)C2), approved by KU and DOA in 1987, yielded 10% higher than Suwan 1 cycles 8 and 9 and it was resistant to downy mildew (Chutkaew *et al.*, 1986, 1987, 1989).

11. Inbreds Ki23 to Ki30 were released in 1987.

12. Suwan 3101, or Kasetsart Three-way Cross (KTX 3101), derived from (Ki28 x Ki27) x Ki21,

was approved by KU and DOA in 1991 (**Table 6**).

13. Inbreds Ki31 to Ki44 were released in 1992 (**Table 7**). The latest open-pollinated variety Suwan 5 (Kasetsart Synthetic 5) was released this year.

Table 6. Mean grain yield of Suwan 3101 tested in 95 experiments at different locations and seasons during 4 years. 1986 through 1989.

Variety	Yield (kg/rai)					% of check			No. of
	1986	1987	1988	1989	Mean	SW 2602	SW1(S)C11	SW3(S)C4	experiments
Suwan 3101	1028	1174	1068	1028	1049	116	-	-	95
Suwan 3101	-	-	-	1013	1013	-	121	-	50
Suwan 3101	-	-	1015	1011	992	-	-	113	52
Suwan 2602	811	968	923	891	905	100	-	-	
Suwan 1(S)C11	-	-	-	835	835	-	100	-	
Suwan 3(S)C4			1085	883	878	-	-	100	

All these OPVs are good sources of germplasm for inbred extraction and hybrid production.

Materials and methods.

Many accessions of maize germplasm have been introduced to Thailand since the beginning of the breeding program. These have been planted in breeding nurseries for selection. The superior or promising materials have been used in crossing exotic and indigenous sources for different purposes. Materials which exhibited good performance have been used to extract inbred lines for the development of the hybrid corn program.

The breeding procedures used in development of varieties include mass selection, backcrossing, S1 selection, half-sib, full-sib, line improvement, top crossing using the latest cycle of Suwan 1 and Suwan 3 as testers, and test crossing using promising inbred lines or hybrids as testers (Chutkaew, 1989).

Evaluation of varieties was initially done at research stations. Promising materials have then been sent for testing both at experiment stations and in farmers' fields at different locations in corn growing areas. Testing of elite varieties, composites, synthetics, and hybrids has been conducted at many locations. To obtain more reliable information, data have been collected over years, seasons and locations (Chutkaew, 1986).

Results and discussion.

By using a number of good sources of germplasm, appropriate breeding methodologies, evaluation of varieties and analysis of data collected over years, seasons and locations, high yielding OPVs and hybrids, have been approved by the committee of KU and the DOA, as mentioned above.

1. Evaluation of baby corn. The promising Kasetsart Baby Corn Three-way Cross 3501 (KBTX 3501) was developed in 1987 from (Ki39 x Ki20) x Ki40. Final testing with 12 other varieties carried out at five provinces (Titatarn *et al.* 1992) revealed that KBTX 3501 gave the highest yield of fresh dehusked standard baby corn at 167 kg/rai, 47% higher than the check Suwan 2 (S)C7 yielding 113.7 kg/rai (**Tables 8** and **10**). Other promising varieties were Suwan 3101 and NS1 with 146.5 kg/rai and 123.6 kg/rai, respectively. KBTX 3501 had the lowest downy mildew infection (0.2%), followed by the check Suwan 2 (0.4%) (**Table 9**).

The average yield of fresh baby corn with husks, dehusked, and incidence of downy mildew infection from tests in five provinces in 1991, are shown in **Table 10** (Titatarn *et al.*, 1992). KBTX 3501 gave the highest yield both with husk (1,072.2 kg/rai) and dehusked (167.0 kg/rai) and had the lowest downy mildew infection (0.2%) (**Table 10**). Baby corn also yields useful by-products, i.e. green husks and stalk which may be ensiled or sold as fodder for cattle.

Table 7. Inbred lines of corn released by the Corn Breeding Project, KU.

Inbred	Color and type	Year released	Developed from
Ki 1	Orange Yellow Flint	1982	Suwan 1(S)C4-S8-1-5 (2001)
Ki 2	"	"	Suwan 1(S)C4-S8-1-7 (2002)
Ki 3	"	"	Suwan 1(S)C4-S8-5-3 (2007)
Ki 4	"	"	Suwan 1(S)C4-S8-5-5 (2008)
Ki 5	"	"	Suwan 1(S)C4-S8-5-6 (2009)
Ki 6	"	"	Suwan 1(S)C4-S8-5-9 (2011)
Ki 7	"	"	Suwan 1(S)C4-S8-7-3 (2012)
Ki 8	"	"	Suwan 1(S)C4-S8-14-9 (2019)
Ki 9	"	"	Suwan 1(S)C4-S8-16-7 (2021)
Ki 10	"	"	Suwan 1(S)C4-S8-17-3 (2022)
Ki 11	"	"	Suwan 1(S)C4-S8-18-7 (2025)
Ki 12	"	"	Suwan 1(S)C4-S8-18-8 (2026)
Ki 13	"	"	Suwan 1(S)C4-S8-18-9 (2027)
Ki 14	"	"	Suwan 1(S)C4-S8-19-5 (2028)
Ki 15	"	"	Suwan 1(S)C4-S8-20-2 (2029)
Ki 16	"	"	Suwan 1(S)C4-S8-20-5 (2031)
Ki 17	"	"	Suwan 1(S)C4-S8-20-8 (2032)
Ki 18	"	"	Suwan 1(S)C4-S8-22-4 (2034)
Ki 19	"	"	Suwan 1(S)C4-S8-22-9 (2035)
Ki 20	Yellow Orange Flint	1984	Caripeno DMR(S)C1-S8-125-5-3
Ki 21	Yellow Orange Semident	1986	Pacific 9-S8-45
Ki 22	Yellow Orange Dent	"	Pacific 11 x Suwan 1(S)C6-S8-30
Ki 23	Yellow Orange Flint	1987	(Ki 11 x Suwan 1(S)C7-S6-6-2-2)-S8-152-1-3
Ki 24	Orange Flint	"	Suwan 1(S)C7-S8-2-2-3-3
Ki 25	Orange Yellow Semiflint	"	Suwan 1(S)C8-S8-84-1
Ki 26	Orange Yellow Flint	"	Suwan 1(S)C8-S8-84-2
Ki 27	"	"	Suwan 1(S)C8-S8-220-2
Ki 28	"	"	Suwan 1(S)C8-S8-223-1
Ki 29	"	"	Suwan 1(S)C8-S8-322-5
Ki 30	Yellow Orange Flint	"	Caripeno DMR(S)C1-S8-114-1-1
Ki 31	Orange Yellow Flint	1992	Suwan 1(S)C9-S8-329-1 (Kei 8901)
Ki 32	Orange Flint	"	Suwan 1(S)C9-S8-346-2 (Kei 8902)
Ki 33	Orange Yellow Flint	"	Suwan 1(S)C9-S8-385-1 (Kei 8903)
Ki 34	Orange Flint	"	Suwan 1(S)C9(L)(S)C1-S8-163-3-2-1-2 (Kei 9001)
Ki 35	Orange Yellow Flint	"	Suwan 3(S)C1-S8-14--2-2-1-2 (Kei 9002)
Ki 36	"	"	Suwan 3(S)C2-S8-102-1-1-4-3 (Kei 9003)
Ki 37	"	"	Suwan 3(S)C2-S8-194-1-1-1-1 (Kei 9004)
Ki 38	"	"	Suwan 3(S)C2-S8-302-3-1-1-1 (Kei 9005)
Ki 39	Yellow Flint	"	Rangsit 1(H)C1-S8-5
Ki 40	Orange Yellow Flint	"	Suwan 2(S)C7-F2-S9-2-4
Ki 41	"	"	Alexander High Oil 19-1-4-3-1-4
Ki 42	Orange Flint	"	Alexander High Oil 19-1-4-3-3-4
Ki 43	Orange Yellow Flint	"	Suwan 3(S)C3-S8-138 (Kei 9101)
Ki 44	"	"	KS 6(S)C2-S8-366 (Kei 9102)

Trakoontiwakorn *et al*. (1993), used nine corn inbred lines from five different germplasm sources i.e. Suwan, CIMMYT, Hawaiian Sugar Super Sweet, Tropical Corn Belt Stiff Stalk, and Tropical Corn Belt to make a 9 x 9 diallel cross, and found that with respect to standard ear yield, Suwan source inbreds SW.Ki28 and SW.CG1 gave good heterosis when crossed with the CIMMYT inbred Amarillo Dentado-63 and Tropical Corn Belt Stiff Stalk inbred Trop.SS.CG3. The high potential inbreds with highest yielding performance of baby corn were SW.Ki 28, Amarillo Dentado-63 and SW.CG1. Inbreds SW.Ki28 and Amarillo Dentado-63 had a highly significant positive GCA effect for all important economic yields of baby corn.

Table 8. Mean yields of fresh dehusked baby corn (kg/rai) tests in five provinces. 1991.

Variety	Locations 1/ (kg/rai)					Mean	% Check
Planted:	KB 24/7/91	RB 8/7/91	SS 25/8/91	PC 24/9/91	CM 4/10/91		
KBTX 3501	171.0	160.1	163.2	183.0	158.0	167.0	147
Suwan 3101	161.0	132.4	152.1	160.2	127.0	146.5	129
CM 90	145.0	128.1	141.3	151.0	107.3	134.5	118
NS 1(S)C1F2	123.2	122.0	120.2	149.1	103.5	123.6	109
Super Sweet DMR	98.5	91.0	92.6	128.6	90.5	100.2	88
Suwan 2(S)C7 (check)	116.0	105.0	103.4	143.0	101.2	113.7	100
Mean	141.9	132.3	134.8	153.4	113.3	135.1	

1/ KB = Kanchanaburi; RB = Ratchaburi; SS = Samut Sakhon; PC = Pichit; CM = Chiang Mai.

Table 9. Mean percentage of downy mildew infection of baby corn tested in five provinces. 1991.

Variety	Locations (% DM)					Mean
Planted:	KB 24/7/91	RB 8/7/91	SS 25/8/91	PC 24/9/91	CM 4/10/91	
KBTX 3501	0.2	0.2	0.8	0	0	0.2
Suwan 3101	2.3	3.5	2.9	0	0	1.7
CM 90	6.5	14.2	7.8	9.0	0	21.5
NS 1(S)C1F2	8.5	5.0	6.3	5.0	1.2	5.2
Super Sweet DMR	15.2	17.7	18.3	5.0	10.0	13.2
Tien	100	100	100	95.3	91.3	97.3
Tien + Apron 35SD	0.8	58.6	0	100	0	31.8
Suwan 2(S)C7 (check)	0.2	1.7	0.4	0	0	0.4
Mean	10.8	16.6	17.2	16.6	8.1	13.9

Remarks: KB = Kanchanaburi; RB = Ratchaburi; SS = Samut Sakhon; PC = Pichit; CM = Chiang Mai.

Table 10. Mean yields of fresh baby corn with husk, dehusked, and percentage of downy mildew infection in five provinces. 1991. 1/.

Variety	Fresh weight (kg/rai) With husk	Fresh weight (kg/rai) Dehusked	% of check	Downy mildew %
KBTX 3501	1,072.2	167.0	147	0.2
Suwan 3101	715.7	146.5	129	1.7
CM 90	836.0	134.5	118	21.5
NS 1(S)C1F2	875.6	123.6	109	5.2
Super Sweet DMR	675.8	100.2	88	13.2
Tien	-	-		97.3
Tien + Apron 35SD	-	-		31.8
Suwan 2(S)C7 (check)	783.8	113.7	100	0.4
Mean	873.9	135.1		13.9

1/ The five provinces were: Kanchanaburi, Ratchaburi, Samut Sakhon, Pichit and Chiang Mai.

2. Evaluation of inbred lines extracted from early versus late cycles of Suwan 1.

2.1. In comparing yields of single crosses derived from inbreds extracted from Suwan 1(S) cycles 4, 5 and 6, Suphanviwat *et al.* (1987) found that the inbred lines which showed good general combining ability in cycle 4 were Ki3, Ki9, and Ki17; those in cycle 5 were KCP 1-5-S5-2-21, KCP 1-5-S5-5-5-1, and KCP 1-5-S5-40-2-3; those in cycle 6 were KCP 1-6-S5-349-1-1, KCP 1-6-S5-424-1-3 and KCP 1-6-S5-695-1-2.

Table 11. Mean grain yield and yield relative to a check hybrid Suwan 3101, of 4 Kasetsart Single Crosses tested at experiment stations and farmer's fields in Corn Belt areas over 5 years (1988 through 1992).

Variety	Mean grain yield (kg/ha) 1/						% of SW3101	No. Expts.
	1988 2/	1989 3/	1990 4/	1991 5/	1992 6/	Average		
KSX 3501	7991	7564	6230	7825	8198	7680	108.7	109
KSX 3502	-	8366	6433	8959	8896	7835	108.5	48
KSX 3503	-	-	6947	7369	8260	7703	110.3	63
KSX 3504	-	-	7911	7394	8353	7876	110.1	61
SW 3101	7653(2	6898(3	6055(10)	7233(38)	7408(24)	7063	100.0	109
SW 3101	-	7555(3	6183(13)	8212(8)	8081(22)	7219	100.0	46
SW 3101	-	-	6913(3)	6665(35)	7438(25)	6984	100.0	63
SW 3101	-	-	6913(3)	6690(29)	7645(29)	7155	100.0	61

1/ Value in brackets is the number of experiments.
2/ Data taken from Chutkaew *et al.*(1989).
3/ Data taken from Chutkaew *et al.* (1990); Thiraporn *et al.*(1990); NCSRC (1989); Grudloyma 1990.
4/ Data taken from the KU Corn Breeding Project; Thiraporn *et al.* (1991).
5/ Data taken from the KU Corn Breeding Project; Thiraporn *et al.*(1992); Boonrumpun (1992); NCSRC (1991); Noradechanon *et al.* (1992).
6/ Data taken from the KU Corn Breeding Project; Boonrumpun *et al.* (1993); NCSRC (1992); Noradechanon *et al.* (1993).

2.2 From yield evaluation of 45 single crosses derived from inbreds extracted from Suwan 1 cycles 4,5,6,7,8 and Amarillo Dentado C5, Sittipanuwong *et al.* (1988) found that twenty-four out of the 45 crosses yielded higher than the mean yield, and 20 of these were crossed using inbreds of the two varieties. The cross of Ki27 x Amar. Dent. (FS) C5-S5-9-5-1-1 gave the highest yield of 1,081 kg/rai, which was 114% of the check KTX 2602, but this apparent yield advantage was not significant.

3. New Kasetsart Single Crosses (KSX) are 3501, 3502, 3503 and 3504. These were developed using inbreds Ki32, 36, 43 and 44 crossed with Ki21. In tests over five years (1988-92), Aekatasanawan *et al.* (1993) found that KSX 3501, KSX 3502, KSX 3503, and KSX 3504 produced mean yields of 7,680, 7,835, 7,703 and 7,876 kg/ha, which was higher than Suwan 3101 by 8.7, 8.5, 10.3 and 10.1% in 109 (5 yrs), 48 (4 yrs), 63 (3 yrs), and 61 (3 yrs) experiments (**Table 11**). Regression coefficients showed that the four single crosses adapted well from low to higher level of environments (**Table 12**). Some of their agronomic traits e.g. stalk lodging, husk cover, and rotten ears (**Table 13**) were better than those of Suwan 3101.

Table 12. Mean grain yield, regression coefficient (b), and deviations from regression (S^2d) of 4 Kasetsart Single Crosses tested at different locations in 1989, 1991, and 1992 by the National Corn and Sorghum Research Center (NCSRC) and the Nakorn Sawan Field Crops Research Center (NSFCRC).

Variety	NCSRC (1989)			NSFCRC (1989)			NCSRC (1991)			Noradechanon (1992)			NCSRC (1992)		
	Mean yield	b	S^2d	Mean yield	b	S^2d	Mean yield	b	S^2d	Mean yield	b	S^2d	Mean yield	b	S^2d
	kg/ha														
KSX 3501	8351	0.75	0.35	7170	0.96	1.21**	8534	0.90	0.25**	7625	0.54	**	8095	1.18	0.15
KSX 3502	-	-	-	-	-	-	-	-	-	-	-	-	8066	0.79	0.16
KSX 3503	-	-	-	-	-	-	8725	1.18	0.22**	7069	0.65	**	8100	1.37	0.31**
KSX 3504	-	-	-	-	-	-	8726	1.06	0.18**	-	-	-	8097	0.77	0.22**
SW 3101	8010	0.73	0.15	6660	1.02	0.63**	7803	1.11	0.21**	8544	0.85	**	7196	1.10	
Mean	7572			5880			7529			6181			9.4		
C.V. (%)	8.1			11.8			8.5			5.1			350		
LSD(0.05)	644			360			296			175			460		
LSD(0.01)	850			480			389			231			8		
No. locations	7			7			9			6					

** Significantly different at the 0.01% probability level

4. Prevention and control of aflatoxin in corn. Research on prevention and control of aflatoxin in corn by using conventional and biotechnological methods has also been carried out by the Corn Breeding Project of KU with the cooperation of workers in many disciplines and financial support from 1988-1991 from the National Science and Technology Development Agency (NSTDA). The results indicate that there are possibilities for solving the problem, but that it would take 12-15 years of research and development (Chutkaew, *et al.*, 1991).

Table 13. Agronomic characters of four Kasetsart Single Crosses from 1992 Cooperative Hybrid Corn Yield Trial tested at eight locations. NCSRC. 1992.

Character	KSX 3501	KSX 3502	KSX 3503	KSX 3504	Check varieties SW 3101	SW 1(S)C11	NS1
Days to 50% silking (d)	53	52	51	52	52	53	51
Plant height (cm)	188	174	169	166	175	193	183
Ear height (cm)	117	98	97	97	101	105	98
Stalk lodging (%)	13.2	11.5	10.4	10.4	13.5	11.4	14.6
Foliar diseases (1-5) 1/	1.6	1.8	1.4	1.5	1.7	2.0	2.1
Downy mildew (%) 2/	0.3	0.7	3.0	5.0	3.0	0.1	-
Husk cover (%)	0.3	0.5	0.4	1.5	2.4	4.3	8.2
Rotten ear (%)	3	4	2	3	19	13	9
Ears/plant (%)	100	100	98	98	99	98	97
Grain moisture (%)	25.4	23.6	24.7	24.7	24.4	24.8	23.3
Shelling (%)	80	80	79	81	79	78	80
Grain type, color 3/	OYSF	OYF	OYSF	OYSF	OYSF	OYF-SF	OYF-SF

1/ : 1 = Good, 5 = Poor.
2/ : From S. Titatarn (1992, unpublished data).
3/ : OY = Orange-Yellow, F = Flint, SF = Semiflint.

5. New Kasetsart high oil hybrids. Chutkaew *et al.* (1992, 1993) and Chutkaew (1993c), reported that the potential high oil hybrid corn KOSX 3503 tested by both public and private sector cooperatives at nine locations during 1990-92, yielded 1,379 kg/rai with 7.2% oil, 19% higher than the check, Suwan 3101 (1,160 kg/rai, 5.8% oil) (**Table 14**). The benefit of high oil corn fed to hogs was feed savings of 6.1% per unit of gain in body weight, reducing the protein in feed composition (Nordstrom, *et al.*, 1972; Han *et al.*, 1987). The skins of chickens fed with high oil corn are more attractive to consumers than those of birds fed with normal corn. High oil corn is high in nutritive value for humans because it contains up to 80.12% unsaturated fatty acid, higher than in many other vegetable oils. It also contains essential amino acids, 42% of which is linoleic acid, capable of reducing cholesterol in the human body by stimulating the utilization of cholesterol in synthesizing hormones, including sex hormones and other important substances in the body. Since it is so useful as food and feed, high oil corn has been studied for about 25 years (Chutkaew et al., 1970, 1979, 1980, 1992, 1993; Manupeeraphan *et al.*, 1982; Jongmee *et al.*, 1986, Chutkaew, 1993c).

Table 14. Mean grain yield (kg/rai) of high oil hybrid corn tested in nine experiments at different locations and season. 1990-1992.

Character	KSX 3501	KSX 3502	KSX 3503	KSX 3504	Check varieties SW 3101	SW 1(S)C11	NS1
Days to 50% silking (d)	53	52	51	52	52	53	51
Plant height (cm)	188	174	169	166	175	193	183
Ear height (cm)	117	98	97	97	101	105	98
Stalk lodging (%)	13.2	11.5	10.4	10.4	13.5	11.4	14.6
Foliar diseases (1-5) 1/	1.6	1.8	1.4	1.5	1.7	2.0	2.1
Downy mildew (%) 2/	0.3	0.7	3.0	5.0	3.0	0.1	-
Husk cover (%)	0.3	0.5	0.4	1.5	2.4	4.3	8.2
Rotten ear (%)	3	4	2	3	19	13	9
Ears/plant (%)	100	100	98	98	99	98	97
Grain moisture (%)	25.4	23.6	24.7	24.7	24.4	24.8	23.3
Shelling (%)	80	80	79	81	79	78	80
Grain type, color 3/	OYSF	OYF	OYSF	OYSF	OYSF	OYF-SF	OYF-SF

1/ : 1 = Good, 5 = Poor.
2/ : From S. Titatarn (1992, unpublished data).
3/ : OY = Orange-Yellow, F = Flint, SF = Semiflint.

6. Asian International Hybrid Corn Trials. With the initiation of the first author, Drs. Salazar, Logrono (Philippines), and Tseng (Taiwan), the First Asian International Hybrid Corn Trials wre conducted in February 1992 in these three countries. The results are shown in Tables 15, 16, and 17).

Table 15. Mean grain yield and agronomic characters of entries in International Hybrid Corn trial. Farm Suwan 1993 dry season.

Entry No.	Pedigree	Yield at 15% moist kg/ha	Days to 50% silk	Height (cm) Plant	Height (cm) Ear	Lodging Stalk (%)	Lodging Root (1-5)	Foliar dis. (1-5)	Husk cover (1-5)	Aspect (1-5) Plant	Aspect (1-5) Ear	Ear/plt (%)
18	KSX 3504	7014	71	183	99	6	1.5	1.5	1.9	1.5	1.7	93
12	Ki 21 x Ki 42	6924	71	193	106	1	1.7	2.3	1.7	2.0	2.3	92
7	Ki 39 x Ki 42	6897	72	184	105	4	1.6	1.5	3.0	1.5	2.2	95
10	Ki 29 x Ki 42	6844	74	204	101	4	1.9	3.0	2.3	2.2	2.0	95
11	KSX 2903 x Ki 42	6782	73	199	107	3	1.5	2.0	2.5	2.0	2.0	95
9	Ki 37 x Ki 41	6470	75	202	100	2	1.5	2.5	3.0	2.0	2.0	97
13	Ki 27 x Ki 42	6335	74	190	103	2	1.3	2.7	2.0	2.3	2.0	97
14	Ki 43 x KSX 2903	6235	70	204	98	2	2.0	2.7	2.0	2.2	1.5	95
5	Ki 43 x Ki 42	6177	78	204	107	1	1.0	2.5	1.0	2.0	2.0	93
3	KSX 3501 x Ki 42	6109	78	211	112	3	2.0	1.7	2.2	1.7	1.5	94
17	Suwan 3502	6110	74	176	96	3	2.3	1.7	1.5	1.9	2.0	95
15	Ki 42 x Ki 32	5722	76	214	110	4	2.5	2.0	1.2	2.0	2.0	91
2	Ki 37 x Ki 42	5714	73	211	102	2	2.3	1.7	2.0	1.7	2.2	101
1	KESX 9902 x Ki 42	5664	75	217	118	1	2.7	1.7	1.2	1.7	2.0	92
9	Ki 35 x Ki 42	5490	74	195	95	1	1.2	2.7	2.7	2.3	2.0	93
0	Ki 43 x Ki 41	5433	73	193	64	3	2.2	2.2	1.9	2.2	2.2	99
4	KESX 9902 x Ki 42	5390	74	205	113	5	2.3	1.5	2.3	2.0	2.2	95
16	Suwan 3101 (check)	6056	71	179	97	5	2.3	1.7	1.9	1.9	2.3	91
	Mean	6199	74	199	103	3	1.7	2.1	2.0	2.0	2.0	95
	C.V. (%)	15.1										
	LSD (0.05)	1554										
	LSD (0.01)	2087										

Table 16. Mean grain yield and agronomic characters of entries from Philippines in International Hybrid Corn Yield Trial. Farm Suwan 1992 late season.

Entry No.	Pedigree	Origin	Grain yield (15% moist) kg/ha	Relat. to check (%)	Days to 50% silk	Plant hgt (cm)	Ear hgt (cm)	Root Lodging	Foliar dis. (1-5)	Husk cover (1-5)	Aspect (1-5) Plant	Aspect (1-5) Ear	Seed char.
9	KTX 8902 x AHO-3-4	SW 91E-B10	9348	125	57	240	133	2.0	2.0	2.0	1.5	1.0	OSF
6	IPB x H 941		6649	89	54	193	101	2.5	2.5	2.0	2.5	1.3	OYSF
11	TX 471	SW 90D-C11	6348	85	51	225	110	2.7	2.5	2.7	2.5	1.3	OYSF
10	SX 47	SW 90D-C11	6284	84	53	201	116	2.3	2.3	2.8	2.3	1.5	OYSF
1	IPB x H 911		6172	82	55	183	92	2.5	2.7	2.5	2.5	1.0	OYSF
2	IPB x H 913		5704	76	54	195	93	2.3	2.5	1.8	2.5	1.5	OYSF
5	IPB x H 929		5594	75	55	185	96	2.7	2.7	2.7	2.7	1.7	OYSF
7	IPB x H 943		5568	74	54	200	104	2.3	2.5	2.8	2.5	1.5	OYSF
3	IPB x H 921		5425	72	55	184	104	2.8	2.5	2.3	2.7	1.5	OYSF
4	IPB x H 927		4622	62	55	209	115	3.0	2.7	2.7	2.7	1.3	OYSF
8	Pool 1 Bal. buk		3594	48	56	201	103	3.3	3.0	3.0	2.8	1.8	OSF
12	Suwan 3101 (check)	SW 91E-Com.	7501	100	51	201	112	2.3	2.0	2.5	2.0	1.2	OSF
		MEAN	6067		54	201	107	2.6	2.5	2.5	2.4	1.4	
		C.V. (%)	11.7										
		LSD (0.05)	1205										
		LSD (0.01)	1638										

Table 17. Mean grain yield and agronomic characters of entries from Taiwan in the International Hybrid Corn Yield Trial. Farm Suwan 1992 late season.

Entry No.	Pedigree	Origin	Grain yield (15% moist) kg/ha	Relat. to check (%)	Days to 50% silk	Plant hgt (cm)	Root Lodging	Foliar dis. (1-5)	Husk cover (1-5)	Aspect (1-5) Plant	Aspect (1-5) Ear	Seed char.
11	KTX 3501	SW 91E-B10	10035	131	57	224	1.7	1.7	1.5	1.7	1.0	OSF
7	P 61592-7-5-3-2 X p 7910376-7-1-2-1-1		5967	78	56	196	2.8	2.3	3.0	2.5	1.5	OSF
8	P 3228-5-5-5-1 x P 7910376-7-1-2-1-1		5858	77	55	190	2.8	2.0	2.7	2.5	1.5	OSF
1	Thai-101-CVR x Hi 31		3433	45	51	191	2.5	2.5	2.7	2.5	2.8	YOSF
9	P 10-2-3 x Suwan 9-1-1		3364	44	51	187	2.8	2.5	2.3	3.0	2.3	OYSF
10	Suwan 9-1-1 x Mo 17 (HT)		3255	43	52	190	3.0	2.7	2.2	3.0	2.2	OYSF
2	Suwan 9-1-1 x Hi 31		2707	35	54	198	2.7	2.5	2.5	2.5	2.8	OYSD
4	P 3184-1-3-1 x Suwan 9-1-1		2676	35	54	177	2.8	2.8	2.5	2.8	2.5	OYSD
6	P 3184-1-3-1 x PR 10-1-1-2		1920	25	51	161	3.3	3.0	3.0	3.0	2.2	YSD
3	P 3184-1-3-1 x ICAL 210		1361	18	53	167	3.2	2.8	3.3	3.0	3.5	YSD
5	P 3184-1-3-1 x PR 10-1-5-2		1347	18	54	167	3.3	3.0	2.7	3.3	2.8	YSD
12	Suwan 3101 (check)	SW 91E-Com.	7652	100	54	204	2.0	2.0	2.0	2.0	1.3	OYSF
		MEAN	4131		53	188	2.7	2.5	2.5	2.7	2.2	
		C.V. (%)	13.4									
		LSD (0.05)	935									
		LSD (0.01)	1270									

7. International cooperation. The establishment of the Inter-Asian Corn Program in 1964, the Asian Regional Maize program in 1981, and the Tropical Asian Maize Network (TAMNET) in 1993, indicates the good cooperation within the corn industry in Asia which extends to other regions of the world.

In addition to the above described results, another important benefit of this research and development (R & D) work has been that a number of graduate students have been involved and have thereby gained skills and experience which will enable them to increase maize productivity and production.

Conclusions

The following observations on the success of corn research and development in Thailand have been cited by Chutkaew (1993):

1. It has depended in part upon cooperation through different agencies: USAID, Rockefeller Foundation, CIMMYT, FAO and of visiting scientists.
2. Introduced germplasm has been of prime importance.
3. Appropriate germplasm and breeding procedures have been utilized.
4. Cooperation among researchers in "Teamwork" has been important in R&D and testing materials developed over locations, seasons and years.
5. Through continued experiments, experience has been gained in analyzing and interpreting data, crucial in making progress in corn breeding.
6. There are capable successors to devote their efforts to continue ongoing research and initiate new projects to produce new varieties.
7. In view of the limitation of natural resources and other environmental problems, one area in which research should be conducted is in exploiting the marvelous corn plant even more so that full use can be made out of it.

References

Aekatasanawan C., S. Jampatong, and C. Chutkaew. 1993. New Kasetsart Single Cross-Hybrid Corn: KSX 3501, KSX 3502, KSX 3503, and KSX 3504. Proc. 31st Annu. Conf. Plt. Sci. 31:193-199.

Agricultural Statistics of Thailand, Crop Year 1964-1990. Ministry of Agriculture and Co-operatives.

Chutkaew, C., S. Pookawasa, and A. Senanarong. 1970. A preliminary study on oil content in corn. Proc. Natl. Conf. Agric. and Biol. Sci. 9:98-104. (in Thai).

Chutkaew, C., N. Iamsupasit, S. Thaiwase, P. Srisukprasert, S. Noradechanont, and P. Jantawong. 1979. A preliminary study on oil content in corn. Annu. Conf. Plt. Sci. 17. Abstr. (in Thai).

Chutkaew, C., P. Puddhanon, P. Jan-aram, and S. Noradechanont. 1980. Evaluation of corn grain yield and oil content. Annu. Conf. Plt. Sci. 18. Abstr. (in Thai).

Chutkaew, C. 1982. Maize improvement in Thailand. *In* Progress of Plant Breeding: 75-91. Dept. of Agric., Bangkok.

Chutkaew, C., T. Lekakul, and V. Benjasil. 1983. New young ear corn. Kasetsart Extension J. 6:9-15.

Chutkaew, C. 1985a. Hybrid Maize of Kasetsart Univ. *In* Plant Breeding II: 7-27. Dept. of Agric., Bangkok.

Chutkaew, C., Sriwatanapongse, S. Jampatong, B. Paisuwan, and C. Aekatasanawan. 1985b. Development of Kasetsart Univ. maize hybrids. Proc. 5th Intl. Cong. (SABRAO). Thailand: 263-277.

Chutkaew, C. 1986. Maize production and research in Thailand. Proc. 2nd Asian Regional Maize Worshop: 104-108. Jakarta, Indonesia.

Chutkaew, C., S. Jampatong, C. Aekatasanawan. 1987. Potential Kasetsart Synthetic 4 corn, KS 4, high yielding variety: 272-282. Proc. 5th Genetics Seminar. (In Thai).

Chutkaew, C., S. Jampatong and C. Aekatasanawan. 1989. Research and development of corn variety Suwan 3. Proc. 27th Annu. Conf. Plant Sci: 161-172.

Chutkaew, C. 1989. Successful utilization of germplasm for maize improvement in Thailand. Proc. 6th Intl. Cong. Soc. Advancement of Breeding Researches in Asia and Oceania (SABRAO): 645-648.

Chutkaew, C. 1990. Research on field corn production in the paddy field. Internatl. Seminar on Integrated technology of field corn production in the paddy field. College of Agriculture, Univ. Philippines at Los Banos (UPLB). March 26-31.

Chutkaew, C., C. Aekatasanawan and S. Jampatong. 1991. Prevention and control of aflatoxin in corn I. Corn breeding. Proc. 29th Annu. Conf. Plant Sci. 29:525-530.

Chutkaew, C., P. Wannapee and C. Chainuvati. 1992. Integrated technology and cooperation in field corn production in the paddy field. College of Agriculture, Univ. Philippines at Los Banos (UPLB). February 24-29.

Chutkaew, C., C. Aekatasanawan, and S. Jampatong. 1992. Development of high oil hybrid corn in Thailand. Proc. SABRAO International Symposium on Impact of Biological Research on Agricultural Productivity: 95-104. Taichung, Taiwan, R.O.C.

Chutkaew, C. 1991. Supply analysis for corn in Thailand. Faculty of Agric. Econ. Ramkamhang Univ.

Chutkaew, C. 1993a. Maize research and development in Thailand. 1st South-East Asian Maize Workshop. Asian Inst. Technol., Thailand: 122-143. January 12-15.

Chutkaew, C. 1993b. Half-Century KU and her latest decade of corn development. Proc. 31st Annu. Conf. Plant Sci. 31:216-228.

Chutkaew, C. 1993c. High oil hybrid corn developed from exotic and indigenous inbred lines. 10th Australian Plant Breeding Conf., Gold Coast. April 18-23.

Chutkaew, C., U. Pupipat, P. Juthawantana, V. Lertmongkol, A. Saimaneerat, P. Sinchaisri, S. Noradechanon, and S. Sonwai. 1993. Potential high oil hybrid corn of KU. Proc. 31st Annu. Conf. Plant Sci. 31:207-215.

Han, Y., C.M. Parsons, and D.E. Alexander. 1987. Nutritive value of high oil corn for poultry. Poultry Sci. 66:103-111.

Jongmee, S., C. Chutkaew, T. Manupeerapan, and P. Srinives. 1986. S2-lines testing for inbred extraction and hybrid production in high oil corn. Proc. 24th Annu. Conf. Plant Sci. 1:79-87.

Manupeerapan, T., C. Chutkaew, S. Noradechanon, and P. Puddhanon. 1982. Corn improvement for high oil. Proc. 20th Annu. Conf. Plant Sci.: 104-105.

Nordstrom, J.W., B.R. Brecrends, R.J. Meade, and E.H. Thompoon. 1972 Effect of feeding high oil corns to growing-finishing swine. J. Animal Sci. 35:357-361.

Sittipanuwong, S., C. Chutkaew, A. Silapapun, and S. Oupadissakoon. 1988. Yield evaluation of single crosses hybrid corn from inbreds extracted from Suwan 1 cycles 4,5,6,7,8 and Amarillo Dentado cycle 5. Proc. 26th Annu. Conf. Plant Sci.: 235-240.

Suphanvivat, S., C. Chutkaew, C. Rojanaridpiched, and S. Oupadissakoon 1987. Yield testing of single crosses from inbred lines extracted from Suwan 1 (S) C4, C5 and C6. Proc. 25th Annu. Conf. Plant Sci.: 173-180.

Titatarn, S., V. Titatarn, D. Anchareesangas, S. Sompong, M. Muangnoicharoen, V. Sritaves, and A. Bamrungkit. 1992. Screening for baby corn varieties resistant to downy mildew in baby corn production areas in Thailand. 11th Natl. Vegetable Annu. Report: (8)-(1)-(7).

Trakoontiwakorn, P., C. Chutkaew, T. Kunta, and P. Chandhanamutta. 1993. Heterosis in baby corn hybrid. Proc. 31st Annu. Conf. Plant Sci.: 167-174.

Questions to the author:

FROM : M. M. Palikhe

Q : It looks to me that upgrading the Suwan 1 variety by continuous selection may reduce its genetic variability, and the resulting variety may be susceptible to insects, disease, and environmental factors.

A : We applied S1 recurrent selection in every cycle and considered yield, diseases, and insect resistance along with agronomic characters and other traits of interest, and from our evaluation of both Suwan 1 from cycle zero (CO) to cycle 11 (C11) (Suwan 1 Co-C11) and Suwan 3 (CO-C5) found that selection is still positive in both populations.

FROM : N. N. Singh

Q : Why is it that since last year production and productivity of maize in Thailand have not increased inspite of the better cultivars and quality seed available from public and private seed agencies?

A : This is because corn planted areas have been replaced by sugarcane, cassava, and other crops plus drought hazards. The price of corn has also been another important factor to explain the decrease of of total corn production of the country.

AGRONOMIC RESEARCH ON MAIZE AT KASETSART UNIVERSITY, THAILAND. 1991-1993.

Rachain Thiraporn [1/]

Introduction.

Maize (*Zea mays L.*) is an important feed grain mostly produced in the North, northeast, and central regions of Thailand. More than two thirds of the production is used domestically by feed industries, and the rest is exported accounting for 7% of the world market. Maize exports contribute substantially to foreign exchange earnings of the country (Office of Agric. Economics, 1992). In recent years, rapid expansion of the livestock industry has triggered an increased demand for maize affecting the exports of the grain.

However, the gross production of maize is still below the amount targeted by the National Economic and Social Development Plan. Agronomic research to increase productivity in farmers' fields is important to raise the national economic level.

Previous studies reported that the appropriate planting rate of 3 corn varieties, Guatemala CMS-PB 5, Puerto Rico Gp.1, and Veracruz 181 x Antigua Gp.2 grown in the early and late rainy seasons, ranged from 6400-8500 plants/rai (Owaht *et al.*, 1970) (1 ha=6.25 rai). In 1971, Owaht *et al.* also reported that using 5 different densities ranging from 6,400 to 17,000 plants/rai of 5 corn varieties, the number of ears/plant showed a negative correlation with plant density. Yields of all entries did not differ within densities. However, treatments of 8,500 plants/rai or more tended to yield lower. Supot *et al.* (1971) studied the response to high plant density (32,000 to 16,000 plants/rai) of 2 corn varieties, Cuba 11 x Georgia Cow Corn-Prolific, and Guatemala PB 8. It was found that the number of barren plants increased as the plant density increased. Barreness in Guatemala PB 8 was nearly 10% higher than in Cuba 11 x Georgia Cow Corn-Prolific. In 1982, Supot *et al.*, studied the optimum density of Suwan 1 and Suwan 2301 planted at various densities. Results indicated that the optimum planting rates of Suwan 1 and Suwan 2301 were 9,600 and 14,800 plants/rai, respectively, but grain yields from both planting rates were not different from that of 8,500 plants/rai. In 1981 the Dept. of Agriculture, Ministry of Agriculture and Cooperatives, recommended 7,000 and 8,500 plants/rai in low to moderate soil fertility, and 12,000 plants/rai in fertilized soil. Supot *et al.* reported that the optimum density for growing corn for silage was 1-1.5 times higher than that for grain production.

Studies on the effects of various rates of nitrogen on corn yield and quality have also been reported. In 1978, Thiraporn *et al.* reported that six corn varieties planted at 0, 30, 40 and 80 kg N/rai at Farm Suwan showed different results of N-response which could be classified into 3 groups as low, medium, and high input varieties. Another unpublished report by Thiraporn on N-use efficiency of 16 corn varieties indicated that selection under N-stress could improve the yield response of low N selections such as Across 8328 C3, which yielded higher than the original population Across 8328 C0. Feil *et al.* (1992) studied N, P and K content of Suwan 2301 compared with CP1. Both entries were grown in different N-fertilization treatments at Farm Suwan. The results revealed that N-content in seed increased with N-fertilization. The response was higher in Suwan 2301 than in CP 1. It was also found that with N levels of 80-160 kg N/ha the assimilation of P and K was more efficient than in low N. Thiraporn *et al.* (1992) indicated that N fertilization increased levels of N, P, and K in the grain.

There are three distinct maize growing seasons in Thailand. Each year, the rainy season extends from March to November. Early rains generally begin in March and extend up to mid-June. There is a dry spell during June to July, and the late rainy season extends from August to mid October. Corn and other rain-fed field crops are grown in the early and late rainy seasons.

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Early rainy season plantings have a higher risk of drought damage. In 1987, Tawatchai *et al.* evaluated the drought tolerance of 40 corn varieties by calculating harvest index, and reported that Hercules 31 and Hercules 40 gave the highest yields under both drought stress and good water conditions.

A summary of our results on trials planted during 1991-1993, follows:

1. **Varietal improvement.** Most of the improved varieties evaluated had higher grain yields than the checks. Highest yield was found in single cross hybrids. KS 5, the best open pollinated variety, yielded as much as the commercial hybrids Suwan 3101 and Car.633 and it was significantly higher than Suwan 2602, Pac.9715 and DK 211.
2. **Population density.** Results showed that when plant densities were over 53,333 plants/ha, yield tended to increase but there was a decrease in ears/plant and ear weight. Higher plant densities increased yield significantly with appropriate times and rates of fertilizer.
3. **Forage use.** The new open pollinated variety Suwan 5 was tested for forage yield under high population density. Times for best silage and grain yield were 90 and 115 days after planting, respectively.
4. **Removal of leaves.** Results indicated that at anthesis stage, the removal of leaves above and below the ear, and total removal of the leaves, caused 42, 22, and 93.4% yield loss, respectively. Removing the tops at 2, 3, and 4 weeks after silking also significantly reduced the yield.
5. **Fertility:** Studies on response of corn to nitrogen fertilizer and ability for N-P-K uptake indicated that grain yield and biomass increased considerably with up to 80 kg N/ha. Higher levels (160 kg N) did not increase the biomass, and only slightly increased yield. The response of harvest index was not uniform with increasing rates of N. Nitrogen fertilization increased yields of grain N, P, and K. The effect of increasing rates of N on P and K concentrations in the grains was different. Total uptake of N and P increased to 160 kg N, and K up to 80 kg N. The N harvest index was slightly affected by N fertilization, whereas the K harvest index tended to increase, and the P harvest index increased with increasing rates of N. The weights of N, P, and K in the kernel remained stable or increased slightly with increasing rates of N fertilizer.

   Fertilizer trials indicated that varieties differed in their response to various fertilizer formulations. The variety Across 8328 C3, tolerant to low n stress yielded significantly higher than the original Across 8328 CO.
6. **Drought:** Drought stress at preflowering stage caused an increase of ASI value, reduction in plant height and ears/plant as well as ear and grain weights. Under rainfed conditions, both CIMMYT germplasm and Thai improved germplasm had lower grain yields than when under irrigated conditions being reduced by 44.9 and 25.2% respectively. Response of various corn varieties tested at different stages of growth indicated that yield was significantly correlated to a drought index at any stage of development.

ACHIEVEMENTS OF MAIZE RESEARCH AND PRODUCTION IN VIETNAM

Tran Hong Uy [1/]

Abstract

The report presents important aspects of the role of maize in the food production strategy followed in Vietnam. To fullfil the production requirements in recent years the National Maize Program has implemented several measures to increase production and productivity, such as:
1. Released several OPV's to be grown in predominantly marginal regions. These OPV's are TH-2A, TH-2B, VM-1, MSB-49, TSB-1, TSB-2, HLS, HL-36, DT-6, and Q-2.
2. Developed hybrid maize cultivars to be used in intensive farming areas. These are non-conventional hybrids i.e. LS-3, LS-4, LS-5, LS-6, LS-7, LS-8, and conventional hybrids LDSB-1, LDSB-2, LDSB-3, LVN-6, LVN-10, LVN-11, LVN-12, and LVN-14.
3. Released advanced maize production technologies to farmers such as the technique of transplanting maize on wet soil after two rice crops, increased productivity using early maize varieties tolerant to drought in the mountainous areas, and the technique of transplanting winter maize in zero tillage. The report also indicates some activities on agricultural extension on maize in Vietnam.

I. Role of maize cultivation in food production in Vietnam

The food production program is one of three major programs worked out by the Vietnamese government to satisfy domestic demand for human food and animal feed, and gradually to enter the export market in the Asian region. Maize is second to rice as a food crop. In 1992, there were 6,400,000 ha planted to rice with a total output of 21.5 mt. That same year, there were nearly 500,000 ha planted to maize with a total production of over 900,000 t (**Fig. 1**).

By the year 2000, the population of Vietnam is estimated to reach about 80 m. Therefore, required food production will be 29 to 30 mt of food grains, including 25-26 mt of rice, 3 mt of maize, and 1-2 mt of other food crops (Uy, 1990).

This is a very ambitious target. However, thanks to the renovation and open door policies decided by the government, our economic growth rate will increase. This will result in improvement of our people's living standard and there will be more demand for grains as well as their by-products. It will be possible to attain this objective provided there are sound policies to rapidly increase average yields, lower costs of production with a view to bringing profits to farmers, and keep a level of competitivity in the international market.

Data in **Table 1** indicates the production of the two most important cereal crops in Vietnam during the period of 1985-1992.

II. Achievements in maize breeding

In Vietnam, the maize research institution was founded rather late in comparison with other countries. It was not until September 1973, that the first maize research institution of the maize program was established at the Song Boi Maize Research Station Hao Binh province, 90 km SW of Hanoi. In 1987, our government decided to shift the Song Boi Maize Research Station to the National Maize Research Institute (NMRI), with headquarters in Dan Phuong district, Ha Tay province, 20 km West of Hanoi.

Since 1973, two activities were envisioned for the maize breeding work:
1. To develop open pollinated varieties (OPVs) from domestic and imported tropical germplasm, suitable to ecological conditions of Vietnam (Uy, 1990) to gradually replace the low yielding

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[1/] Director, Natl. Maize Res. Inst. (MMRT), Dan Phuong, Ha Tay, Vietnam.

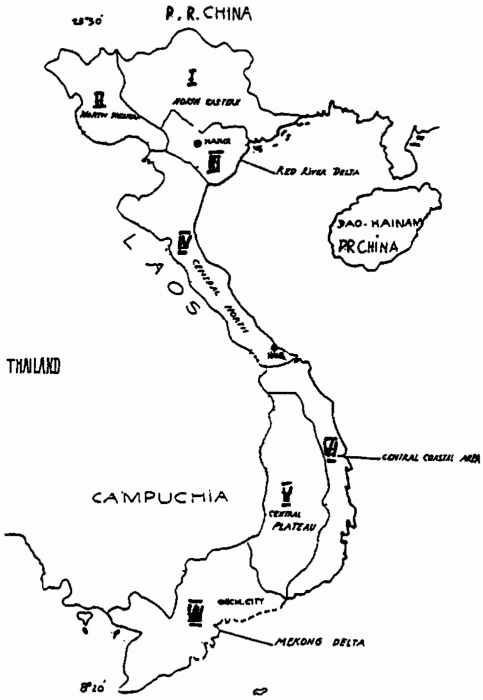

Fig. 1. Maize growing regions in Vietnam.

Table 1. Total output and acreage planted with rice and maize in Vietnam.

Year	Production (equivalent to paddy) ('000 t)			Area ('000 ha)		
	Rice	Maize	Total	Rice	Maize	Total
1985	15874	587	18200	5703	397	6833
1986	16002	569	18379	5688	400	6812
1987	15102	561	17562	5588	405	6709
1988	17000	814	19583	5726	510	6967
1989	18996	837	21515	5895	509	7089
1990	19225	671	21488	6027	431	7110
1991	19621	672	21989	6302	447	7448
1992	21500	707	24000	6422	457	7614
1993(estimated)		900			500	

local varieties. These improved OPVs, in the future, will be mainly used in areas with adverse conditions.

2. In concert with the OPV breeding program, strengthen activities on a hybrid breeding program by extracting inbred lines from the improved OPVs, or by importing these inbreds and improving them when possible.

Implementing the above two approaches, from 1973 to 1993, we developed OPVs having higher yields than local varieties, better disease and insect resistances, and wider range of adaptation throughout the country.

- Two synthetics, TH-2A and TH-2B, with average yields of 3-4 t/ha were released for production in 1977 and 1978.
- Composite VM-1, with a yield potential of 5-6 t/ha, was released for production in 1980 and since then has been highly appreciated by our farmers.

Since 1980, thanks to full cooperation with CIMMYT, new possibilities opened up and since then most of our maize varieties originated from CIMMYT's germplasm. For instance, the first two early maize varieties, MSB-49 and TSB-2, with yield potentials of 4-5 t/ha, were released for production in 1983 and 1984. They have been the principal maize cultivars for areas using the transplanting technique on wet land after two rice crops in North Vietnam. Later, 9 intermediate and intermediate-late varieties with good adaptation to many ecological zones of Vietnam with yield potentials of 4-6 t/ha were released from 1985 to 1991.

The OPVs can be grouped as follows:

Early group: HLS, TSB-2, and CV-2, with yield potentials of 3-5 t/ha.

Early-intermediate group: MSB-49, MSB-49B, HL-36, and Q-2, with yield potentials of 4-6 t/ha.

Intermediate and intermediate-late group: TSB-1, CV-1, VM-1, VN-1, and DT-6, with yield potentials of 4-7 t/ha.

Good drought tolerant varieties: VM-1, VN-1, MSB-49, MSB-49B, and CV-1.

Lodging resistant and saline-acid soil tolerant variety: MSB-49.

Downy mildew resistant variety: TSB-1, VN-1, Q-2, CV-1, and CV-2.

The introduction of the improved OPVs has increased the average yields in many areas where intensive farming is practiced as well as in low input maize areas.

III. The hybrid maize program (HMP)

Since the 1970s, the HMP has been costly and difficult to implement. A successful HMP requires time, an adequate budget, and proper orientation.

In the 1960's, some hybrids and inbred lines from Rumania were introduced to Vietnam by the Hanoi Agric. Univ. in cooperation with a Rumanian institution. After 2 years of testing, this program failed even though under the supervision of Rumanian experts.

In 1972 and 1973, several hybrids and inbred lines were introduced from the Martonvasar Inst., Hungary. This program was also unsuccessful and closed. The introduced hybrids and inbred lines had severe adaptation problems in Vietnam:

- Grown duration was too short, 60% less than in Europe.
- *Helminthosporium turcicum* and *H. maydis* incidence was heavy, with a disease scale rating of 8 or 9 (1 = healthy, 9 = highly susceptible)
- All yield components were much reduced.

Therefore, their yield potential very low.

All the data obtained pointed to the conclusion that the European hybrids and inbred lines adapted to temperate conditions were not adaptable to our tropical and humid conditions, and could not be directly utilized in a breeding program in Vietnam.

Based on the above conclusions, since 1973 the National Maize Program of Vietnam, located at its former headquarters in Song Boi Station, initiated two new activities: to create new inbredlines from tropical germplasm i.e. the improved populations; and to import tropical inbred lines. Other international germplasm from different ecological zones had been only used as donors of certain valuable characters.

At present, varietal and nonconventional hybrids have been also developed.

The HMP is being strengthened to develop hybrids mostly to be planted in fertile soil areas with highly intensive farming and irrigation, such as the delta of the Red river, the SE area, the Mekong river, delta and the central plateau area.

In 1988, after 15 years of research, the NMRI had developed three single crosses ready for testing. These were the early maturity hybrid LDSB-1, and the intermediates LDSB-2 and LDSB-3.

In 1991, the total initial area used for hybrid testing was about 500 ha. The test including hybrids developed by NMRI, P-9901, and P-11 imported from Pacific Seed Ltd., DK-888 introduced from CP-Thailand, and Bioseed 9670 introduced from Bioseed Genetics-Vietnam Joint Venture Ltd.

In 1992, the hybrid maize acreage increased sharply to 12,800 ha, of which 80% was planted with the NMRI's hybrids.

In 1993, the area planted to hybrid maize in the whole country is about 40-50,000 ha. For this area, in addition to hybrids developed by official institutions, there are hybrids produced by several seed companies, including those from CP group, Uniseed (Thailand), ICI Seed, Bioseed, Ciba Geigy, and Cargill.

It can be concluded that the above mentioned company hybrids are suitable to the ecological conditions in Vietnam and their yield potential ranged from 6-10 t/ha in the various locations.

For our maize program in particular, the following domestic hybrids have been developed for testing in the recent years:

Non-conventional hybrids:

- Early: LS-3 and LS-5
- Early intermediate: LS-4 and LS-6
- Intermediate late: LS-7 and LS-8

Due to the low price of hybrid seed, its wide range of adaptation, and yield potential of 5-8 t/ha, the area under hybrids has rapidly increased.

Conventional hybrids:

- Single crosses: LDSB-1, LDSB-2, LDSB-3, LVN-6 and LVN-10
- Three-way cross: LVN-11
- Double crosses: LVN-12 and LVN-14.

Yield potential of these hybrids is 5 to 10 t/ha.

III. Achievements on crop management research

The research on crop management practices of maize production has covered several technological aspects including: cropping seasons, densities, fertilizer rates, control of insects and diseases, intercropping maize with soybean or soybean with maize, etc. We will discuss and show the impact of 4 major technologies:

1. **Technique of transplanting winter maize seedlings on wet land after two rice crops:**

This technique was originally studied and tested in 1982 in **Hop Thinh Cooperative, Vinh Phu province** on an area of 5 ha. In 1988, area planted with this technique increased rapidly to 127,000 ha in the Red river delta, central, and northern central areas. Due to this technique, an additional 200,000 t of maize were annually added to the total output of food, contributing to satisfy the demand during the critical food shortages of Vietnam in the 1980s.

It is estimated that 300,000 ha of maize in North Vietnam can be planted following this system, in addition to the conventional maize growing area.

When transplanting maize with seedling balls on wet land, the varieties MSB-49 and TSB-2 have yielded 3-5 t/ha, and hybrid maize cultivars have yielded 5-7 t/ha, when following adequate management practices.

The following crop rotations have been recommended:

Spring rice	+	Early autumn-summer rice	+	Early winter maize
Feb. - May		June - Early Sept.		Sept.-Dec. or Jan.
Spring rice	+	Summer soybean	+	Winter maize
Feb. - May		June - Aug		Sept. - Dec.
Spring groundnut	+	Early autumn-summer rice	+	Winter maize
Feb. - Jun.		June - Early Sept.		Sept.-Dec. or Jan.

Due to the fact that there is one winter maize crop per year, the problem of production of animal feed and fodder can be solved, creating more employment for inactive farmers during the winter season.

Formerly, farmers only obtained 8 to 9 t/ha of rice when only planting two rice crops each year. Now, there is an additional winter maize crop per year, and they can get 12-13 t of food per year.

At present, we are establishing models to produce 20 t/ha/yr of food in terms of paddy.

2. **Technique of multiplying the maize crop on untilled wetland after floating rice crop in the Mekong river delta:**

In the Mekong river delta of South Vietnam there are about 70-100,000 ha of arable land. Every year, deep water rice is sown in May during the early rainy season, and plants grow at a water level of 1.5 to 2.5 m. Deep water rice is harvested in December. After harvest of this rice crop, an early maturing maize is planted in January on untilled wetland and harvested in April.

This model was first developed in An Giang and Hau Giang provinces, and it has spread to thousands of hectares. In these conditions average yields of OPVs are 3.0-3.5 t/ha, wutg a maximum of 5 t/ha by skilled farmers. The crop rotation is as follows:

Maize			+	Deep water rice		
Jun.	-	April		May	-	Dec.

3. **Technique of increasing yields by using early maturing drought tolerant maize varieties in land previously planted with only one rice crop:**

In the six northern provinces of Vietnam, there are about 140,000 ha of arable land. Formerly, only one summer-autumn rice crop was planted in June during the early rainy season, and harvested in November. After that planting the land was left fallow until the rainy season in the following year.

This model increases maize hectarage, i.e. after harvesting rice in November, land is ploughed to keep moisture during winter. Then, maize is directly sown in February and harvested in early June. The crop rotation is as follows:

Spring maize			+	Autumn-summer rice		
Feb.	-	Jun.		Jun.	-	Nov.

In this system, the varieties TSB-2, MSB-49, and Q-2 have yielded 2 to 4 t/ha, and have now reached an area of several thousand hectares in this region.

If this potential is fully exploited, every year there will be and additional 200,000 t of maize to be used for human consumption and for animal feed, for the ethnic nationalities in the mountainous regions of Vietnam. As a result, there will be a restriction on the devastation of forest to exchange the timber for food, and having land available to cultivate poppy to exchange the drug for food.

4. **Technique of transplanting winter maize with seedling balls, intercropping winter soybean with maize or planting winter soybean on zero tillage soil after two rice crops.**

This is a newly developed technique in Vietnam that ensures timely planting of maize and soybean. During the time of harvesting the summer-autumn rice in late September, the farmers are too busy to prepare land to plant winter maize and soybean. With zero tillage, the farmer decreases expenditures on land preparation, and thus lowers costs of production.

This model was initially implemented in 1992, and has increased to about 500 ha in the present 1993 winter crop. The maize and soybean plants grow very well on this land.

IV. Results of extension work on maize.

In recent years, much attention has been paid to extension work in Vietnam. Extension work on maize has been very successful by transferring new technologies to farmers in the five following ways:

1. Establishing high yielding pilot plots with skilled farmers and experienced cooperatives, and

organizing visits as well as field days to these plots.
2. Training farmers.
3. Printing short technical leaflets for farmers.
4. Informing people via mass communication media.
5. Having adequate policies.

The fifth method is very important in production, and it can be implemented by:
1. Partly subsidizing seed and irrigation prices,
2. Eliminate taxation on the additional crop (winter maize),
3. Lending farmers low interest capital,
4. Seeking markets at home or abroad, and
5. Reducing or eliminating import taxes for hybrid maize seed.

Owing to the above mentioned measures, the results of the extension work undertaken by central organizations to help farmers to enhance utilization of the new varieties and application of the advanced technique, can be summarized as follows:

1. The period from introduction to population application of the technique of transplanting winter maize with seedling balls on wet soil was very short. In 1982-83, the test area was only 5 ha. In 1985, the acreage increased sharply to 127,000 ha.
2. The rate of increase in planting high yielding maize hybrids in intensive farming areas has been very rapid:

- In 1990, 20 ha
- In 1991, 500 ha
- In 1992, 12,800 ha
- In 1993, 50,000 ha

These areas have obtained average yield of 5 to 8 t/ha, and 9 to 10 t/ha by experienced farmers.

From the experience of the extension work on maize, we have concluded that achievements in research originating from farmers concepts and practices can be rapidly adopted. Of course, adoption is more rapid when there is a profitable market for farmers' products.

Thanks to the high yielding yellow grain hybrids adaptable to intensive farming areas with irrigation, the National Maize Program is planning faster achievements in the years to come, i.e. the hybrid acreage will reach to 80-100,000 ha by 1994 and 400,000 ha by the year 2000, approximately 40% of the total projected hectarage of maize.

At present, we are rearranging the cropping patterns in the extensive rice growing regions in the Mekong river delta and central provinces of Vietnam. Formerly, three rice crops were grown there. Now, those are being changed into 2 rice crops and one maize or soybean crop, to better protect rice from insects and diseases, diversify food crops, and bring more benefit to farmers.

These are the main activities of the National Maize Program of Vietnam. It would not be as successful if there had not been invaluable assistance from CIMMYT, UNDP, and FAO. Also the fruitful cooperation between the National Maize Program and many other countries, especially in the Asian region.

On this occasion, on behalf of the National Maize Program, I would like to express our sincere thanks to CIMMYT and the international organizations such as UNDP and FAO. I am very grateful to all of you for your participating in the Fifth Asian Regional Maize Workshop in Vietnam.

References

Uy, T. H., and T. C. Tin. 1990. Progress in maize development program and maize breeding for stress environments in Vietnam. *In* C. De Leon, *et al.* Eds. 1990. Proc. Fourth Asian Regional Maize Workshop. Pakistan, Sept. 21-28, 1990.

MAIZE RESEARCH AND PRODUCTION IN SOUTH VIETNAM

Pham Van Bien and Pham Thi Rinh [1/]

Abstract

Maize is the second main food crop after rice in South Vietnam with a total maize area of about 130,000-140,000 ha, average yield of 1.6-1.7 t/ha and total production of 217,000 -267,000 t/year. In 1993, some hybrid maize varieties were imported and planted on 10,000 ha. This resulted in increasing the average yield to 2.63 t/ha in the first 1993 crop season.

The main maize production constraints are unfavorable climate, insects and diseases, socioeconomic problems, processing and storage after harvesting, and seed production. Maize research is divided into breeding and agronomic programs. For the breeding program, improved open pollinated varieties are considered, and for the agronomic program some new practices are recommended such as efficient fertilizer application, use of herbicides, adequate plant density, and intercropping maize with soybean or mungbean. Limitations in maize research include lack of plant breeders with postgraduate studies, laboratories and equipment. Experiment stations at far away from the Institute, and development of new varieties and transfer of improved technologies to the farmer's fields are still lacking. In recent years, many extension centers have been established in various provinces paying attention to maize hybrid production.

In the future, it is expected that our program will continue to cooperate with the National Maize Research Institute, CIMMYT, FAO, and other organizations inside and outside the country in order to raise the average yield to 2.8 t/ha and increase the total production in the country to 2.8 mt by the year 2000.

I. Introduction

In South Vietnam, maize is the second main food crop after rice. The area planted to maize varies from year to year, from 130,000-140,000 ha with an average yield of 1.6-1.7 t/ha and total production of 217,000-267,000 t per year (**Table 1**).

Maize is cultivated throughout South Vietnam, from the Central highlands to the lowlands of the Mekong river delta. The areas planted to maize in South Vietnam are divided into four zones 1) central plateau, 2) central coastal, 3) southeastern, and 4) Mekong delta.

The Southeastern, Central coastal and the Central plateau, including Bong Nai, Ba Ria, Vung Tau, Lam Dong, Dac Lac, Ninh Thuan, Binh Thuan, Tuy Hoa, and Phi Yen (**Table 2**) areas plant two crops per year as follow:

Early : from April to August
Late : from August to November

Maize is grown mostly in the early season in rotation or mostly intercropped with soybean, peanut, and mungbean.

In the Mekong delta zone, maize is grown in the highlands in the summer and in the lowlands in the dry season. In South Vietnam the climate is tropical and divided into rainy and dry seasons. The dry season starts in early November and lasts until late April. Maize can grow practically throughout the year, when favorable temperature and rainfall conditions exist for the crop.

In 1993, the area planted to maize in South Vietnam was 86,500 ha, including 10,000 ha planted to hybrid maize. Several provinces in the Mekong delta have imported maize hybrid seed from Thailand to plant in the dry season after rice. Seed of hybrid maize DK 888 and Pacific 11

1/ Director and Maize breeder, respectively. Inst. Agric. Sci. of South Vietnam, 121 Nguyen Binh Khiem Street, Ho Chi Minh City, Vietnam.

Table 1 Area, production and yield of maize in South Vietnam.1985-1992.

Year	Area ('000 ha)	Production ('000 t)	Yield (t/ha)
1985	155.4	267.1	1.72
1990	133.7	218.1	1.63
1991	135.1	217.0	1.60
1992	137.0	232.9	1.70

Table 2. Maize production in South Vietnam. First crop 1993.

Province	Area (ha)	Production (tons)	Yield (t/ha)
Lam Dong	12,000	22,060	1.84
Minh Thuan	2,000	3,000	1.50
Binh Thuan	1,500	2,250	1.50
Dong Nai	29,000	95,000	3.28
Song De	2,000	4,000	2.00
Tay Ninh	0,300	330	1.10
Vung Tau - Ba Ria	10,780	21,770	2.02
Tien Giang	1,000	2,400	2.40
Dong Thap	1,300	3,060	2.35
Tra Vinh	1,477	3,485	2.36
An Giang	4,000	15,010	3.75
Can Tha	4,000	990	0.25
Soc Trang	5,000	1,550	0.31
Minh Hai	1,200	2,400	2.00
Total	75,557	177,305	2.35

was imported by the Ministry of Agriculture and Provincial companies and was planted in many provinces. Many hybrids have been tested in South Vietnam such as Cargill 333, Cargill 777, Bioseed 9670, Uniseed 30, Uniseed 90, etc. The price of the seed ranges from US$1.5 to 3.2/kg.

II. Production constraints in South Vietnam

As mentioned above, from 1985-1992 the average yield was 1.6-1.7 t/ha. This is very low when compared to the yield potential of the currently available improved varieties. Limited use of new varieties and traditional practices with very low levels of inputs are the main reasons for these low yields. Production is limited by many other factors including:

a. Climate constraints: During the early rainy season, in some regions rainfall sometimes is not sufficient and drought spells of 1-2 weeks are common. The farmers that need to plant before the rains start may lose the seed and have to replant 2-3 times. During the rainy season, the problem is that heavy rains create waterlogging normally followed by dry weather leading to poor emergènce. Maize suffers great damage from excessive moisture, but more commonly from drought.

Because of heavy rains, it is difficult for farmers to do the necessary hand weeding, since very few farmers use herbicides in maize.

b. **Insects:**

- Stem borer, ear worm, and many other insects are a serious problem for maize.

c. **Diseases:**

- The most common disease affecting maize in South Vietnam is Rhizoctonia banded leaf and sheath blight. Incidence of bird damage has also been high, especially in the late season plantings.

d. **Socioeconomic constraints:**

- The maize farmers are very poor. They lack the financial resources to buy the basic inputs such as fertilizer, seeds, etc. Credit schemes through the bank have been organized, but loans and credit are not available to everybody. Most of the farmers grow maizé using poor technology,and few investments.

e. **Storage:**

- It is difficult to dry maize harvested in the rainy season and it gets spoiled during storage.

f. **Marketing constraints:**

- In 1992-1993 the maize was sold at a high price but previously corn was bought at a very low price. This situation has worried the farmers from year to year.

g. **Seed production constraints:**

- The inadequate supply of seed of high yielding improved varieties/hybrids is also an important limiting factor in production. The lack of qualified personel and facilities for seed production, processing, and storage are most important.

III. Maize research

In 1981, the National Maize Program was established. The Maize Research Program in South Vietnam emphasizes breeding and agronomy. Research in physiology, plant protection, and postharvest technology have not been well developed.

Breeding:

The aim of the breeding program is to develop high yielding, Rhizoctonia resistant open pollinated composites, varieties and hybrids that are stable under various environmental conditions.

The maize breeding activities give much emphasis to the development of improved open pollinated varieties (OPVs). These activities include:

- Collection and introduction of new materials.
- Improvement of open pollinated varieties using mass selection, half-sib, and S1 methods.
- Topcrosses using the latest cycle of TSB1 as tester.
- Yield testing.

Activities on agronomy include the following topics:

- Efficiency of NPK fertilizer application.
- Herbicide use.
- Plant densities.
- Intercropping maize with mungbean and soybean.

These activities are conducted in cooperation with a number of other organizations within and outside South Vietnam, including the National Maize Research Institute, Regional Agricultural Stations, CIMMYT, and FAO.

Research results

1. During recent years, many improved composite varieties have been released. Available early maturing varieties are HL 31, HLS, Pool 18 and HL31S. Intermediate maturity varieties are HL 36, HL 24, HL 26, HL 27, HL 28, TSB 1 and DL 11. These new varieties have been tested over several locations from 1988 to 1992. Results are shown in **Table 3**.
2. Fertilizer application experiments indicated that the rates to be recommended to farmers are 60-100, 60, and 30-60 kg of N, P_2O_5 and K_2O, respectively.
3. After multilocation research on plant population, the following plant densities were recommended:

Early maturing varieties: 62 000 plants/ha (70 cm x 45 cm, two plants per hill).

- Intermediate varieties: 53,000-57,000 plants/ha (70 cm x 50 cm or 75 cm x 50 cm, two plants per hill)

4. Intercropping experiments using maize with soybean led to the following recommendations:

Table 3. Mean grain yields (kg/ha) of varieties at four locations.

Variety	1988	1989	1990	1991	1992	Average
Hl 31	4,275	4,093	4,441	5,424	3,907	4,438
HLS	4,382	4,289	4,675	5,480	4,169	4,599
HL 319				5,862	4,466	5,164
DL 11	4,461	4,336	4,131			4,309
TSB 1	5,328	4,732	4,830	6,274	4,427	5,118
HL 24	4,845	4,476	4,628	5,556	4,412	4,783
HL 26	4,402	4,054	4,327	5,426	4,265	4,495
HL 28	4,923	4,709	4,955	5,844	4,163	4,919
HL 36	4,790	4,633	4,720	5,486	4,317	4,789
HL 27	4,624	4,324	4,310	5,753	4,426	4,687
Mean	4,670	4,495	4,557	5,678	4,283	4,729

- In early season (April-August) monocropped maize gave more benefit than maize intercropped with mungbean.
- For the late season planting, 2 rows of maize + 2 rows of legume crops is most suitable.

Full season varieties like DK-888 are more suitable in intercropping systems than the early ones.

Problems in maize research:

In South Vietnam, the Inst. of Agric. Sci. (IAS), is responsible for maize research. The number of plant breeders is adequate,but the amount of staff with advanced degrees is limited. The Maize Program has been developing, but there are several problems:

a. Lack of laboratories and equipment.

b. Experiment stations for maize research are passing through a difficult financial situation and far from the Institute (60-300 km).

c. Among the many new high yielding varieties released by the IAS, only a few varieties have been transferred to farmers fields. A similar situation exists with the new technologies.

IV. Extension

During recent years, many Extension Centers have been establis in various provinces. The government is paying much attention to maize hybrid production. Agronomic technology has been suggested and implemented through extension programs in several provinces where maize is produced. The Government developed policies to stimulate maize cultivation and has supplied to farmers the required money to buy seed and fertilizer.

V. Cooperation

The Maize Program at IAS collaborates with the Maize Research Institute, CIMMYT, and FAO. In addition to these, we cooperate with a number of other organizations inside and outside the country, including seed companies in South Vietnam, seed companies in every province, Pacific Seeds, Cargill, and CP-DK group in Thailand.

VI. Future development

By the year 2000, our target is to increase the maize producing area to 1 m ha, yield to 2.8 t/ha, and total production to 2.8 mt. To reach this objective, a number of problems in research, extension, and Government policies must be solved.

1. Continue developing new high yielding composite varieties and proper cultural practices for hybrids.
2. Introduce new hybrids from abroad and carry out yield testing, transferring the suitable hybrids to farmers fields through the extension system after identification of suitable hybrid maize growing areas.
3. Transfer new technology to the farmers fields.
4. Cooperate with the private sector to produce hybrid seed in South Vietnam, reducing the cost of seed.
5. Develop grain drying and processing systems.

It will be necessary for the Government to give priority to establish pricing policies of maize grain.

VIETNAM YELLOW MAIZE EXPORT: MARKET PROSPECTS

Mathieu Delorme [1/]

I. Purpose of the presentation

To assess prospects for Vietnam maize exports in the context of Vietnam's efforts to boost production.

- Brief background about the Andre Group.
* Swiss international development.
* 120 years in the grain business (processing/shipping/marketing).
* Always in close cooperation with farmers to improve quality and efficiency, resulting in returns to producers.

II. The markets

- Vietnam located near a major importer: Malaysia.
- Malaysia is not only important but fast growing (average import growth in the past 5 years, at 8% per annum) due to economic growth and resulting rise in meat demand.
- In addition, Indonesia and Philippines, are occasionally importing (0.2-0.3 mt each) and face the same economic outlook (Fig. 1).

III. The competitor

A. Thailand.

- Thailand is the nearest competitor for Southeast Asian markets (Figs. 2, 3, 4).
- Due to higher land costs (a result of industrialization) and more profitable crops like sugarcane, area sown with yellow maize has steadily decreased over the past 8-9 years.
- As yields stabilized, production has also decreased and is not experiencing any growth.
- Meanwhile, Thailand is facing the same domestic economic growth and increase in resulting meat demand as the other Southeast Asian nations. In addition, Thailand is a meat exporter.
- Its domestic consumption of yellow maize has therefore grown rapidly, at a 12% per year average over the past 8-9 years.
- Exports have shrunken from a high of 3.5 mt to about 0.5 mt over the past 8-9 years.

B. **People's Rep. China (PRC)**

- China has replaced Thailand as a major supplier of yellow maize to Southeast Asia.
- Its sown area and yield growth, however, have slowed down (Table 1).
- Its domestic feed consumption is booming and as a result domestic local maize demand is growing at an average of 5-6% per year.
- A major market, Taiwan is importing over 5.0 mt of maize per year which could open up to the PRC any time. This would leave enough demand in an area adjacent to China's producing region (North China), i.e. Japan, the Korean peninsula and Taiwan, and possibilities to cut off their supply to Southeast Asia.

C. **Others**

The US, Argentina and South Africa all have growing markets near them, and are at a freight disadvantage to Vietnam.

1/ Director/Regional Manager. Andre & Co. (S). Pte Ltd. 150 Beach Road. 19-08 Gateway West. Singapore 0718.

Table 1. Situation of maize in People's Rep. China.

YEAR	1985	1986	1987	1988	1989	1990	1991	1992	1993
AREA	17,700	19,100	20,200	19,700	20,400	21,000	21,500	21,400	21,500
PRODUCTION	63,800	70,900	79,200	77,400	78,900	98,800	98,800	95,000	95,000
YIELDS	3.60	3.71	3.92	3.93	3.87	4.61	4.60	4.44	4.42
EXPORTS	6,400	3,800	4,100	3,700	3,200	6,600	9,200	8,500	8,500
DOM. CONS.	67,400	71,600	74,100	74,400	75,700	79,400	82,400	87,900	87,500
DOM. CONS. GROWTH RATE	5.66% AVERAGE	24.74%	3.49%	0.40%	1.75%	4.89%	3.78%	6.67%	-0.46%

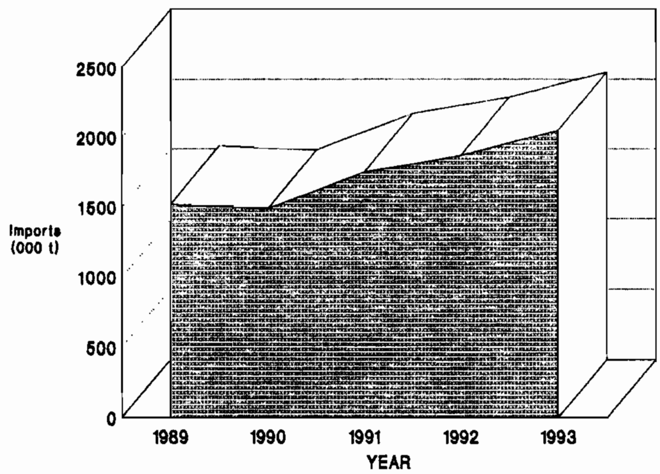

Fig. 1. Imports of yellow corn in Malaysia.

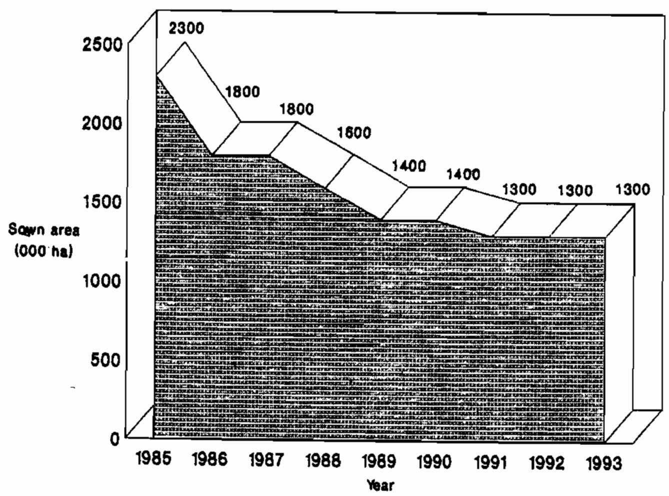

Fig. 2. Area sown to yellow maize in Thailand.

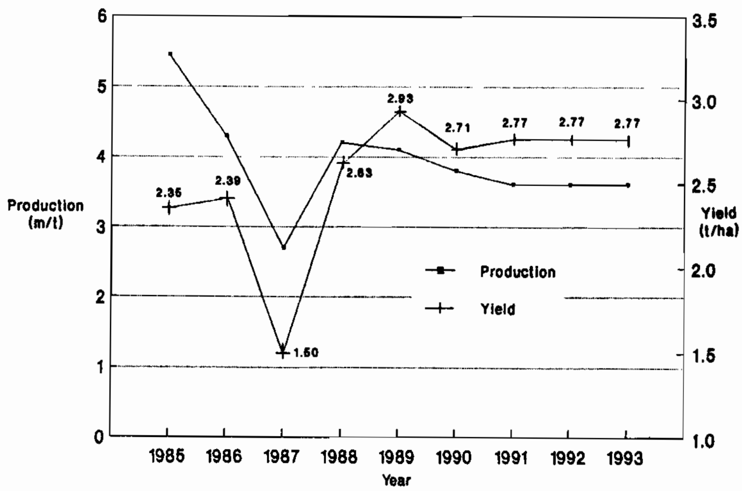

Fig. 3. Production and yield trend of yellow maize in Thailand.

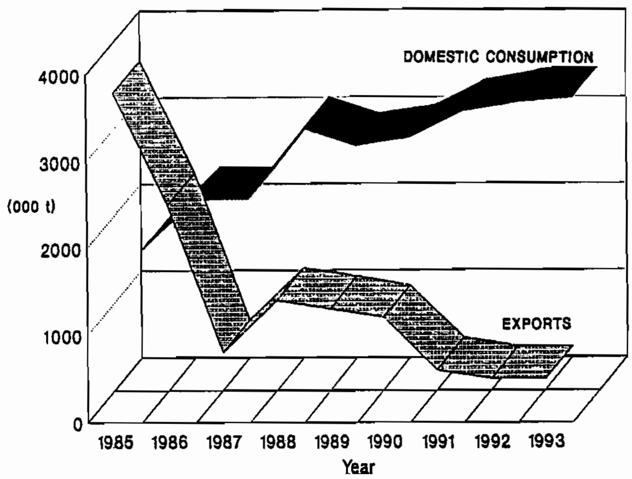

Fig. 4. Exports and domestic consumption of yellow maize in Thailand.

IV. Conclusion

- It appears that there are bright prospects for Vietnam to find advantageous market conditions should there be any exportable surplus after its own growing domestic demand is satisfied.
- The key to an successful export program can be summarized as follows:
  * Quality
  * Infrastructure:
    Processing
    Storage
    Transport
    Ports
  * Reliability (consistent supplies)
- Andre has the expertise and the wish to invest in and participate in the success of maize exports from Vietnam, if it can be of service in these areas.

Questions to the author:

FROM : M. Morris

Q : You mentioned three keys to a successful maize export program for Vietnam: 1) quality 2) infrastructure 3) reliability. What role will the public sector (government) have to play in helping to bring about these key factors?

A : 1) Internal transportation infrastructure (roads)

2) Port facilities

3) A legal system making possible enforcement of contracts.

MAIZE BREEDING

Arnel R. Hallauer[1/]

Abstract

Successful maize (*Zea mays* L.) breeding programs include two equally important components: identification and improvement of source germplasm and effective methods for the development of inbred lines and hybrids. Both components are necessary to maintain consistent genetic advance either for genetically broad-based cultivars (i.e., open-pollinated varieties and synthetic varieties) or for hybrids produced from inbred lines (i.e., single crosses, three-way crosses, and double crosses). The two components should not be considered separately, but as integral components to realize maximum benefits of the two components.

Applied maize breeding programs usually are concerned with the improvement of traits that are controlled by an unknown number of genes whose expressions are affected by environmental effects. Effective selection requires the evaluation of progenies in different environments to determine the breeding values of the progenies for both components. Recurrent selection methods, in the broadest sense, are used for both components of maize breeding. Development and genetic improvement of germplasm are continuous and long-term. Germplasm is provided for developing inbred lines and hybrids from each cycle of germplasm improvement. Elite lines can be recycled by pedigree selection methods to develop second-cycle lines for hybrids. Thus, the development of progenies, evaluation of progenies in replicated trials repeated over environments, and intermating of elite progenies are conducted cyclically for both components to gradually increase the frequency of desirable alleles for the traits emphasized in selection.

Introduction

Maize (*Zea mays* L.) is the most widely and intensively grown crop species in the world and ranks third, behind rice and wheat, in total production. Maize originated in southern Mexico or northern Guatemala 5,000 to 10,000 years ago. Maize is extremely variable genetically, and selection pressures were effective in developing maize strains to meet the needs of the native inhabitants. Most of the genetic variability in maize was present before the European colonists arrived in the Western Hemisphere. Native Americans had developed races that were being grown in present-day southern Canada, the United States, Mexico, Central America, islands of the Caribbean, and throughout South America by 1492. Columbus collected maize on the northern coast of Cuba on his first trip. After maize was introduced in Spain in 1493, within two generations it became distributed throughout the world in areas where it could be grown and cultivated (Manglesdorf, 1974).

Maize is a cross-pollinated crop species that has been studied extensively since the European colonization of the Western Hemisphere. Several features of maize made it amenable to genetic and breeding studies: male (tassel) and female (ear) flowers are separate which permit cross and self-pollinations with equal facility; 300 to 500 seeds can be produced on each ear to permit adequate evaluation and analysis of plants and progenies; the genome (2n = 20) of corn is relative simple permiting extensive genetic and cytogenetic analysis; and studies on the effects of inbreeding from self-pollination and the heterosis effects expressed in crosses have made maize a model crop species for plant breeding method studies. Breeding and selection methods developed and evaluated for improvement of germplasm and development of lines to produce hybrids in maize are studied by plant breeders for use in other crop species.

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Modern maize breeding includes two separate, but equally important, components: 1) germplasm improvement and 2) development of inbred lines for use in hybrids. Genetic advance depends on the systematic improvement of germplasm, and all breeding programs should include both components. In areas where hybrids do not have widespread use, the systematic improvement of germplasm resources will provide genetically improved cultivars to the growers. In areas that emphasize the use of hybrids, systematic improvement of germplasm resources provides the source breeding materials on a regular basis. Improvement of genetic resources and development of lines for hybrids will be discussed to illustrate their relative importance in successful breeding programs.

Germplasm improvement

Genetic variability is the essential raw material (or ore) that is necessary for successful plant breeding. In maize, genetic variability has not been a restraint in making genetic progress. Extensive quantitative genetic studies during the 1950s and 1960s provided evidence that adequate genetic variability was available in maize populations to expect response to selection. Generally, it has been found that if effective screens are either available or developed, response to selection will be realized. Effective screens are those techniques that separate genetic and environmental effects so that selection is based primarily on genetic differences and not confounded by the effects of the environments, such as escapes, nonuniform infection, genotype environment interactions, etc. Effective screens include artificial infestation with eggs, larvae, or adults of insects to reduce the occurrence of escapes, artificial infection with spores of diseases to ensure uniform coverage of all plants, standardized chemical analyses for quality traits, and replicated trials replicated in different environments to separate and estimate components of variance caused by genetic effects, environmental effects, and genotype by environment interaction effects.

Careful consideration, therefore, should be given in the choice of germplasm included in breeding programs. But genetic variability, for the sake of genetic variability, can be misleading. Because most maize populations seem to have adequate genetic variability to expect response to selection, other parameters should be used in choice of germplasm. Other parameters include the overall productivity of the population, general resistance to important pests in your area, general tolerance to acid soils if needed for your area, grain type and color for acceptance by growers and users, proper maturity, drought tolerance, and other traits that may be important for maize production and use. Definitive information on maize populations for these traits, however, often has been lacking. It is necessary that you contact colleagues and organizations to secure all information available before you make your choice of germplasm. Contact individuals within your country and other countries who have experience in maize breeding, including regional and international centers conducting maize research, and individuals in other areas of the world who have similar maize growing conditions. Read carefully the information available in reports of local and regional workshops, conferences, and symposia. It has been realized recently that breeding information (combining ability, inbreeding depression, heterosis, and performance per se) is essential to make wise choices in germplasm. CIMMYT (International Maize and Wheat Improvement Center) and the Latin American Maize Project (LAMP) have been evaluating maize populations, and very useful information can be gathered from their reports to assist you in the choice of tropical germplasm that can be of potential value for your respective areas.

After you carefully choose the maize population(s) that you judge have the necessary traits for your area, the choice of selection method(s) to genetically improve the population(s) needs to be determined. These selection methods for the cyclical improvement of populations are collectively designated as methods of recurrent selection. Paradoxically, the choice of method(s) seems to be of less importance than the choice of populations. Evidence suggests that if effective screens are available all selection methods, with few exceptions, are effective (Hallauer and Miranda, 1988). Because maize is a cross-fertilizing species, several different methods of recurrent selection have been applied to maize populations (**Table 1**). The choice of method, therefore, should be the one that best meets your specific needs and conditions. The choice of method also can be either modified or changed if your situation warrants a change, i.e., changes in disease and insect pressures. A useful equation to assist you in choice of method was provided by Eberhart (1970):

Table 1. Methods of recurrent selection that have been suggested and used for the genetic improvement of maize populations.

Method	Parental control (c)†	Years per Cycle (y)‡	Genetic variability (σ^2_G) σ^2_A	σ^2_D	Reference
Intrapopulation:					
Mass	< 0.5	1	1	1	Original
Unselected males	0.5	1	1	1	Gardner (1961)
Selected males	1.0	1	1	1	Eberhart (1970)
Ear-to-row	< 0.5	1	0.25	0	Hopkins (1899)
Modified	0.5	1	0.25	0	Lonnquist (1964)
Modified-modified	1.0	2	0.25	0	Compton and Comstock (1976)
Half-sib					
GCA-Half-sib intermated	1.0	2	0.25	0	Jenkins (1940)
S1 intermated	2.0	2	0.25	0	
SCA-Half-sib intermated	1.0	2	0.25	0	Hull (1945)
S1 intermated	2.0	2	0.25	0	
Full-sib	1.0	2	0.50	0.25	Moll and Robinson (1966)
Inbred S1	1.0	2	1.00	0.25 §	Eberhart (1970)
S2	1.0	3	1.50	0.12 §	
Sn	1.0	n + 1	~ 2.00	~ 0.0	
Interpopulation:					
Half-sib	1.0	2-3	0.25	0.0	Comstock et al. (1949)
Full-sib	1.0	2	0.50	0.25	Hallauer and Eberhart (1970)

† Parental control (c) depends on the seed source used in recombination. If the seed source used in recombination is the same as seed source used in evaluation trials, then c = 1, otherwise c is same value other than 1.

‡ Years per cycle are listed for temperate areas where two seasons per year are used. Years per cycle are either extended if only one season is available or reduced if there are more than two seasons per year.

§ Coefficients of dominance variance for p = q = 0.05.

$\Delta G = [ck\sigma^2_G]/y\sigma_p$, where

ΔG is predicted genetic gain;

c is parental control, which is the relation between seed used for progeny evaluation and seed used for intermating (Table 1);

k is the standardized selection differential determined by the intensity of selection;

σ^2_G is the genetic variability among progenies determined from the analysis of variance (Table 2);

y is the number of years required to complete one cycle of selection; and

σ_p is the square root of the phenotypic variance (Table 2).

In a simplified form, expected response to selection can be expressed as:

$\Delta_G = (\bar{X}-\bar{X}_s)h^2/y$, where

$\bar{X}$ is the mean of all progenies evaluated;

$\bar{X}_s$ is the mean of the selected progenies; and

h^2 is the heritability for the trait (Table 2).

Table 2. Analysis of variance of progenies evaluated in replicated trials conducted in different environments.

Source of variation	d.f.[+]	Mean squares	Expected mean squares
Environments (E)	e-1	MS_5	$\sigma^2 + eg\sigma^2_r + r\sigma^2_{ge} + rg\sigma^2_e$
Replications/E	e(r-1)	MS_4	$\sigma^2 + eg\sigma^2_r$
Progenies (G)	g-1	MS_3	$\sigma^2 + r\sigma^2_{ge} + re\sigma^2_g$ [‡]
G x E	(e-1)(g-1)	MS_2	$\sigma^2 + r\sigma^2_{ge}$
Error	e(r-1)(g-1)	MS_1	σ^2
Total	erg-1		

+ e, r, and g indicate the number of environments, replications, and progenies, respectively.

‡ Genetic expectation for σ^2_g depends on type of progeny evaluated (see **Table 1**). If half-sib progenies evaluated, $\sigma^2_g = (0.25)\sigma^2_A$ and if full-sib progenies evaluated $\sigma^2_g = (0.50)\sigma^2_A + (0.25)\sigma^2_D$, etc.

$h^2 = \sigma^2_g/\sigma^2_p$, where $\sigma^2_g = (MS_3 - MS_2)/re$, and $\sigma^2_p = MS_3/re = \sigma^2/re + \sigma^2_{ge}/e + \sigma^2_g$

To compare possible methods of selection for choosing among them, it is necessary to know how much of the total genetic variance can be partitioned into the variance due to additive genetic variance (σ^2_A) and deviations due to dominance (σ^2_D). In most instances, however, this is not known and the information is expensive to obtain in time and resources for each population. Your only recourse is to use information obtained from similar types of maize populations and make theoretical comparisons among recurrent selection methods. The choice of method would be the one that had the greatest genetic gain per year, ignoring other possible factors that will be discussed later. Either formula presented can be used to predict genetic gain in the next cycle based on information obtained from the current set of trials (**Table 2**).

If the breeding program is either involved with or anticipates development of hybrids, then some form of interpopulation selection may be used. Interpopulation selection is based on progenies produced by crosses between the two populations. Response to selection is based on the population cross. For half-sib reciprocal recurrent selection, predicted gain is:

$\Delta_G = (ck/y)(\sigma^2_{g_{12}} / \sigma^2_{p_{12}} / \sigma^2_{g_{12}} / \sigma^2_{p_{12}})$, where:
$\sigma^2_{g_{12}}$ is the variation among half-sib families for males of population 1 crossed to population 2 and $\sigma^2_{g_{21}}$ is the variation among half-sib families for males of population 2 crossed to population 1. Full-sib reciprocal recurrent selection only has one set of progenies that are evaluated and predicted gain of the population cross is $\Delta_G = ck\ \sigma^2_{g_{12}} / y\ \sigma_{p_{12}}$, which is same as intrapopulation full-sib recurrent selection except full-sib families are produced between two populations.

Recurrent selection

Recurrent selection has two objectives: 1) change of the mean of the population in the desired direction by increasing the frequency of desirable alleles; and (b) maintain genetic variability within the population by intermating selected progenies between cycles of selection. To attain these objectives requires the completion of three phases for each cycle of recurrent selection for all of the methods listed in Table 1, except for mass selection: development of progenies (e.g., half-sib, full-sib, S_1, etc.) (**Table 1**); evaluation of progenies in replicated trials to determine the breeding values of the progenies (**Table 2**); and intermating of selected progenies to generate genetic variability for the next cycle population. Each phase is repeated for each cycle of recurrent selection and they are equally important to the success of the selection program.

Phase 1: Different types of progenies are available for use in maize populations, but the important concern is that the number of progeny developed represents the genetic variability of the population. The greater the number of progenies available for evaluation, the greater the chance that the population was adequately sampled. The adequate number of progeny needed also can vary by the complexity of inheritance of the trait under selection. It seems, however, that 180 to 240 progenies are a minimum number for most traits considered for recurrent selection.

Phase 2: Determination of the correct breeding values of the sampled progenies is essential for effective selection. Progenies are evaluated in replicated trials to separate the genetic and environmental effects and to determine the relative importance of each (Table 2). Effective screens are essential. It seems that a minimum of 6 to 10 replications are required to differentiate among progenies for grain yield (Lamkey and Hallauer, 1984). The replications should be distributed among environments to reduce bias due to genotype by environment interactions.

Phase 3: Intermating restores genetic variability to permit continued selection. To maintain genetic variability for future selection, it is imperative that adequate effective population sizes are used to reduce loss of genetic variability due to either inbreeding or genetic drift, or both. Rawlings (1970) studied the effects of effective population size relative to expected short-term and long-term responses to selection and concluded that 25 to 35 individuals should be intermated for each cycle of selection. Numbers of progenies selected for intermating also affects the method(s) used for intermating selected progenies. It is essential that selected progenies are equally represented in the intermatings to ensure that the planned effective population size is realized. If 10 or fewer progenies are intermated, which is not recommended, the diallel crossing scheme can be used to make all possible n(n-1)/2 crosses. If 20 or more progenies are intermated this may be done either by use of an isolation planting or by the bulk-entry method. In all instances, it is necessary that each selection is equally represented in all crosses, and an equal number of seeds is composited to form the selected population for the next cycle of selection.

Recurrent selection methods are flexible and are useful for different aspects of maize breeding. Recurrent selection can be used to increase the level of resistance to important diseases and insects, change chemical composition of grain, change plant architecture, change grain type, improve stress tolerance, increase productivity, and adapt exotic germplasm. Materials derived from recurrent selection programs that are integrated with other aspects of a breeding program can have several useful end products (Eberhart *et al.*, 1967). Some possible uses of materials derived from recurrent selection programs include the following:

Cultivars -- In those areas that are not committed to the use of hybrids, the improved cycles of selection can be made available to the growers as improved cultivars. It is not to be expected that each cycle of selection will be released for use by the growers: only when the improved cycles are significantly better than cultivars currently being used by growers should they be released. Otherwise, it will be difficult to convince growers that the "new" cultivars are better than those currently used.

Cultivar crosses -- If two populations are being improved in a parallel manner (e.g., reciprocal recurrent selection), the cross of the improved populations can be released to the growers, using the same criteria as for cultivar releases.

Genetic stocks -- Assume a particular pest (e.g., Asian downy mildew) or problem (e.g., aluminum toxicity) is a major concern for a particular area. A recurrent selection program may be initiated to develop a population with greater level of tolerance to downy mildew and/or aluminum toxicity. Greater levels of tolerance are developed, but the level of productivity of the population may not be acceptable in pest-free environments. The selected population for pest tolerance could be crossed with the local cultivars to upgrade the level of tolerance. This requires, however, careful planning. Selection should be emphasized, if possible in local materials, but frequency of alleles may be too low to increase levels of tolerance, and outside source materials are used. Attention should be given in choice of populations used to select for greater levels of tolerance as well as for productivity and maturity.

Recurrent selection methods also are flexible for the number of traits selected (multiple-trait selection) and for generations within each cycle of selection (multiple-stage selection); e.g., selection for different traits in S_1 and S_2 generations. Single-trait selection has been shown to be very effective, but the correlated effects for other traits may not be desirable (Hallauer *et al.*, 1988). The direct effects of selection are positive, but the indirect (or correlated) effects of selection may not be acceptable. One, therefore, has to closely monitor the selection methods to ensure useful germplasm sources are developed. Recurrent selection methods are long-term, and it is imperative that acceptable germplasm is developed to justify the expense in time and resources allocated to it. Plan carefully, make adjustments when needed, monitor carefully the responses to selection, and determine the desires and needs of the growers when you initiate and conduct recurrent selection programs. Reviews on planning and conducting recurrent selection in maize were provided by Hallauer (1985, 1992).

Examples of recurrent selection conducted in maize

Examples of the responses obtained from recurrent selection methods will be presented to illustrate some of the advantages and disadvantages of the methods used. Direct response to the trait emphasized in selection was realized, but in some instances the indirect effects of selection were not desirable. The examples illustrate what responses can occur and what we can expect in most instances.

***Pest resistance*:**

Stalk rots (a complex of fungi that includes [*Diplodia maydis* (Berk.) Sacc.; *Gibberella zeae, Fusarium moniliforme*, and *Colletotrichum gramincola*) and the European corn borer (*Ostrinia nubilalis* Hubner) are important pests of maize in the U.S. Corn Belt. Both pests cause yield losses by stalk lodging and by loss of ears at harvest. Recurrent selection, based on S_1 progeny evaluation, was used to increase levels of resistance to both pests. Effective screens were developed to infect with the stalk-rot fungi and infest with either eggs or larvae of the European corn borer. Artificial methods of infection and infestation were used to reduce the incidence of escapes and increase the heritability of the traits in selection.

Two generations of the European corn borer usually occur in the U.S. Corn Belt: the first generation infests young corn plants (ca. 30 cm) and the second generation infests plants at flowering. Klenke *et al.* (1986) conducted a recurrent selection program to develop resistance to both generations (**Table** 3). Selection was only for European corn borer resistance with no consideration given to other traits. Direct responses to selection for the European corn borer were effective for both generations, suggesting the methods use (S_1 progenies under artificial infestation) were effective. This is in contrast to the results of Williams and Davis (1983) who based selection on individual plants (mass selection) for resistance to the southwestern corn borer [*Diatraea grandiosella* (Dyar)]; they were not successful in realizing increased resistance based on individual plant selection. But Klenke *et al.* (1986) found that effective selection for greater resistance was accompanied by a 21.1% decrease in yield for first-generation resistance, and a 17.1% decrease in yield for second generation resistance.

Devey and Russell (1983) reported a study that used S_1 progeny recurrent selection in a strain of Lancaster Sure Crop for greater resistance to incidence of stalk rot (*Diplodia zeae*) and greater stalk strength. Seven cycles of selection were completed and evaluated to determine response to selection (**Table 4**). Selection was effective. The incidence of stalk rot infections significantly decreased ($b = -0.26 + 0.03$) and stalk strength significantly increased ($b = 4.74$ kg) over the seven cycles of selection. There were correlated responses between incidence of stalk rot and stalk strength; i.e., stalk strength increased as incidence of stalk rot decreased. There were other correlated responses, however, that were not desirable: the C7 population was later flowering, had reduced number of ears and a significant decrease (26.4 q/ha or 40%) in grain yield. Devey and Russell (1983) suggested the loss of yield was due to inbreeding effects from the small effective population size used and changes in partitioning of photosynthates from the ear to the stalk.

The studies by Klenke *et al.* (1986) and Devey and Russell (1983) illustrate one very important principle in selection: single-trait selection can be very effective, but the correlated effects may be undesirable if they are not monitored during selection. Direct response to selection would have been reduced if maturity and grain yield had been included with selection pest resistance. This can be illustrated if we assume a selection intensity of 10% for "n" traits. If selection is for one trait selection intensity will be 10, but if selection intensity is 10% for two traits then selection intensity is $0.10^{1/2}$ or 31.6% for each trait. If selection is for three traits with 10% selection intensity for each trait, then selection intensity is $0.10^{1/3}$ or 46.5% for each trait; i.e., selection intensity becomes the nth root for n traits

Table 3. Response to selection for resistance to first-generation and second-generation European corn borer in BS9 (Adapted from Klenke *et al.*, 1986).

Populations	First-generation Rating	First-generation Yield	Second generation Rating	Second generation Yield
	1-9†	q/ha	1-9	q/ha
BS9 C0	3.6	60.7	6.4	53.1
C1	3.6	65.0	5.9	47.5
C2	2.8	52.4	5.7	44.4
C3	2.5	56.2	4.4	40.8
C4	2.7	47.9	4.4	44.0
Change, % ‡	-31.1	-21.1	-31.2	-17.1
LSD (0.05)	1.4	13.8	1.3	13.8

† Rating scale of 1 (resistant) to 9 (susceptible).
‡ Change of C4 relative to C0.

Table 4. Responses to selection for decreased root rot infection and increased stalk strength after seven cycles of selection in Lancaster Sure Crop (Adapted from Devey and Russell, 1983).

Cycle of selection	Root rot rating	Stalk strength	Days to flower	Ear per 100 plants	Grain yield
	1-6†	kg	no.‡	no.	q/ha
C0	3.3	28.7	16.0	94.5	66.5
C1	3.0	36.0	18.6	93.0	66.3
C2	2.0	42.0	19.3	97.5	66.3
C3	2.3	46.5	18.9	93.0	61.8
C4	2.2	47.9	18.4	91.5	54.4
C5	1.8	52.5	18.7	88.5	50.2
C6	1.6	54.0	20.4	81.0	46.9
C7	1.3	59.6	21.8	75.5	40.1
b	-0.26**	4.7**	2.7**	ns.	-1.2

† Rating scale of 0.5 (resistant) to 6.0 (susceptible).
‡ Days after July 1.

considered in selection. If one increases the number of traits included in selection, the selection intensity is reduced for each trait and slower progress is realized for each trait. For the examples of Klenke *et al.* (1986) and Devey and Russell (1983) for pest resistance, only one trait (pest resistance) was included in selection. Consequently, the populations they developed can be placed in the category of "genetic stocks". Both populations (BS9C4 and Lancaster C7) have good resistance to the pest considered in selection, but they have limited value in breeding programs.

Inbred progeny and half-sib family selection:

Use of S_1 progeny and of half-sib family selection has been of particular interest to maize breeders because of the types of genetic effects important in maize populations and in the expression of heterosis. There were differences in opinion among individuals on the relative importance of dominant vs. overdominant effects. Hull (1945) suggested that overdominant effects were of greater importance, and selection methods that emphasized selection for overdominant effects should be used. To provide definitive evidence on the relative importance of additive and nonadditive effects in selection, Hull (1952) suggested conducting parallel recurrent selection programs that emphasized 1) selection based on half-sib families for general combining ability (Jenkins, 1940), 2) selection based on half-sib families for specific combining ability (Hull, 1945), and 3) selection based on inbred progenies. If additive genetic effects are of greater importance, than nonadditive effects, selection for general combining ability (GCA) based on half-sib families and selection among inbred progenies would be more effective than selection for specific combining ability (SCA) based on half-sib families. The reverse would occur if nonadditive effects (i.e., SCA) were of greater importance than additive effects. Comstock (1964) also concluded that if additive genetic effects were of greater importance then inbred recurrent selection would be at least twice as effective as half-sib family recurrent selection. Because the genetic expectation among S_1 progenies is σ^2_A, among S_2 progenies is $(3/2)\sigma^2_A$, and among S_7 progenies is $2\sigma^2_A$ compared with the expected variation among half-sib families of either $0.25\sigma^2_A$ (F = 0) or $0.50\sigma^2_A$ (F = 1), interest in inbred progeny increased.

Extensive studies have been conducted to compare the relative responses to selection for inbred progeny and half-sib family selection, and the results from two studies are summarized in **Table 5**. In BSK(S) S_1 progeny selection was more effective than half-sib family selection for the first four cycles of selection (62.1 q/ha vs. 52.9 q/ha, **Table 5**). The same response, however, was not realized after eight cycles (C8) of selection: no further response was attained with S_1 progeny selection (C8 = 60.1 q/ha), whereas half-sib family selection continued to respond to selection (C8 = 64.5 q/ha). The difference (60.1 q/ha vs. 64.5 q/ha) was not significant, but the trend suggests no further response to S_1 progeny selection after four cycles of selection. The selfed progenies for each method of selection were similar (41.3 q/ha vs. 39.1 q/ha, **Table 5**) after eight cycles of selection, but again a very small change occurred after C4 for S_1 progeny selection.

Horner (1985) reported a comparison of S_2 progeny selection and testcross selection (half-sib) after three cycles of selection. Responses to selection were similar for the testcrosses and population crosses for both methods of selection (**Table 5**). The S_2 bulks of the C3 populations suggested less inbreeding depression with S_2 progeny selection compared with testcross selection (31.6 q/ha for S_2 vs. 26.9 q/ha for testcross selection, **Table 5**), which is similar to the results reported by Tanner and Smith (1987).

Two generations of inbred-progeny (S_1 and S_2) recurrent selection were conducted for five cycles in BS2 and BSTL, and for four cycles in BS16. BS2, BSTL, and BS16 included exotic germplasm, and inbred progeny selection was initiated to improve the three populations for use in US Corn Belt breeding programs. The selection protocol was similar for each population: 500 to 800 S_1 progenies were evaluated for resistance to first-generation European corn borer, stalk quality, maturity, plant type, and seed set; 200 to 300 plants were selfed after selection among and within S_1 progenies to advance to the S_2 generation; 150 to 250 S_2 progenies were evaluated in two replications at 3 or 4 locations; based on S_2 progeny trials, 20 to 25 progenies were intermated using remnant S_1 generation seed; two generations of intermating were completed between each cycle of selection, requiring 3 years to complete each cycle of selection; and selection of superior S_2 progenies emphasized grain yield, grain moisture, and root and stalk lodging. A selection index suggested by Smith *et al.* (1981) was used in making the selections.

Iglesias and Hallauer (1991) evaluated the populations per se and the bulk selfs for each cycle of selection (**Table 6**). Responses to selection were similar for the three populations. In each population, positive response was realized from the C0 to the C2 (BS16) and to the C3 (BS2 and BSTL) for grain yield in populations per se and the self generation; no further responses for grain yield were obtained after the C3 cycle, which was similar to the data reported by Tanner and Smith (1987) (**Table 5**). Responses in the selfed generations would be a more direct measure

Table 5. Comparative responses for grain yield (q/ha) to inbred progeny and half-sib family recurrent selection in BSK (Tanner and Smith, 1987) and FSHmR (Horner, 1985).

Cycle of selection	BSK(S)		BSK(S) x BSK(HI)		BSK(HI)	
	Per se	Self	Per se	Self	Per se	Self
	LSD (0.05) = 7.9 q/ha					
C0	48.7	27.7	48.7	27.7	48.7	27.7
C4	62	39.0	61.6	40.8	52.9	31.9
C8	60	41.3	71.1	43.6	64.5	39.1
Change, %	23.4	49.1	46.0	57.4	32.4	41.2
	Testcross means		Cn x Cn crosses		S2 bulks	
	FSHmR(S)	FSHmR(TC)	FSHmR(S)	FSHmR(TC)	FSHmR(S)	FSHmR(TC)
C0	49.1	49.1	47.1	47.1	---	---
C1	50.0	51.5	49.4	52.8	---	---
C3	55.0	55.5	56.1	56.8	31.6	26.9
b	1.9**	2.2**	3.4**	2.2**		

of the inbred progeny recurrent selection, but the responses for the self generation were similar to the populations per se. The results for grain yield, on a long-term basis, are not encouraging. BS16C0, for example, has a greater yield (47.1 q/ha) than BS16C4 (44.9 q/ha), and the C4 (44.9 q/ha) had significantly lower yield than the C2 (53.9 q/ha). Other agronomic traits were considered in selection, and except for stalk lodging, the changes for the other traits were in the desired direction (Table 6).

It seems that inbred-progeny recurrent selection must be used with caution. Inbred-progeny recurrent selection was effective for increasing resistance to important pests, but the

Table 6. Responses to S_1 and S_2 recurrent selection in BS2, BSTL, and BS16 maize populations (Adapted from Iglesias and Hallauer, 1991).

Population	Cycles of selection	Grain Yield	Grain Moisture	Days to flower	Ear hgt	Lodging Root	Lodging Stalk
		q/ha	%	no.	cm	----- %	------
Per se							
BS2	C0	40.1	17.5	71	121	18	22
	C3	51.5	18.0	72	119	5	22
	C5	49.1	17.8	70	104	3	21
BSTL	C0	39.6	19.3	73	116	7	15
	C3	52.2	18.6	72	113	4	17
	C5	49.8	17.8	72	110	2	13
BS16	C0	47.1	19.8	74	133	10	21
	C2	53.9	17.4	69	103	9	13
	C4	44.9	16.3	69	101	3	16
Selfed							
BS2	C0	24.2	17.2	75	96	12	17
	C3	29.5	17.7	74	101	6	19
	C5	30.2	17.7	73	104	12	17
BSTL	C0	23.4	18.3	75	101	5	12
	C3	31.2	18.3	74	104	4	15
	C5	30.7	18.0	73	96	2	10
BS16	C0	27.5	19.7	75	108	7	15
	C2	26.1	17.0	72	95	4	14
	C4	30.0	16.9	70	86	2	15
LSD (0.05)		6.9	0.8	2	6	4	5

correlated effects were not desirable (Tables 3 and 4). Inbred-progeny recurrent selection in BS2, BSTL, and BS16 was effective initially for grain yield, but response for increased grain yield plateaued after the C2 and C3 cycles of selection. BS2, BSTL, and BS16 included 50, 25 and 100% exotic germplasm, respectively, and either the methods of selection used were not satisfactory or the genetic load of the exotic germplasm was too great to realize long-term response to inbred-progeny recurrent selection.

Effective population sizes (20 to 25) may have been too small, and too many alleles were fixed either because of inbreeding and/or because of genetic drift. The lack of continued response by inbred-progeny recurrent selection, however, is not limited to populations with exotic germplasm because a similar response was obtained in BSK (Table 5), which is a strain (Krug) of Reid Yellow dent. Horner *et al.* (1989) compared inbred-progeny and half-sib family recurrent selection and concluded that the inconsistent, and often discouraging, selection response to inbred-progeny recurrent selection was because of the importance of overdominant effects. If overdominant effects are important, these effects would not be retained with inbred-progeny recurrent selection. Perhaps inbred-progeny recurrent selection can be used initially (2 or 3 cycles), and then change to some type of selection that includes crossing with a tester. Lamkey (1993, personal communication), however, found that S_2 progeny recurrent selection was the most effective method of eight recurrent selection methods conducted for five cycles of selection in BS11. Data were obtained at five locations in 1992 and further evaluations are planned for 1993 and 1994.

Reciprocal recurrent selection:

Reciprocal recurrent selection methods are not used as extensively as the other recurrent selection methods because they are not as adaptable for many of the traits we wish to improve. Reciprocal recurrent selection methods are usually considered only for grain yield improvement in the cross of two populations. Hence, direct response is measured in the population crosses rather than the populations themselves. Initially, reciprocal recurrent selection methods seem more complex than the intrapopulation recurrent methods, but in reality they are no more complex and resource demanding than two selection programs that include half-sib family selection. The objectives of reciprocal recurrent selection are the same as for other recurrent selection methods except response is emphasized in the cross of two populations. If a hybrid breeding program is being conducted, or planned in the future, it seems reciprocal recurrent selection should be considered as an integral part of the breeding program. Hybrid breeding programs are based on the exploitation of heterotic patterns. Reciprocal recurrent selection methods are designed to enhance the heterosis expressed in population crosses.

Because reciprocal recurrent selection emphasizes the crosses between populations, the options for producing the families for evaluation are restricted to either half-sib or full-sib family selection. There are fewer reciprocal recurrent selection programs being conducted, but the responses to reciprocal recurrent selection programs based on half-sib family selection (Table 7) and full-sib family selection (Table 8) have been very encouraging for increasing grain production of the population crosses and enhancing heterosis. Both programs involve US Corn Belt germplasm and are being conducted at Iowa State University, Ames, Iowa.

Reciprocal recurrent selection based on half-sib family selection was initiated in 1949 with Iowa Stiff Stalk Synthetic (BSSS) and Iowa Corn Borer Synthetic No.1 (BSCB1) populations. The program is being continued with 13 cycles of selection completed. Responses to selection were determined by Keeratinijakal and Lamkey (1993) after 11 cycles of selection (Table 7). Grain yield was emphasized in selection, but other agronomic traits were considered in making selections among half-sib families. Direct response in BSSS x BSCB1 was 59.4% or an average response of 2.8 q/ha per cycle of selection. The C11 x C11 (67.6 q/ha) was 25.2 q/ha greater yielding than the C0 x C0 (42.4 q/ha). Midparent heterosis increased from 25.5% (C0 x C0) to 78.7% (C11 x C11). The correlated responses in BSSS (10.4%) and BSCB1 (17.1%) were not as great, but the populations were gradually improved by selection based on half-sib families or population testcrosses. Maturity and standability are important agronomic traits if the populations and population crosses are to be used directly or indirectly in hybrid breeding programs. Grain moisture levels at harvest did not increase and stalk lodging was significantly reduced with

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increased response for grain yield. Eleven cycles of half-sib recurrent selection were effective in all respects in BSSS and BSCB1.

Table 7. Responses to 11 cycles of half-sib reciprocal recurrent selection conducted in BSSS and BSCB1 (Adapted from Keeratinijakal and Lamkey, 1993).

Cycles of selection	Grain yield (q/ha)			Grain moisture (%)			Stalk lodging (%)		
	BSSS	Cross	BSCB1	BSSS	Cross	BSCB1	BSSS	Cross	BSCB1
C0	35.5	42.4	32.1	21	19	18	20	25	40
C4	37.6	49.4	31.6	19	18	17	21	30	32
C7	42.4	60.8	36.1	21	20	20	17	20	18
C8	43.4	65.9	33.0	21	20	20	14	14	12
C9	42.5	69.4	38.7	21	19	19	16	15	10
C10	39.8	68.4	35.9	20	19	19	17	16	12
C11	39.2	67.6	37.6	22	19	19	10	11	10
b	0.6	2.8	0.6	0.0	0.0	0.0	-0.6	-1.5	-3.1
Change, %†	10.4	59.4	17.1	4.8	0.0	5.6	-50.0	-56.0	-66.7

† Change of C11 relative to C0.

Reciprocal recurrent selection based on full-sib progenies was initiated in 1964 with BS10 and BS11 populations. This selection program also is being continued with 11 cycles of selection completed. Responses to selection were determined by Eyherabide and Hallauer (1991) after eight cycles of selection (Table 8). Direct response in the population crosses was 60.4% with an average increase of 3.1 q/ha per cycle of selection. Midparent heterosis for grain yield increased from 2.4% (C0 x C0) to 40.8% (C8 x C8). Indirect response for grain yielding BS10 (23.6%) and BS11 (13.0%) also was realized. Other agronomic traits also were considered in

Table 8. Responses to eight cycles of full-sib reciprocal recurrent selection conducted in BS10 and BS11 (Adapted from Eyherabide and Hallauer, 1991).

Cycles of selection	Grain yield (q/ha)			Grain moisture (%)			Stalk lodging (%)		
	BS10	Cross	BS11	BS10	Cross	BS11	BS10	Cross	BS11
C0	41.5	46.5	49.2	20	21	22	22	21	22
C2	43.8	57.2	51.5	17	19	20	24	20	16
C4	50.9	59.6	48.6	19	19	20	19	18	16
C6	52.4	63.6	54.7	21	20	19	13	15	12
C8	51.3	74.6	55.6	18	19	21	16	12	13
b	3.2	3.1	0.8	---	-0.1	-1.4	-1.0	-1.2	-1.1
Change, %	23.6	60.4	13.0	-10.0	-9.5	-4.5	-23.8	-47.8	-40.9
LSD (0.05)		4.4			1.0			5.3	
				Inbred (S1) Generation					
C0	24	26	22	19	20	21	19	19	14
C2	27	34	31	18	20	20	20	18	12
C4	29	36	29	18	20	20	19	14	13
C6	31	37	32	20	20	19	12	13	15
C8	34	43	34	18	20	21	13	11	10
b	1.3	1.9	1.4	-0.1	---	-0.6	-1.0	-1.0	---
Change, %†	41.7	65.4	54.6	-5.2	0.0	0.0	-31.6	-42.1	-28.6
LSD (0.05)		3.9			1.1			4.5	

† Change of C8 relative to C0.

selecting the full-sib families for intermating, and the positive direct and indirect responses for grain yield were accompanied by significant decreases in grain moisture and stalk lodging in BS10, BS11, and their crosses. The 60.4% increase in grain yield of the population cross was not at the expense of later maturity and greater stalk lodging. The bulk S_1 generations of the BS10 and BS11 populations, and the BS10 x BS11 crosses for the C0 and after eight cycles of selection also were evaluated. Correlated responses of the inbred generations also were in the desired directions.

Progress from half-sib and full-sib reciprocal recurrent selection was similar for the two sets of populations. Although selection emphasized grain yield, other agronomic traits were considered in making the final selections to intermate. It was realized that if the products derived from reciprocal recurrent selection were to contribute to development of lines and hybrids, they must have acceptable maturity and stalk quality. The consideration given to the other traits did not restrict response to selection for improved grain yield. Response to selection for grain yield may have been greater without consideration of maturity, root and stalk lodging, ear retention, and stand, but the selected populations and crosses would have little or no value for breeding programs. The data (Table 7 and 8) certainly suggest that reciprocal recurrent selection methods can develop improved germplasm, if properly conducted. These two examples illustrate the potential of recurrent selection if the same selection procedures used in maize breeding programs are used in germplasm improvement programs. Reciprocal recurrent selection should be an important component of any breeding program that emphasizes development of hybrids.

Hybrid maize breeding

The basic concepts of hybrid maize breeding were described by Shull (1909). During the past 80 years sources of germplasm and maize breeding techniques have been identified to develop highly productive hybrids for most areas of the world. Breeding methods and germplasm sources for extraction of inbred lines have evolved over time and will continue to change as information becomes available (Hallauer, 1990, 1992). Initially, the more productive open-pollinated cultivars were used as germplasm sources to initiate development of lines by selfing representative plants within the different sources. The inbred lines were crossed to determine their combining ability, and the lines were tested in different combinations of double-cross hybrids to determine the best combination of lines. Double-cross Ia939 (L289 x I205) x (Os420 x Os426) was a widely used hybrid that included four inbred lines developed from three open-pollinated varieties, Lancaster Sure Crop (L289), Iodent (I205), and Osterland Yellow Dent (Os420 and Os426). Iodent and Osterland Yellow Dent are strains of Reid Yellow Dent developed in Iowa, but Iodent lines tend to have good combining ability with both Lancaster Sure Crop and Reid Yellow Dent lines. It was only by testing lines in different combinations that the widely used heterotic pattern in the US Corn Belt of Lancaster Sure Crop-Reid Yellow Dent was recognized. Subsequently, breeding, selection, and testing methods were adjusted to exploit the Lancaster Sure Crop-Reid Yellow Dent heterotic pattern. Other heterotic patterns surely could be developed, but it would require extensive selection and testing to develop other heterotic patterns that would be as consistent in performance as the widely used Lancaster Sure Crop-Reid Yellow Dent in the US Corn Belt. Other heterotic patterns are recognized and used in other areas of the world; e.g., early European flints-U.S. dents in Europe and Tuxpeno-ETO Composite or Tuxpeno-Suwan 1 in the tropics.

The trend for the use of landrace cultivars as source germplasm decreased rapidly after the initial samplings (Jenkins, 1978); resampling would not identify better or different genotypes if the initial samplings were adequate. Subsequent generations of lines were developed by use of elite-line cross and backcross populations to make incremental improvements of elite lines, which are generally referred to as recycled or second-cycle lines (Bauman, 1977). These sources of breeding germplasm and the breeding, selection, and testing of lines from these sources have been extremely effective in developing genetically superior hybrids (Russell, 1991), but the number of lines used in the breeding populations is very limited (Smith, 1988). Intensive and rigorous selection within families of a few elite lines (B14, B37, B73, Oh43, and C103) also has enhanced the heterotic pattern of Reid Yellow Dent (B14, B37, and B73) and Lancaster

Sure Crop (Oh43 and C103).

Several issues related to breeding methods to increase the effectiveness of line and hybrid development have been suggested during the past 60 years: some are generally accepted as standard procedures, whereas others vary among breeders depending on their past experience and judgment. Some will be discussed as to their general importance and use in current hybrid breeding programs. Some are more important than others, but they all impact on the breeding, selection, and testing methods currently used. The issues will be discussed in somewhat sequential order relative to stage of breeding and historical development.

***Germplasm*:**

Germplasm sources primarily used for inbred line extraction have changed dramatically during the past 70 years. Originally, the only germplasm available was the open-pollinated cultivars, but presently, open-pollinated varieties receive minimal use in line development. Currently, nearly all of the initial germplasm sources are developed from some combination of elite line crosses (F_2, backcross, elite line synthetic of related lines, elite line synthetic of unrelated lines but within the same heterotic group) (Bauman, 1981). Each type of germplasm source has been used successfully, but F_2, backcross, or combinations of crosses and backcrosses are the more common sources. The crossing of elite lines and selection within crosses has been repeated so that there are second, third, and more cycles that some elite lines have been recycled. Breeders plan carefully which elite lines to cross with the objective of selecting segregates that incorporate the best traits of the two elite lines crossed. Although elite germplasm is emphasized, lines have been developed from the different germplasm sources: Mo17 by pedigree selection from a cross of two lines (C103 x 187-2); B64 and B68 by pedigree selection from the same cross (41.2504B x B14) with two backcrosses to B14 and selection for greater European corn borer resistance; A632 from a cross (Mt42 x B14) with two backcrosses to B14 and with selection for earlier maturity; and H99 from a narrow-base synthetic (Ill.Oh43C). B14, B37, B73, and B84 were derived from a synthetic variety (BSSS).

The main concern is how many breeding populations of elite line crosses a breeder can include each season. The number of breeding populations is influenced by the size of sample taken from each population. Bauman (1981) reported a great variance among maize breeders as to the number of individuals they felt should be taken to represent the genetic variation within the breeding populations; i.e., 100 or 1,000. The more frequent sample size reported was 500. If the breeder has 10,000 rows available in the breeding nursery and a desired sample size of 500 individuals, the breeder could include 20 breeding populations. Other breeders may consider smaller sample sizes, in which case they could include more breeding populations. If a sample size of 200 individuals was considered adequate, 50 breeding populations could be sampled for the 10,000 rows available in the nursery.

Inbreeding for line development is usually initiated in the F_2 generations with no intermating within the populations before initiating selection. F_2 populations of elite line crosses would be at maximum linkage disequilibrium. If repulsion and coupling phase linkages limited the recovery of recombinant segregates, intermating may be helpful. It does not seem, however, that intermating of F_2 populations before initiating inbreeding is worthwhile (Covarrubias *et al.*, 1989).

***Selection*:**

After the sources of germplasm are chosen, the methods used in developing and evaluating either new lines or recovered lines varies among breeders within the same areas and among areas. Because the ultimate value of a line is its performance in hybrids, breeders naturally were interested if a relation exists between traits of a line and either the same or different traits in their hybrids, and how effective visual selection was for fixing traits in lines that were transmitted to their hybrids. Several studies were conducted to determine correlations of traits of lines with the same traits in their hybrids, both for each line and the average of parents in hybrids, correlations of traits of lines with yield of their hybrids, and correlations of yields of lines per se with yield of their hybrids. In all instances, the different combination of correlations were too low and inconsistent to have good predictors of how inbred lines perform in hybrids (Hallauer and Miranda, 1988).

Visual selection, however, does receive consideration by breeders during development of lines (Bauman, 1981). Among the traits considered during inbreeding, visual selection was considered to be effective for some traits (**Table 9**). The breeders also rated the traits for their relative importance in lines and hybrids. There was not a close agreement ($r = 0.58$) between the importance of traits and effectiveness of visual selection for these traits (**Table 9**). Maize breeders, however, continue to practice rigid selection during the development of lines because the eventual value of the lines is their relative performance in hybrids. Although the traits of the lines have low predictability for their hybrids and visual selection is generally not effective for many important traits, selection certainly remains effective for monitoring maturity, conforming to standards for plant and grain type, screening for disease and insect resistance to enhance resistance of their hybrids, and developing lines that can be maintained and used in seed production at reasonable costs. Visual selection will continue to have a role in maize breeding, but evaluation of lines in hybrids is an imperative.

Table 9. Ratings for the relative importance and effectiveness of visual selection for 17 plant and ear traits in US Corn Belt breeding programs (Adapted from Bauman, 1981).

Traits	Ratings (1 to 4)	
	Importance of trait†	Effectiveness of visual selection ‡
Grain yield	1.2	3.2
Stalk strength	1.2	2.5
Root strength	1.4	2.6
Stalk rot	1.5	2.3
Silk emergence	1.6	1.4
Leaf blights	1.7	1.6
Ear rots	1.8	2.1
Flowering date	1.9	1.3
Pollen shed	1.9	1.7
Seedling vigor	1.9	1.9
Insect damage	2.0	2.3
Kernel qualities	2.1	1.9
Plant and ear height	2.2	1.5
Smut (Ustilago maydis)	2.3	2.2
Plant appearance	2.3	1.8
Erect leaf habit	3.0	1.6
Plant color	3.2	1.5

† Rating of 1 trait considered more important and rating of 4 trait less important.

‡ Rating of † visual selection is effective and rating of 4 where visual selection is not effective.

Testing for combining ability:

The importance of testing inbred lines for their performance in hybrids was recognized and emphasized by Shull (1909); only then was the true merit of the new lines determined. Shull also indicated that a group of inbred lines that random crosses among them will not all be equally productive. Hence, one has to make the crosses between pairs of lines and evaluate the crosses in replicated trials before one can determine which pair of lines produces the superior hybrid. Shull (1909), therefore, either had a premonition that appearance of lines would not predict their performance in hybrids or had not visualized how important many traits would be considered during inbreeding to develop lines and evaluate in hybrids.

Methods to increase the efficiency and effectiveness for evaluation of lines in crosses have always been a major focus in the study of hybrid breeding methods. Studies and suggestions were made for appropriate generation of inbreeding to test (early testing vs. late testing), relative importance of additive (GCA) and nonadditive (SCA) effects in crosses, types of testers (good or poor performance), extent of testing, and relative value of among and within progeny testcrossing (Hallauer and Miranda, 1988). Jenkins and Brunson (1932) presented evidence that the topcross method was useful for making an initial screening of lines for combining ability.

Sprague and Tatum (1942) demonstrated that GCA effects were larger and more important for unselected lines and that SCA effects were more important in crosses between lines that have had previous testing. Jenkins (1935) and Sprague (1946) demonstrated that the combining ability of lines was established relatively early in the inbreeding process and remained relatively stable thereafter. The collective information provided by these studies have established that the potential value of new lines can be determined in the early generations (S_1 to S_3) of inbreeding with the use of the testcross procedures. The production and evaluation of testcrosses is a very important and standard component of all modern hybrid corn breeding programs.

Although testcrosses are a standard and key component, there are variations among maize breeders when testcrosses of new lines are produced and tested. The generation used to produce and conduct testcross evaluations varies among plant breeders, but all conduct testcross evaluation of lines at some stage of inbreeding (Table 10). It seems, however, that maize breeders are gradually evaluating lines at earlier stages of inbreeding, even earlier than the data reported by Bauman (1981). The proponents of early testing (Jenkins, 1935; Sprague, 1946) did not claim that a perfect correlation would occur between early and later generation testcrosses. Proponents for early testing indicated that the only value of early generation testing was to only continue breeding effort in those lines that had above average combining ability---they claimed no more or no less for advantages of early generation testing. Additional support for the value of early generation testing includes the progress realized from recurrent selection programs (Hallauer, 1992) and the ineffectiveness of visual selection for agronomically important traits (Table 9). It seems testcross evaluation will continue to be conducted at earlier generations of inbreeding to determine the relative combining ability of new lines with testing conducted with fewer replications--more evidence of the value of early testing.

Recurrent selection and corn breeding

Each of these two aspects have been discussed separately, but it is only if both aspects are considered equally important that the potential of both will have their greatest benefits (Hallauer and Miranda, 1988). Eberhart *et al.* (1967) outlined how the products of recurrent selection can be used effectively to provide products for both the small and large growers in Kenya. The same applications can be made in any situation whether the programs are focused on improved cultivars or emphasis given to developing inbred lines for use in single-cross hybrids. Neither of the methods, which are quite different operationally and have different objectives, have clear advantages over one another (Duvick, 1977). Some excellent lines have been developed by classical pedigree breeding methods (C103, Oh43, and Mo17) and some excellent lines have been

Table 10. Initial samples sizes, selection intensity during inbreeding, and generation of inbreeding that lines are evaluated for combining ability (Adapted from Bauman, 1981).

Generation of inbreeding	Number of progenies	Initial sample	Previous generation	Generation for testcross evaluation
S0	500	---	----	----
S1	500	100%	100%	0%
S2	180	36	36	18
S3	80	16	44	33
S4	40	8	50	27
S5	---	---	---	9
Other	---	---	---	13

developed by recurrent selection methods followed by pedigree selection (B14, B37, B73 and B84). All of these lines also have been effectively used in developing recycled lines by pedigree selection methods (Smith, 1988). Hence, the materials developed by either of the two distinct breeding methods have contributed to the genetic progress realized since the inbred-hybrid concept was proposed by Shull (1909). Both methods contribute to the develop of lines: line developed from recurrent selection programs are used in pedigree selection programs of elite-line crosses, and pedigree selection methods are used in developing lines from different cycles of recurrent selection. Recurrent selection programs that are not an integral part of applied breeding programs probably, in most instances, will not have a direct impact on the applied breeding program. This can happen because the traits emphasized in recurrent selection programs may not be the ones that are necessary in the applied breeding programs. If the same individuals are directly involved with both germplasm enhancement and development of lines and hybrids, a concerted and coordinated effort for genetic advance of the important traits necessary for a given area will be ensured. Conducting recurrent selection programs without any coordination with the applied breeding programs will not be a fruitful endeavor.

References

Bauman, L.F. 1977. Improvement of established maize inbreds. Maydica 22:213-222.

Bauman, L.F. 1981. Review of methods used by breeders to develop superior hybrids. Proc. Annu. Corn Sorghum Ind. Res. Conf. 36:199-208.

Compton, W.A., and R.E. Comstock. 1976. More on modified ear-to-row selection. Crop Sci. 16: 122.

Comstock, R.E. 1964. Selection procedures in corn improvement. Proc. Annu. Corn Sorghum Ind. Res. Conf. 19:87-94.

Comstock, R.E., H.F. Robinson, and P.H. Harvey. 1949. A breeding procedure designed to make maximum use of both general and specific combining ability. Agron. J. 41:360-367.

Covarrubias-Prieto, J., A.R. Hallauer, and K.R. Lamkey. 1989. Intermating F_2 populations of maize. Genetika 21:111-126.

Devey, M.E., and W.A. Russell. 1983. Evaluation of recurrent selection for stalk quality in a maize cultivar and effects on other agronomic traits. Iowa State J. Res. 58:207-219.

Duvick, D.N. 1977. Genetic rates of gain in hybrid maize yields during the past 40 years. Maydica 22:187-196.

Eberhart, S.A. 1970. Factors affecting efficiencies of breeding methods. African Soils 15:669-680.

Eberhart, S.A., M.N. Harrison, and F. Ogada. 1967. A comprehensive breeding system. Zuchter 37: 169-174.

Eyherabide, G.H., and A.R. Hallauer. 1991. Reciprocal full-sib selection in maize. I. Direct and indirect responses. Crop Sci. 31:952-959.

Gardner, C.O. 1961. An evaluation of effects of mass selection and seed irradiation with thermal neutrons on yield of corn. Crop Sci. 1:241-245.

Hallauer, A.R. 1985. Compendium of recurrent selection methods and their application. Critical Reviews Plant Sci. 3:1-24.

Hallauer, A.R. 1990. Methods used in developing maize lines. Maydica 35:1-16.

Hallauer, A.R. 1990. Germplasm sources and breeding strategies for line development in 1990's. Proc. Annu. Corn Sorghum Res. Conf. 45:64-79.

Hallauer, A.R. 1992. Recurrent selection in maize. Plant Breeding Rev. 9:115-179.

Hallauer, A.R., and S. A. Eberhart. 1970. Reciprocal full-sib selection. Crop Sci. 10:315-316.

Hallauer, A.R., and J.B. Mirada Fo. 1988. Quantitative Genetics in Maize Breeding. Iowa State Univ. Press. Ames, IA.

Hallauer, A.R., W. A. Russell, and K.R. Lamkey. 1988. Corn breeding. p. 463-564. *In* G.F. Sprague and J.W. Dudley (ed). Corn and Corn Improvement. American Society of Agronomy, Madison, WI.

Hopkins, C.G. 1899. Improvement in the chemical composition of the corn kernels. Illinois Agric. Exp. Stn. Bull. 55:205-240.

Horner, E.S. 1985. Effects of selection for S_2 progeny versus testcross performance in corn. Proc. Annu. Corn Sorghum Ind. Res. Conf. 40:142-150.

Horner, E.S., E. Magloire, and J.A. Morera. 1989. Comparison of selection of S_2 progeny vs. testcross performance for population improvement in maize. Crop Sci. 29:868-874.
Hull, F.H. 1945. Recurrent selection and specific combining ability in corn. J. Am. Soc. Agron. 37:134-145.
Hull, F.H. 1952. Recurrent selection and overdominance. p. 451-473. *In* J.W. Gowen (ed.) Heterosis. Iowa State Univ. Press. Ames, IA.
Iglesias, C.A., and A.R. Hallauer. 1991. Response to S_2 recurrent selection in exotic and semi-exotic populations of maize (*Zea mays* L.). J. Iowa Acad. Sci. 98:4-13.
Jenkins, M.T. 1935. The effect of inbreeding and selection within inbred lines of maize upon hybrids made after successive generations of selfing. Iowa State College J. Sci. 9:429-450.
Jenkins, M.T. 1940. The segregation of genes affecting yield of grain in maize. J. Am. Soc. Agron. 32:55-63.
Jenkins, M.T. 1978. Maize breeding during the development and early years of hybrid maize. p. 13-28. *In* D.B. Walden (ed.) Maize Breeding and Genetics. John Wiley and Sons. New York.
Jenkins, M.T., and A.M. Brunson. 1932. Methods of testing inbred lines in crossbred combinations. J. Am. Soc. Agron. 24: 523-530.
Keeratinijakal, V., and K.R. Lamkey. 1993. Responses to reciprocal recurrent selection in BSSS and BSCB1 maize populations. Crop Sci. 33:73-77.
Klenke, J.R., W. A. Russell, and W.D. Guthrie. 1986. Recurrent selection for resistance to European corn borer in a corn synthetic and correlated effects on agronomic traits. Crop Sci. 26:864-868.
Lamkey, K.R., and A.R. Hallauer. 1984. Comparisons of maize populations improved by recurrent selection. Maydica 29:357-374.
Lonnquist, J.H. 1964. A modification of the ear-to-row procedure for the improvement of maize populations. Crop Sci. 4:227-228.
Manglesdorf, P.C. 1974. Corn: Its Origin, Evolution, and Improvement. Harvard Univ. Press. Cambridge, MA.
Moll, R.H., and H.F. Robinson. 1966. Observed and expected response in four selection experiments in maize. Crop Sci. 6:319-324.
Rawlings, J.O. 1970. Present status of research on long and short term recurrent selection in finite populations--choice of population size. Proc. Second Meet. Work. Group Quant. Genet., Sect. 22. IUFRO, Raleigh, N.C. p. 1-15.
Russell, W.A. 1991. Genetic improvement of maize yields. Adv. Agron. 46:245-298.
Shull, G.H. 1909. A pure-line method in corn breeding. Am. Breeders' Assoc. Rep. 5: 51-59.
Smith, J.S.C. 1988. Diversity of United States hybrid maize germplasm: Isozymic and chromatographic evidence. Crop Sci. 28:63-69.
Smith, O.S., A.R. Hallauer, and W.A. Russell. 1981. Use of selection index in recurrent selection in maize. Enphytica 30:611-618.
Sprague, G.F. 1946. Early testing of inbred lines. J. Am. Soc. Agron. 38:108-117.
Sprague, G.F., and L.A. Tatum. 1942. General vs. specific combining ability in single crosses of corn. J. Am. Soc. Agron. 34:923-932.
Tanner, A.H., and O.S. Smith. 1987. Comparison of half-sib and S_1 recurrent selection in Krug Yellow Dent maize populations. Crop Sci. 27:509-513.
Williams, P.N., and F.M. Davis. 1983. Recurrent selection for resistance in corn to tunneling by the second-brood southwestern corn borer. Crop Sci. 23:169-170.

Questions to the author:

FROM : C. De Leon
Q : Most programs in lowlands are trying to "tropicalize" temperate lines. However, you are going "the other way" by selection for lowland tropical germplasm adapted in your temperate conditions. Would you suggest to continue tropicalizing the temperate adapted lines, or go

straight and select for good combining lines extracted from tropical germplasm?

A : Yes, I would certainly continue to adapt temperate lines to tropical conditions. Widely used temperate lines have had extensive selection for high, stable performance by the recycling of lines in elite by elite line crosses. At Iowa State University, we have adopted tropical lowland germplasm to temperate conditions with intense mass selection (500 plants) in large populations. Everett Gerrish, however, also was effective in adapting tropical germplasm to temperate areas by crossing and backcrossing to elite lines. I feel the reverse situation can be done (and should be done to capture the superior alleles of temperate lines), but it may be more difficult because of the disease and insect pressures of the tropical environments. The disease pressures experienced by tropical germplasm enhances their potential value in temperate areas. Because temperate lines have not been exposed to the disease and insect pressures of the tropics, more intercrossing between cycles of backcrosses may be needed to pyramid the necessary levels of resistance. But it can be done.

FROM : E. R. Bautista

Q : In hybrid maize development, which should be given more emphasis, heterotic pattern or combining ability values? Is there any relationship between the two which could be used as a good basis in hybrid maize development?

A : Heterotic patterns vs general combining ability are two different issues. Assume we are interested in identifying a heterotic pattern among 10 populations of maize. We could produce a diallel set of 45 crosses among the 10 populations. We evaluate the 10 populations and 45 populations crosses in replicated experiments conducted in different environments, analyze the data, and estimate the general (GCA) and specific (SCA) combining ability effects for the populations and population crosses, respectively. GCA effects are the average performance of a parent in crosses and are due to primarily additive genetic and additive x additive epistatic effects. A significantly positive estimate of GCA for a parent indicates the parent had above average performance in crosses. A significantly positive estimate of SCA effects indicates that the specific cross exceeded the expected, based on the average performance of the parents, or GCA, i.e. non additive effects were expressed in the cross. This does not mean that a parent with good GCA will not have good SCA with one specific parent. Iowa Stiff Stalk Synthetic (BSSS) is a good example: BSSS has good GCA with other populations but it also has good SCA with Lancaster Sure Crop. A Significantly positive SCA effect suggests a possible heterotic pattern, but one must be careful because the one parent may have poor performance per se. Generally, populations with good GCA also can have good SCA with other populations; the reverse situation of high SCA for a specific pair may not indicate good GCA with other parents.

FROM : S. J. Patil

Q : In the population improvement or maintenance how often you advise the introgression of new variability?

A : I feel that populations under selection to develop germplasm for breeding programs should be open-ended populations, but the introgression of new genetic materials in the populations has to be considered very carefully. Presumably, selection has been effective for increasing the frequency of desirable alleles in the populations for the trait(s) considered in selection. Hence, it seems genetic variability was reduced. If we introgress other materials into the selected population, we do not want to dilute the previous progress from selection. If other germplasm sources are introduced into a selected population, we would want to ensure that the new genetic variability will not regress the previous gains. If information from other studies suggest that other germplasm could enhance the selected population; then it would be appropriate to introgress the other germplasm source into the selected population.

FROM : M. Dahlan

Q : In recurrent selection, the progeny is evaluated say in 3 very different environments. There is high genotype by environment interaction, therefore difficult to select families with good yield in all environment. How do you select the families for intercrossing?

A : You will need to identify your target environments. It seems that if selection and evaluation are conducted in only one environment, the resultant selected population is environment specific; i.e., response to selection is realized only for the one specific environment. If the selected population, or families from the population, are to be grown in other environments, it seems necessary to test in the appropriate environments. Genotype by environment interactions reduce response to selection because the heritability is reduced. Genotype by environment interactions are common, and I think they have to be included in selection if the selected germplasm is expected to be used in a range of environments.

Selection of families for intercrossing is based on yield, maturity, and standability. The heritability estimates from the combined analysis of variance are used as the weighting factors for each trait and index value based on the sum (or difference) for each family; i.e., $h_1^2 \bar{X}_{i1} - h_2^2 \bar{X}_{i2} - h_3^2 \bar{X}_{i3} - h_4^2 \bar{X}_{i4}$ = index value, where $\bar{X}_{i1}$ (grain yield), $\bar{X}_{i2}$ (grain moisture), $\bar{X}_{i3}$ (root lodging), and $\bar{X}_{i4}$ (stalk lodging) are the family means across environments for family 1.

FROM : C. Chutkaew

Q : Could we use the same population size for all traits of selection in breeding program starting from yield (quantitative) traits to qualitative ones such as protein, oil, agronomic performance and how big that effective population size?

A : The choice of population size for any trait depends on the goals of selection, whether the trait is quantitative or qualitatively inherited. In most instances in the development of germplasm for breeding purposes, they are long-term selection programs and population sizes necessary for the improvement of the more complex traits should be used. The improvement for the qualitative traits would be realized if they were considered in the selected progenies intermitated, but at a slower rate than if selection was based only on qualitative traits. If selection only for a specific qualitative trait and other traits are not considered in the selected progenies that are intermated, intense selection within larger populations would be appropriate.

FAO REGIONAL ACTIVITIES FOR MAIZE DEVELOPMENT IN ASIA

R. S. Paroda [1/]

Abstract

Maize accounts for 18% of the world's cereal hectarage and around 25% of the world's cereal production. In Asia, it accounts for 15% of the region's cereal production. Maize has registered the highest growth rate (4.1%) in the Asia-Pacific region during the last decade compared to the rest of the world (0.2%). Almost 24 out of 30 countries in this region grow maize.
Yet, regional variations exist for both production and productivity, mainly due to variable adoption of production technology. There is considerable scope for improving maize productivity in the region provided suitable strategies and policies are evolved and adopted. Also much could be achieved through regional collaboration. FAO has initiated some of the activities to strengthen required regional linkages in the recent past. Also steps have been taken to establish a Tropical Asian Maize Network (TAMNET) and needed support has been extended to some national maize programmes. Details of these efforts and the need for future activities for promoting maize research and development activities are enumerated in this paper.

I. MAIZE PRODUCTION SCENARIO

1. In the Asia-Pacific region, maize contributes approximately 15% of the cereal production and the region's share of the world production of maize is almost 25%. Twenty-four of the 30 countries in the region produce maize. Major maize producing countries in the region are China, India, Indonesia, Philippines, and Thailand, each having more than 1 m ha under maize. Other countries where maize is an important crop are Pakistan, Vietnam, Nepal, and DPR Korea. Details of production, yield, and area under maize in the Asia-Pacific region are given in **Tables 1, 2,** and 3.

2. Among major cereals, maize has shown consistent progress in production having a growth rate of 4.3%, compared to rice (2.3%) and wheat (3.0%). Similarly, the yield advancements in rice (1.9%), and wheat (2.4%), are lower than maize (2.8%). Hence, the future of maize in the Asia-Pacific region appears to be bright, especially in view of rising demand for feed and fodder purposes, in addition to its use for food consumption. According to a World Bank forecast, maize is likely to achieve an annual growth rate of 7.0% by the year 2005 in the Asia-Pacific region.

II. PRODUCTIVITY VARIATIONS

3. Compared to the world average (3.98 t/ha), maize productivity in the Asia-Pacific region is only 3.36 t/ha, which is much lower than the rest of the world (4.24 t/ha). Considerable variation for productivity of maize exists in the region. For example, China with 21 m ha area has a yield level of 4.5 t/ha, whereas India with 6 m ha area has productivity of only 1.6 t/ha. Hence, there is considerable scope for improving maize productivity level in the region.

III. SOME INTERESTING DEVELOPMENTS

4. In the Asia-Pacific region, some very exciting developments towards increased maize production have taken place, especially in non-traditional maize areas. In this context, examples of winter maize in India, Nepal, and Philippines, and transplanting of maize after paddy rice in the winter season in North Vietnam could be cited as success stories. Almost a decade ago, such possibilities were non-existent. Today, almost 100,000 ha are planted under winter maize in the

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Table 1. Maize: Production

Unit 1000 tons

Country	1982	1989	1990	1991	1992	Average Annual Growth Rate 1982-92
DEVELOPING COUNTRIES						
1. Bangladesh	1	3	3	3	3	12.3%
2. Bhutan	81	31	40	40F	40	9.6%
3. Cambodia	51	50F	55F	50F	50F	1.0%
4. China	60678	79259	97158	99091	95340F	4.7%
5. Cook Islands	-	-	-	-	-	-
6. DPR. Korea	4200F	4450F	4400F	4500F	4400F	0.2%
7. Fiji	1F	1	2	2	2F	0.2%
8. India	6549	9651	9073	8700	9740*	3.1%
9. Indonesia	3235	6193	6734	6256	7987*	6.5%
10. Iran	28*	60*	130F	188	190F	18.2%
11. Laos	35	44	67	69	59	7.8%
12. Malaysia	9	34*	35*	35*	36*	11.0%
13. Maldives	-	-	-	-	-	-
14. Mongolia	-	-	-	-	-	-
15. Myanmar	239	194	187	196	241	0.4%
16. Nepal	718	1201	1231	1205	1164*	5.9%
17. Pakistan	1005	1179	1185	1203	1279	2.5%
18. Papua New Guinea	1	1F	1F	2F	2F	4.4%
19. Philippines	3126	4522	4854	4655	4570*	4.3%
20. Rep. of Korea	117	121	120	75	100*	-2.3%
21. Samoa, W.	-	-	-	-	-	-
22. Solomon Islands	-	-	-	-	-	-
23. Sri Lanka	24	31	33	34	29	1.0%
24. Thailand	3002	4393	3722	3793	3610*	0.6%
25. Tonga	-	-	-	-	-	-
26. Vanuatu	1F	1F	1F	1F	1F	0.9%
27. Vietnam	438	838	671	652	660F	4.8%
SUB-TOTAL	83539	112255	129702	13076	129501	4.3%
DEVELOPED COUNTRIES						
28. Australia	212	217	219	194	210	0.1%
29. Japan	2	1F	1F	1F	1F	8.2%
30. New Zealand	170	139	162	183	160	0.1%
SUB-TOTAL	385	356	381	378	371	0.0%
ASIA-PACIFIC TOTAL	83924	112612	130083	131124	129872	4.3%
REST OF WORLD	366415	361951	349057	359877	396538	1.3%
WORLD	450338	474563	479140	491001	526410	1.9%

SOURCE: FAO RAPA Publication: 1993/26

Table 2. Maize: Yield

Unit: kg/ha

Country	1982	1989	1990	1991	1992	Average Annual Growth Rate 1982-92
DEVELOPING COUNTRIES						
1. Bangladesh	739	942	1001	978	932	2.6%
2. Bhutan	1421	742	889	889	889	-6.4%
3. Cambodia	836	1250	1375	1250	1250	4.2%
4. China	3269	3879	4523	4577	4522	2.9%
5. Cook Islands	-	-	-	-	-	-
6. DPR. Korea	6176	6312	6197	6338	6223	0.2%
7. Fiji	2062	1260	2108	2000	2000	3.1%
8. India	1145	1632	1524	1440	1637	2.7%
9. Indonesia	1569	2103	2132	2150	2204	3.4%
10. Iran	2000	2400	2955	4500	4524	6.2%
11. Laos	1100	1444	1815	1007	1827	6.3%
12. Malaysia	1125	1789	1750	1750	1714	3.2%
13. Maldives	1000	1000	1000	1000	1000	-
14. Mongolia	-	-	-	-	-	-
15. Myanmar	1760	1580	1495	1539	1541	1.5%
16. Nepal	1406	1599	1625	1598	1595	1.4%
17. Pakistan	1273	1367	1383	1420	1460	1.4%
18. Papua New Guinea	1326	1474	1450	1500	1455	0.9%
19. Philippines	990	1226	1271	1297	1348	3.0%
20. Rep. of Korea	4119	4878	4613	3411	4545	0.2%
21. Samoa, W.	-	-	-	-	-	-
22. Solomon Islands	-	-	-	-	-	-
23. Sri Lanka	895	1051	1035	1172	1039	0.7%
24. Thailand	2299	2569	2409	2712	2553	1.2%
25. Tonga	-	-	-	-	-	-
26. Vanuatu	520	538	538	538	538	0.5%
27. Vietnam	1148	1654	1554	1505	1478	2.5%
SUB-TOTAL	2491	2965	3318	3379	3354	2.8%
DEVELOPED COUNTRIES						
28. Australia	3482	4191	4182	3994	3962	4.2%
29. Japan	2030	2564	2524	2589	2500	4.1%
30. New Zealand	9070	9334	9509	10188	9143	0.8%
SUB-TOTAL	4761	5326	5475	5656	5236	3.5%
ASIA-PACIFIC TOTAL	2496	2969	3322	3383	3357	2.8%
REST OF WORLD	4038	3948	3955	3956	4237	1.0%
WORLD	3621	3662	3760	3785	3980	1.3%

SOURCE: FAO RAPA Publication: 1993/26

Table 3. Maize: Area harvested

Unit 1000 ha

Country	1982	1989	1990	1991	1992	Average Annual Growth Rate 1982-92
DEVELOPING COUNTRIES						
1. Bangladesh	2	4	3	3	3	9.5%
2. Bhutan	57	42	45F	45F	45F	-3.5%
3. Cambodia	61	40F	40F	40F	40F	-3.1%
4. China	18564	20434	21483	21648	21085*	1.8%
5. Cook Islands	-	-	-	-	-	-
6. DPR. Korea	680F	705F	710F	710F	707F	0.4%
7. Fiji	-	1	1	1	1F	3.3%
8. India	5720	5915	5954	6040	5950*	0.4%
9. Indonesia	2061	2944	3158	2908	3624*	3.0%
10. Iran	14F	25*	44*	42	42F	11.3%
11. Laos	32	30	37	34	32	1.5%
12. Malaysia	8	19*	20*	20*	21*	7.5%
13. Maldives	-	-	-	-	-	-
14. Mongolia	-	-	-	-	-	-
15. Myanmar	136	123	125	127	157	2.5%
16. Nepal	511	751	758	754	730F	4.4%
17. Pakistan	790	863	856	848	876	1.0%
18. Papua New Guinea	1	1F	1F	1F	1F	5.4%
19. Philippines	3157	3689	3820	3589	3390*	1.3%
20. Rep. of Korea	28	25	26	22	22*	-2.5%
21. Samoa, W.	-	-	-	-	-	-
22. Solomon Islands	-	-	-	-	-	-
23. Sri Lanka	27	29	32	29	28	0.3%
24. Thailand	1306	1710	1545	1399	1414	0.6%
25. Tonga	-	-	-	-	-	-
26. Vanuatu	1F	1F	1F	1F	1F	0.5%
27. Vietnam	381	507	432	433	447F	2.2%
SUB-TOTAL	33538	37857	39090	38695	38615	1.5%
DEVELOPED COUNTRIES						
28. Australia	61	52	52	49	53	-3.9%
29. Japan	1	-	-	-	-	-
30. New Zealand	19	15	17F	18*	18F	0.8%
SUB-TOTAL	81	67	70	67	71	-3.3%
ASIA-PACIFIC TOTAL	33619	37924	39160	38761	38686	1.5%
REST OF WORLD	90747	91679	88262	90966	93580	0.3%
WORLD	124366	129603	127422	129728	132266	0.6%

SOURCE: FAO RAPA Publication: 1993/26

Bihar and western Uttar Pradesh region in India. In these conditions, the productivity of winter maize is around 5-7 t/ha, with less water requirement and relatively shorter duration than the wheat crop. Also in the Diara lands, experiencing floods during the rainy season, maize is becoming a successful crop on receding moisture during the winter season.

5. In northern Vietnam, almost 80,000 ha are presently grown under maize in the winter season along the Red River after two crops of rice. This has become possible mainly due to the adoption of transplanted maize technology. Earlier, no such possibilities existed of raising a third crop in the traditional rice-rice system in North Vietnam. Transplanting of maize also helps in reducing the growth period of the crop, thus enabling it to fit into a rice-rice-maize system successfully. Very high yield levels of 6-9 t/ha are realized through this practice.

6. Winter maize is also becoming a successful crop in northern Philippines and relatively cooler regions of Punjab in India and tarai of Nepal.

7. These developments clearly reveal future possibilities of increasing both additional area under maize and the productivity in the region. These experiences will have to be translated into practice in similar areas in other countries where such a potential exists. No doubt, more Research and Development (R & D) efforts supported by appropriate policies would be necessary. Also, such a technology would require intensive agricultural practices and higher inputs, appropriately supported by market and pricing policies, as well as demand of maize for the processing industry.

8. Another interesting development is the cultivation of maize for vegetable purposes as "baby corn" in Thailand.

IV. EXISTING CONSTRAINTS

9. As reflected earlier, the Asia-Pacific region has shown remarkable progress towards increases in both the production and productivity of maize. Yet, of the 24 maize producing countries, 15 of them still produce <2 t/ha, which is a matter of concern today. No doubt, the tropical climate in most of these countries is associated with increased pressure of diseases and pests, abiotic pressures such as drought, waterlogging, temperature variations, etc. and several natural, technological and sociopolitical constraints. Maize is largely grown as a rainfed crop with practically very little use of inputs such as fertilizers, herbicides, and pesticides. In addition, a declining trend in the real price of maize in international markets is also operating as a negative factor for the required growth of maize in the region.

10. Scientific advances in maize research have amply demonstrated the distinctive advantage of maize hybrids over open pollinated varieties (OPV's). In developed countries, almost all the area is presently planted to superior hybrids, whereas in the developing countries, especially in the Asia-Pacific region, coverage under superior hybrids is hardly upto 20%. This acts as one of the major constraints. The national programmes in the Asian region released not more than 20-40% of the total hybrid releases up to 1985. It is only during the last 5-7 years that increased emphasis is being given on R&D of maize hybrids.

11. Another important constraint to productivity is poor adoption of improved production technology, especially the use of inputs such as fertilizers, herbicides and pesticides. Very little use is made of these inputs in predominantly rainfed agriculture experiencing frequent droughts, increased pressure of diseases (downy mildew, leaf blights, rusts, etc.), pests (especially corn borers), weeds, poor nutrient status of the soil, especially organic matter, shorter crop growing seasons, variations in mega-environmental conditions such as lowland tropical, subtropical, midaltitude, and highland, and growing of maize in varying farming systems, all impose considerable production constraints which have to be scientifically addressed and resolved. In many countries, proper R&D support is still lacking.

12. To sum up, the major constraints are as follows:

i) Lack of appropriate policy on hybrids at the national level, including pricing support and procurement,

ii) Insufficient R&D support,

iii) Less area coverage due to non-availability of quality seed and required infrastructure for seed development and marketing,

iv) Lack of information and material exchange concerning hybrids,

v) Incentives to private sector are often lacking,
vi) Required trained manpower is invariably not available in some countries, and
vii) Required regional collaboration is not in place.

V. STRATEGY FOR THE FUTURE

Suitable strategy on hybrids is necessary to overcome existing constraints. This would also help in improving further both the production and productivity of major cereals in Asia-Pacific Region. Action on the following would be helpful towards improving the present situation:

i) National policy concerning adoption of hybrid technology would obviously determine the extent to which the impact of this technology would become visible. There is need to sensitize policy makers concerning importance of this matter. Policy support for seed production and pricing would also determine the role that public and private sectors will have to play towards R&D efforts on hybrid technology.

ii) Greater thrust is needed for R&D efforts on hybrid development and adoption at the field level. Present spending on hybrid research are relatively inadequate in a number of countries. Also the involvement of Private Sector for generating hybrid technology is much less in the developing countries compared to the developed countries.

iii) Organized seed production of hybrids for higher replacement rates would enable countries in Asia-Pacific Region to improve their productivity further.

Besides Public system, there is a need to encourage the Private Seed Sector to play an effective role in the future so as to have an appropriate and efficient delivery system in place. Clear policies of the Government regarding area coverage under hybrids *vis a vis* open pollinated varieties would go a long way in improving the situation.

iv) The pace for the adoption of hybrid technology will have to be accelerated in the future. Present casual approach in many countries, still dependent on first generation technology, such as use of OPVs in maize and pearl millet or double cross hybrids in maize, is not likely to yield required advancements through hybrid technology, as experienced elsewhere. Hybrid rice is another example in this context, where much could be learnt from Chinese experience.

v) Regional collaboration for seed development and promotion of hybrid technology, based on experiences and successes gained in the Region, would go a long way in improving the present scenario. Presently, there is lack of communication and no mechanism exists fro regular flow of information concerning promotion of hybrids. Also systematic testing of hybrids at the regional level is lacking and exchange of germplasm is quite limited between countries. Regional cooperation is also needed for human resource development as well as cooperation for economic production and supply of hybrid seeds at competitive price. Accordingly, regional cooperation is needed in order to achieve following objectives:

a) exchange of information on hybrid technology and seed production and marketing;
b) regional testing of promising hybrids and exchange of germplasm;
c) cooperation among public and private seed organizations, especially to draw strength from each other in view of comparative advantages;
d) human resource development in the field of hybrid technology; and
e) advice concerning policy and strategy for promoting R&D efforts on hybrid technology and development of seed sector, especially Private Sector involvement through appropriate provisions for plant variety protection (IVP) systems.

Recent efforts by FAO to establish Asia-Pacific Seed Association (details of which will be explained by Mr. Lemonius during this Consultation) would possibly address some of these issues in future. Mechanisms are, therefore, required to be devised to ensure fulfillment of these objectives in the near future so that benefits reach the common farmers of the developing countries in the Region.

VI. NEED FOR REGIONAL SUPPORT

13. Considering the extent of variation that exists for research, extension, and policy support and the disparity of maize productivity levels, it becomes apparent that considerable gains could be achieved through mutual cooperation and sharing of experiences. Maize is a crop which has

tremendous potential for improved production as well as productivity. There is scope for horizontal expansion through its adoption in different farming systems in the Asia-Pacific region. Maize, as explained earlier, also has a future in view of its increasing demand for food, feed, and various other uses. Thus, it would be appropriate to target for higher maize production in the future to meet the regional demands rather than to depend on large scale imports. This could be achieved through better R&D support, development of human resources as well as infrastructure, production and supply of quality seeds of both hybrids and OPV's and other inputs, incentives to the private sector, policy support for pricing and procurement, and strengthening of the regional collaboration for the exchange of information, materials, and expertise. Unfortunately, public sector investment on maize research in Asia is highly variable and inadequate.

VI. FAO ACTIVITIES IN THE REGION.

14. There is an apparent demand on international organizations, such as FAO, to play a catalytic role for strengthening regional linkages and programmes, including building of national capabilities to meet future challenges successfully. Some of the efforts made by FAO in the last two decades have helped to a certain extent.

15. FAO has supported maize programmes in a number of countries in the region, especially Vietnam (to promote transplanting of maize in the winter season in North Vietnam), hybrid maize programme in DPR Korea, and maize development in Laos.

16. A regional project on Food Legumes and Coarse Grains funded by UNDP has helped a number of cooperating countries for manpower training, information exchange, sharing of improved germplasm, seed production, improved management, and post-harvest handling of maize. Similarly, another training project has helped in human resource development and in sharing of information.

17. A regional Expert Group Meeting was organized at Bangkok in February 1993. It recommended future collaboration through the establishment of a Tropical Asian Maize Network (TAMNET) for required linkages. A Newsletter is being planned and as a follow-up, a regional trial of hybrid maize was constituted for the first time in 1993, involving 20 hybrid entries from six countries in the region. TAMNET Newsletter will be published from the Indian Agricultural Research Institute (IARI), New Delhi. The data of the hybrid trial will be analyzed and compiled by the Regional Office of CIMMYT at Bangkok.

18. FAO is also contemplating establishment of an Asia-Pacific Seed Association for promoting required regional collaboration for seed development. For promoting hybrid maize technology in the region, FAO has organized a Regional Expert Consultation among 15 countries during November 1993. The Consultation has highlighted the need for promoting research on hybrids and also the linkages among the seed organizations in the region to strengthen further maize hybrid programmes.

19. FAO/RAPA has recently established an Asia-Pacific Association of Agricultural Research Institutions (APAARI) and through this institution it envisages publishing the success stories on "baby corn in Thailand", "transplanted maize in Vietnam" and "winter maize in India" for the benefit of others.

20. The Regional Maize Hybrid Trial will also be conducted next year, and continued support for the Newsletter is envisaged. It is also proposed to have regular meetings of the group organized in the future in collaboration with the CIMMYT Maize Regional Office, Bangkok.

VII. CONCLUSION

21. Maize is the third most important cereal crop in the Asia-Pacific region. Its demand is increasing substantially for food, feed, and industrial uses. Several countries in the region have shown remarkable progress for increases in areas, production, and productivity. Yet, there exists considerable variation with regard to level of technology generation and its adoption. Many countries are still to make use of hybrid technology, especially the single cross hybrids. For this, needed support for the seed industry is lacking and appropriate policies and programmes are not yet in place. In spite of this, maize production has recorded higher growth rates in the Asia-Pacific region than in the rest of the world. Many interesting developments have already taken place. What is needed now is to remove intraregional variations to the greatest extent

possible through adoption of suitable strategies and action programmes, based on each other's experiences. The future for maize in Asia appears to be bright provided sincere efforts for sustainable maize production are made by all concerned by adopting appropriate strategies and programmes. FAO and CIMMYT are already playing an active role to promote regional collaboration on maize. However, donor support for regional cooperation is still needed for accelerating programmes that would improve regional capabilities for increased maize production and productivity.

HYBRID RESEARCH AT CIMMYT TO ACCELERATE HYBRID MAIZE BREEDING IN THE DEVELOPING COUNTRIES

S. K. Vasal and G. Srinivasan [1/]

Abstract

This paper discusses the various hybrid research activities at CIMMYT which will help in accelerating the hybrid maize research efforts in the developing countries. The paper starts with an account of hybrid adoption in both developing and developed nations. Although the adoption of hybrid maize in developed countries has been spectacular in the current century, the developing world has been lagging behind in this technology. The emphasis on hybrids in the developing world has been see-sawing over the years, but has picked up momentum in recent years, due to the increased presence of the private sector in many countries and also due to the demand for hybrids from the farmers. Several reasons are speculated and discussed for this trend including the increased growth of national and multinationals, an increase in hybrid research efforts on the part of several national programs, and relatively less apparent impact of the open pollinated varieties (OPVs) for the past several decades. The activities of the hybrid program at CIMMYT are discussed emphasizing several aspects including characterization of CIMMYT germplasm, development of hybrid oriented source populations, development of inbred and non-inbred progenitors, testers, integrated population improvement and hybrid research activities, development and performance of hybrids and the recent announcement of CIMMYT maize lines (CML). The development of hybrid oriented source germplasm is discussed in detail highlighting the development of germplasm tolerant to inbreeding stress, enhanced combining ability and cross-bred performance, formation of new heterotic groups while improving the existing heterotic patterns through interpopulation improvement schemes, formation of new inbred-based populations and special trait germplasm. Heterotic patterns among CIMMYT germplasm have been reported and the performance of various kinds of hybrids has been presented. The recent release/announcement of CIMMYT maize lines and their adaptation are presented for possible use by the national programs. The different sections of the paper detail how the information and germplasm generated by CIMMYT's hybrid research activities will greatly benefit and accelerate hybrid related activities in the national programs. This ecological zone. In this paper, CIMMYT's expanded role in hybrid research will be described highlighting those activities which will help directly or indirectly in accelerating hybrid maize breeding in the developing countries.

I. Introduction

In maize (*Zea mays* L.), a wide array of germplasm products can be developed by the breeder to meet the farmers need in various distinct environments encountered in the developing world countries. Presently, approximately 58.5 m ha of non-temperate maize are grown in different regions of the developing world. The above figure does not take into account about 16 m ha grown in temperate China, Argentina, Chile and Turkey. The coverage of maize area with improved maize varieties has been somewhat slow and currently no more than 50% of the area in the developing countries is planted with improved maize varieties. In South, East, and South-east Asia, the improved maize varieties cover roughly 57% of the total available area, of which 72.8% is comprised of lowland tropical, 26.8% subtropical and only 0.4% highland. The impact of improved germplasm thus has been greatest in the lowland tropics as in evident from more than two-thirds of the acreage planted to this ecology. In this paper, CIMMYT's expanded role in hybrid research

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will be described highlighting those activities which will help directly or indirectly for accelerating hybrid maize breeding in the developing countries.

II. **Hybrid development in the developed and developing world.** Historical trends

Hybrid manifestation in varietal crosses of maize dates back to the 19th century. Beal (1880) demonstrated that varietal hybrids in maize outperformed the parental varieties by a substantial margin. The inbred-hybrid concept, on the other hand, had its beginning in the first decade of the 20th Century and resulted from systematic research done by three great researchers (East, 1908; Shull 1908, 1909; and Jones, 1918). They studied inbreeding and cross-breeding effects which led to important findings that the former was detrimental and the latter beneficial. Their conclusions were based on reduction in vigor, size, seed yield and other harmful effects of inbreeding and then the restoration of the same on cross-fertilization. The detailed and systematic studies also indicated that all inbreds did not behave alike nor did the inter-line crosses. The results and conclusions reached from these studies led Shull (1909) to propose the "pure line method of maize breeding" that was particularly designed to produce single cross hybrids. Such hybrids, however could not be produced in the USA at that time because of weak, reduced vigor and poor yielding inbreds that resulted in high seed costs of the hybrids. The fruits of the hybrid technology could not be utilized until such time as other important developments took place. Among them included the proposed procedure of producing double cross hybrids (Jones, 1918), topcross evaluation test for combining ability (Davis, 1927), and the double cross hybrid prediction procedures (Jenkins, 1934). The commercial exploitation of double crosses started in early 1930s. By 1935, a negligible corn acreage (1.1%) was under hybrids. From this point onwards, the growth in area under hybrid corn was spectacular. In less than one decade, the figure rose to 59%, and by the 1940's the entire Corn-Belt acreage had already been covered by double cross hybrids. Efforts were then directed to developing hybrid types for other regions of the country. By 1955, almost 95% of the corn acreage was planted to hybrids, mostly double crosses. The emphasis on single crosses began in the early 1960s because of greater demand for uniformity and enhanced yield performance. The replacement of multi-parent hybrids by 2-parent single cross.hybrids was also achieved rather rapidly in the next two decades. Currently 90% of the US corn acreage is planted with single crosses. During six decades of intensive breeding efforts the advances in yield heterosis have been impressive and are still continuing. The newer hybrids can withstand higher population densities and are less affected by stress-induced barrenness. It has been estimated by studies conducted by different workers (Duvick, 1977; Russell, 1984 and Meghji *et al.* 1989) that at least 57-63% of the gains could be attributed to genetic improvement. At least one study has also indicated that newer hybrids are heterozygous at more loci for yield genes thus indicating that improvement in inbred parents had been at different loci. The hybrid development efforts in Europe had a late start, almost 20 years later than USA. The adoption rates for hybrids were remarkable in Europe also.

The hybrid development efforts in some of the developing countries dates back to the early 1960s. Countries that had an early start in hybrid breeding include Argentina, Brazil, Colombia, Chile, Mexico, India, Pakistan, Egypt, Zimbabwe, Kenya, Tanzania and some countries in Central America. The balance between OPVs and hybrids however has been oscillating from time to time. In the developing countries, both conventional and non-conventional maize hybrids are used. The former is more popular than the latter. During the period from 1966-90, approximately 852 maize releases have been made by public sector institutions. Of these 59% are OPVs, 27% conventional hybrids, 10% non-conventional hybrids and 4% other (**Table 1**). It is clear from the figures that the number of OPVs released was more than the hybrids in all the regions except West Asia and North Africa (WANA) with 14%. The conventional hybrids together with non-conventional hybrids comprised slightly over one-third of all maize releases.

In the developing countries on the whole, the impact of hybrid maize technology has been slow and less apparent except in some countries such as Argentina, Brazil, Chile, Turkey, Zimbabwe, Kenya and perhaps in Egypt, Mexico and India. An examination of varietal releases during the period 1961-1990 will reveal interesting facts. Though there was disparity among regions, the hybrid releases as proportion of total releases was high in the 1960s, declined

Table 1. Public sector maize releases in developing countries, 1966-1990 (%) a/

Region	OPVs	Hybrids Conv.	Hybrids Nonconv.	Others b/	Total
Sub-Saharan Africa	59	25	15	1	100 (295)
West Asia and North Africa	14	68	18	0	100 (28)
South, East, and Southeast Asia	62	16	8	14	100 (180)
Latin America	61	32	6	1	100 (349)
All developing countries	59	27	10	4	100 (852)
	(503)	(230)	(85)	(34)	

Source: CIMMYT varietal database.

a/ Values in parentheses are total number of releases in each category.

b/ Includes synthetic varieties and other materials not classified under the previous three categories.

slightly at least in three regions (except WANA) during the 70s and registered an increase again during the 80s. This variation in variety vs. hybrid releases during different decades perhaps can be attributed to the following reasons:

1) In 1960s, the public sector maize breeders placed greater emphasis on maize hybrids than OPVs. This was perhaps triggered by the success story of hybrid maize in the US and Europe.

2) The decline in hybrid releases during the 1970s is reflected by the greater proportion of OPVs released. This could be attributed to several reasons including a) the scarcity of germplasm available for hybrid work, b) difficulty and disappointment in obtaining inbred parents with acceptable yield potential, c) lack of clear-cut superiority of maize hybrids over OPVs, d) occasionally hybrids were too late and did not fit into farmer's cropping systems, e) problems in seed production and distribution, f) insufficient public and private seed enterprises, and g) greater emphasis on population improvement and composite breeding because OPVs were less expensive to develop and seed was easier to produce.

The 1980s witnessed a shift back toward an increase in emphasis on hybrids. This change could be the result of: 1) more resources in the national programs to support more sophisticated hybrid development work, 2) availability of improved germplasm developed by the national programs themselves and by CIMMYT and IITA, 3) improved and more convincing performance of hybrids over OPVs in some countries, 4) increasing presence of private companies involved in hybrid breeding, and 5) initiation of hybrid research related activities at CIMMYT. The renewed interest in hybrids is however, true for South, East and Southeast Asia and WANA. In Sub-Saharan Africa, the national programs have consistently released more OPVs than hybrids because of the involvement of only a few programs in hybrid research. The national programs in Latin America, in general, have released fewer hybrids during each of the three decades. Declining support by the Rockefeller and Ford Foundations and the increasing involvement of private seed companies in the region may have led national programs to deliberately de-emphasize hybrid research.

It may also be pointed out that improved maize germplasm made its greatest impact in the lowland tropical areas since two-thirds of the improved germplasm released were for these ecologies. In Latin America, 94.4% of the improved maize germplasm was for lowland tropical ecologies compared with 72.8% in Southeast Asia and 49.2% in Sub-Saharan Africa.

III. Growing interest in maize hybrids by the national programs

In the past decade, the national maize programs have demonstrated an increasing interest in hybrid work. Though the proportion of hybrid releases in relation to total varietal releases does not always reflect this change in some regions, it should be remembered that unlike OPVs, several years of hybrid breeding and testing work is required before a hybrid may actually qualify for a release. Also, depending upon the type of hybrid to be released, this time frame will fluctuate. As a general rule, less time is required in developing two-parent conventional and non-conventional hybrids as against multi-parent hybrids in both categories of hybrids because of the difference in the number of test evaluation phases. The increased supply of hybrid oriented germplasm in recent years and an increased interest in hybrids by NARS scientists point to the increased importance of this type of maize research. It is also apparent that large national programs that had a hybrid component in 1960s, for valid reasons de-emphasized this in the 1970s, and later reemphasized in the 80s. The growing interest of the national programs in maize hybrids is reflected in the changing circumstances in more recent years. Some of them are:

1. The impact of OPVs has been rather slow, less apparent, and not very dramatic and spectacular as has been the case with the introduction of hybrids in some countries. Maintenance of OPVs and supply of fresh seed on regular basis at least once in 3-4 years has not kept pace as seed production of such varieties has to be done by the public seed agencies who often cannot do a good job because of lack of trained personnel added to financial and bureaucratic constraints.
2. The growth of private seed companies both national and multinational has been on the rise in recent years. In the past, the infrastructure for seed production of OPVs or hybrids was less than adequate and sometimes completely nonexistent. In the Asian region, particularly the private seed companies small or large, national or multinational have dramatically increased their presence (**Table** 2). In this region alone there are at least 62 government/public, 20 multinationals and about 83 private national companies.

Table 2. Number of public and private maize seed companies in the different regions of the developing world. 1990-1991.

Region	Public/ Parastatal	Private/ National	Multinational
Sub-Saharan Africa	52	8	-
West Africa and North Africa	3	8	9
Asia	77	63	9
Latin America	16	89	20
Total	148	168	38

Source: Maize Impacts Study Survey 1990-1991. CIMMYT, Mexico.

3. The increased presence of private sector could also be a factor in prompting national maize programs to place some emphasis on hybrid research. This is evident from increased hybrid-related activities particularly inbreeding, combining ability studies, and development of heterotic populations.
4. The hybrid sales are picking up dramatically in some countries. A good example would be Thailand where hybrid sales have shown a quantitative jump in recent years.
5. There is a greater availability of parental inbred material in more recent years. This was not possible in the past because of restrictions in the free exchange of parental material of this kind. The situation in recent years has changed dramatically because of announcement of inbred lines from CIMMYT, IITA, Kasetsart Univ. and lines available from Univ. of Hawaii from Dr. Brewbaker's program. CIMMYT and IITA made this germplasm freely available to everyone on request. However, in other cases one may have to pay certain fee for obtaining seeds of lines. Undoubtedly such inbred lines will boost large companies' hybrid program who are better prepared to exploit this germplasm more expeditiously. Small companies also will benefit greatly as they can start producing seed of some combinations which appear to be superior without spending resources on research. A continuous supply of new and diverse lines will further guarantee the production of new and superior hybrids in the future. Centers like CIMMYT shall be developing and distributing more hybrid-oriented germplasm which will provide greater opportunities for extracting superior lines in higher frequencies.

IV. Pre-hybrid CIMMYT maize program activities

Since its inception in 1966, CIMMYT Maize Program has placed greater emphasis on germplasm development and germplasm improvement activities. A whole array of gene pools were developed and improved using modified ear-to-row system very similar to the one proposed by Lonnquist (1964). Gene pools were kept intentionally open-ended to permit introgression of superior introductions and germplasm bank accessions. The gene pools in turn will serve to provide superior families to the corresponding Advanced Unit populations or in some instances to completely replace it with superior fraction of the gene pool. The gene pools also may give rise to new populations for certain ecologies which at present is not represented in our Advanced Unit populations. The gene pools formed the first tier of the germplasm management and improvement system. They were genetically broad-based and were handled using a mild selection intensity as opposed to populations which made up the second tier. The second tier consisted of refined and so-called "civilized" populations which formed the front line and served as an important vehicle in delivering germplasm to the national programs in addition to effecting improvements in them through a systematic international progeny testing system (IPTT). Cooperators in the national programs were part and parcel of this improvement system. By-products of population improvement system resulted in the formation of the experimental varieties which were named after the site where it was tested, the year, and the populations number. The impact of this germplasm used directly or indirectly by the NARS and private seed companies has been significant and notable. Approximately 13 m ha are currently grown to improved maize containing CIMMYT derived germplasm. The germplasm has been used primarily in improved OPVs but also some in conventional and non-conventional maize hybrids.

V. CIMMYT's changing emphasis towards maize hybrids

CIMMYT Maize Program did not have a hybrid component up until 1984. Some research work was however attempted before this to characterize CIMMYT maize germplasm with respect to combining ability and heterotic patterns. This work was done by E.C. Johnston using Tuxpeno P.B. and ETO P.B. as two testers to characterize all normal and quality protein maize germplasm adapted to lowland tropical and subtropical conditions.

In 1985 a new research initiative was implemented to bring about advances in yield productivity though heterosis manipulation. A modest research effort was initiated that will encompass several hybrid related activities as opposed to a strictly inbred-hybrid development program as is often thought of by most maize breeders. A whole range of activities were initiated as part of this program across materials of different ecological adaptation. An important component of this program also was to impart training in hybrid development to national program scientists who come to CIMMYT for varying periods as breeding trainees. The principal activities that were identified included characterization of CIMMYT maize germplasm available at that time, development of hybrid-oriented source germplasm, development of inbred and non-inbred progenitors formation, evaluation of conventional and non-conventional hybrid combinations, and identification of appropriate testers for germplasm adapted to different ecologies. In 1991, the efforts on hybrid program were further expanded to include this activity as part of subprograms developing materials for different ecologies and various stresses. Below, we are describing several activities related to hybrid development work at CIMMYT, results/information already available/achieved, plans for future modification and their relevance to hybrid development activities in the national programs.

a. Characterization of CIMMYT maize germplasm.

At the inception of the hybrid program this activity was given highest priority. It was felt that results from this work would provide breeders in the national programs with information on the combining ability patterns among tropical and subtropical germplasm. This information will be of immediate benefit as most national programs are using CIMMYT maize germplasm quite extensively. The task was indeed urgent but quite voluminous considering the number of gene pools, populations and quality protein maize germplasm that was available for different ecologies. The materials were grouped into different classes based on adaptation, maturity, endosperms color and QPM characteristics. Eight different dialleles were formed with different number of entries. The parents and F1 crosses were evaluated in several environments with the help of maize breeders from the national programs. The overwhelming support from the U.S breeders in this task was unprecedented. Dr. Larry Darrah from the Univ. of Missouri was particularly helpful in arranging to distribute the trials within the U.S. From this extensive work, several parents exhibiting high GCA were identified. As expected, the heterosis among materials within each group, with a few exceptions, was not very high (**Table 3**). These results did not surprise us considering the broad genetic base of most CIMMYT germplasm. Some clear cut heterotic groupings emerged from this work and some patterns reported earlier by other workers were reconfirmed (**Table 4**). Heterosis among potentially important tropical and subtropical germplasm was also studied. Lowland tropical population 43 gave the best performance in combination with subtropical populations 42 and 44. Population 32 also gave good cross performance with population 44. It may also be pointed out that Suwan-1 was also included in one of the diallels. It exhibited good heterotic performance in crosses with populations 24, 27 and pool 26. Population 24 also showed high level of heterosis with population 36. Among the white endosperms germplasm, populations, 25 and 32 performed well in crosses with populations 21 and 29. In early/intermediate germplasm, the best crosses were population 23 x pool 20, and population 26 x pool 21. The heterotic pattern among QPM germplasm were not clearcut. The best general combinnears for yield were populations 62, 63 and EV PR 7737 in tropical germplasm, and pool 32 QPM and populations 68 and 69 in subtropical germplasm. Detailed information for each diallel has been published in scientific journals (Beck *et al.* 1990, 1991; Crossa *et al.* 1990; Vasal *et al.* 1986, 1992a, 1992b, 1992c, 1993a, 1993b). The above information has provided useful guide to CIMMYT breeders and to breeders in the national programs to initiate hybrid breeding activities. Periodically, additional studies of this kind will be planned to determine combining ability of new maize germplasm emerging from different subprograms.

b. Development of hybrid-oriented source germplasm.

Source populations constitute the building block of hybrid development work. While improved as well as unimproved germplasm can be used, there are greater possibilities of extracting superior lines in higher frequencies from the improved populations. Unimproved germplasm particularly the germplasm accessions rarely, if ever, give rise to usable and useful lines. However, germplasm accessions can provide germplasm with diverse traits which could be used in hybrid work. Such germplasm, however, may have to be carefully tailored and "civilized" through appropriate prebreeding activities. Source populations designed as hybrid-oriented should possess additional attributes including tolerance to inbreeding, good general combining ability, good heterotic relationships, cross-bred performance to at least one or more populations, possessing characteristics that will be useful either as pollen or seed parent, and, most importantly, in possessing desirable agronomic attributes. Source populations tropical as well as subtropical being handled in the national programs are not necessarily the best choices as these have been improved using breeding schemes of mass selection, full-sib, half-sib, modified ear-to-row or various modifications of these which in fact would not necessarily make then potentially useful for hybrid work. We have done some work in developing hybrid-oriented source germplasm at CIMMYT and would like to share this information with you. Also, we would like to suggest some strategies for developing and improving such germplasm.

1. Improving tolerance to inbreeding stress.

Inbreeding depression is of little significance in self-pollinated crops that are accustomed to automat. In out-pollinating species like maize, inbreeding depression is of considerable concern if hybrids involving inbred parents are to be developed. Inbreeding effects in maize have long been known to maize breeders as a result of excellent researches conducted by East (1908) and Shull (1908, 1909). Different materials behave differently for this trait. Some materials may collapse following a few successive generations of selling while others may provide some useful lines even though in much lesser frequency. Maize in general is considered moderately tolerant to inbreeding depression. Though some early generation inbreds can be developed rather easily, it is extremely difficult to develop inbreds with high level of inbreeding that have acceptable seed yield and are self-sustaining without any reproduction abnormality either on male or on female side. This is particularly true of tropical and subtropical germplasm which so far have not involved schemes that involved much inbreeding.

Table 3. Summary of performance of some of the best crosses in CIMMYT diallels from across location data.

Trial type	Germplasm involved	Cross	Grain yield (t/ha)	High parent heterosis
Diallel-1	Early Subtropical	Pop.48 x Pool 27	4.63	113%
		Pop.48 x Pool 28	4.64	112%
		Pop.46 x Pool 30	4.47	110%
		Pop.46 x Pop. 48	4.43	108%
Diallel-2	Intermediate Subtropical	Pop.42 x Pop. 47	5.82	111%
		Pop.42 x Pop. 34	5.64	108%
Diallel-3	Tropical, Subtropical	Pop.32 x Pop. 44	6.65	113%
		Pop.43 x Pop. 42	6.85	111%
		Pop.43 x Pop. 44	6.71	109%
Diallel-4	Tropical Late Yellow	Pop.27 x Suwan-1	6.77	115%
		Pool 26 x Suwan-1	6.60	112%
		Pop.24 x Suwan-1	6.97	110%
		Pop.24 x Pop. 36	6.98	110%
Diallel-5	Tropical Late White	Pop.29 x Pop. 32	7.20	113%
		Pop.21 x Pop. 25	7.16	112%
		Pop.21 x Pop. 32	6.94	108%
Diallel-6	Tropical, Early, intermediate	Pop.26 x Pool 21	7.01	110%
		Pop.23 x Pool 20	7.34	109%
Diallel-7	QPM Subtropical	Pool 33 QPM x Pool 34 QPM	7.43	110%
Diallel-8	QPM Tropical	Pop.65 x PR 7737	6.77	120%
		Pool 25 QPM x PR 7737	6.15	111%

The level of inbreeding adversely affects ear size, seed yield, vigor, and in some cases even the reproductive behavior. Thus the problem of inbreeding depression is not only important but quite crucial in hybrid breeding. The problem is widely known but is highly neglected in research. More serious efforts are thus needed to correct this problem and to increase efficiency and probability of extracting superior lines in a much higher frequency than is currently possible. At the very inception of CIMMYT's hybrid maize breeding program, efforts were devoted to improving this trait as part of an on-going inbred line development program. Studies conducted in both tropical and subtropical germplasm using S3 recurrent selection have proved conclusively that it is possible to improve this trait (**Table 5**). The S1 bulks developed from Cycles 0, 1, and 2 showed that C2-S1 bulk was superior over C1 which in turn was better than C0. The performance of S1 bulk as a percentage of F2 full vigor material of the corresponding cycle also showed improvement indicating reduced inbreeding depression in later cycles. These inbreeding tolerant germplasm are available on request and would greatly aid hybrid efforts in the developing countries.

Table 4. Possible heterotic partner(s) for some CIMMYT populations.

Population	Possible heterotic partner(s)
Population 21	Pop. 32, Pop. 25, Pool 23
Population 22	Pop. 32
Population 23	Pool 20
Population 24	Population 36, Suwan
Population 25	Population 21
Population 26	Pool 21
Population 27	Pool 25, Suwan, Pop. 44
Population 29	Population 32
Population 31	Population 49
Population 32	Populations 21, 22, 29, 44
Population 33	Population 45
Population 34	Population 42, Pool 34
Population 36	Population 24
Population 42	Populations 34, 43, 45, 47
Population 43	Population 42, Population 44
Population 44	Population 32, 25, 27, 43
Population 45	Population 33, Pool 33
Population 46	Population 48, Pool 30
Population 48	Population 46, Pools 27, 28
Population 49	Population 26, 31, Pool 21

* Pools and populations underlined are of different color.

Table 5. Grain yield, plant height, and days to silk in nine tropical maize populations improved for inbreeding tolerance.

Pop. No.	Cycle	Grain yield (t/ha)		Plant hgt (cm)		Silking (days)	
		F2 bulk	S1 bulk	F2 bulk	S1 bulk	F2 bulk	S1 bulk
21	CO	6.1	3.8	190	161	82	85
	C2	7.2	4.7	207	178	82	85
29	CO	6.2	3.7	176	144	79	83
	C2	6.5	4.3	188	157	80	83
32	CO	5.9	3.5	178	151	79	82
	C2	6.1	3.9	181	160	79	82
24	CO	6.4	4.2	192	171	64	67
	C2	6.9	4.8	204	176	63	66
23	CO	6.6	3.5	188	161	59	62
	C2	7.3	4.6	199	176	63	66
26	CO	6.6	3.0	184	156	59	63
	C2	6.0	3.9	186	167	60	64

2. **Improvement of combining ability.**

Good general combining ability (GCA) of source populations and of progenitors derived from them is extremely important for hybrid development. Topcross test helps to evaluate the GCA of the lines (Davis, 1927). With exception of few methods, most standard interpopulation improvement schemes do not permit improvement of this trait specifically. Appropriate modifications can be made to practically every scheme to obtain some information on general combining ability. In later sections of this paper some schemes have been proposed that permit integration of population improvement and hybrid research efforts with particular emphasis on improving this trait.

3. **Improving cross performance.**

In most CIMMYT populations, intrapopulation improvement has been emphasized in the past. However, emphasis on hybrids in recent years would necessitate improving cross-bred performance of already known heterotic populations on a continuous basis. Two well known and most widely used populations in CIMMYT's lowland tropical program are already undergoing interpopulation improvement. A modified version of reciprocal recurrent selection scheme is being used since 1987 and two cycles have already been completed. Modifications over standard scheme are aimed at improving tolerance to inbreeding by saving topcross seed from those S1 families that look good; which is not possible in standard scheme outlined by Comstock, Robinson, and Harvey in 1949. In addition to cyclic improvement of two populations for increased heterosis, several by-products of narrow genetic base synthetics can be generated to develop intersynthetic hybrids. Recycling of superior S1s, or S2s can also be initiated to generate new series of inbred lines within each heterotic group. National programs involved in testing half-sib progenies of these populations can request seed of improved cycles, site specific synthetics and in addition can request seed of early generation line(s) for further inbreeding work to develop inbred lines. Other subprograms within CIMMYT also are now practicing similar schemes.

4. **Development of new heterotic populations.**

Inbred-based material serves not only in hybrid formation but also can be used to develop hybrid-oriented source germplasm. Formation of new heterotic populations can be achieved by identifying progenitors of known heterotic performance followed by genetic mixing of components within each group for at least three cycles. The progenitors involved could be inbred, non-inbred, and even a combination of both types. Involvement of inbred progenitors would be desirable provided vigorous and productive lines are used in their formation. The resulting products would be more readily usable for hybrid work as they would possess essential traits needed in hybrid-oriented maize germplasm. Systematic attempts were made to work out heterotic patterns of lines that had survived inbreeding and also were good general combiners. Since there was no previous experience in developing such populations, four instead of two inbred testers were used, representing Tuxpeno and Eto types of germplasm. Based on heterotic patterns, two inbred testers were finally chosen that had positive GCA and which provided more clearcut separation of lines into one group or another. As a result of this kind of work, two tropical heterotic groups (THG-A and THG-B), and two subtropical heterotic groups (STHG-A and STHG-B), were formed (Vasal *et al.* 1992d, 1992e). Over the years additional heterotic populations have been formed by other subprograms at headquarters and in the CIMMYT regional maize programs at Cali and Zimbabwe. The use of such heterotic populations would greatly facilitate hybrid development work in the national programs as lines developed from one heterotic group would be destined to cross well with lines of the opposite heterotic group. Also, when such populations are subjected to systematic interpopulation improvement schemes, the breeders in the national programs would be able to request early generation lines exhibiting good combining ability. To reduce the number of currently available populations, efforts may be directed in the future to consolidate and broaden germplasm belonging to a similar heterotic group.

5. **Inbred based populations.**

As pointed out earlier, conscientious effort should be made to make the best use of lines in various ways in addition to the development of conventional hybrids. Inbreds within the same heterotic group resulting from one or more populations can be recombined to form synthetics for use as OPVs and broad based synthetic as sources of new improved source germplasm for further improvement. Inbreds from the same heterotic group could be put to other uses in the recycling process to develop new superior lines. We have made use of good performing lines to develop four inbred-based populations designated as IBP-1 (late white dent), and IBP-2 (late white flint), IBP-3 (late yellow dent), and IBP-4 (late yellow flint). These four populations will serve as new sources of hybrid-oriented germplasm. Even though these populations were not made based on heterotic patterns, their genetic constitutions and grain texture (dent vs. flint) suggest their use as heterotic populations. The two white populations and two yellow populations can be combined as heterotic partners within each grain color. Sufficient genetic mixing within each population has already been achieved. In the near future, these materials will be subjected to appropriate breeding schemes for further improvement.

6. Special trait germplasm.

Inbreeding exposes traits which are rarely encountered at population or family level in maize germplasm. This applies to a whole array of traits most sought after by breeders such as lodging resistance, disease resistance, low ear placement, erect leaves, prolifically, long ears, ear shape, deep kernels, ear row number, and several others. It is important that whenever such lines appear during the inbreeding process, one should make every attempt to make the least use of such lines in an efficient and effective manner. A case in point is a lodging resistant line (CML-9) which has withstood high velocity winds and storms of moderate nature at best in three different cycles. Using this and other lines exhibiting the same characteristic, a lodging resistant maize population has been formed. Every such character does not necessarily have to end up in a population. Depending upon the simplicity or complexity of inheritance, such character can be introduced in other lines through perhaps recycling involving a minimal of effort.

7. Development of inbred progenitors.

Inbred line development constitutes an important part of an overall hybrid development effort. Inbred lines serve as parents of conventional hybrids which could either be two-parent or multiparent hybrids. Development of good inbred lines is a difficult task. Many maize breeders in the past have experienced difficulty in developing agronomically desirable lines from the germplasm that they had been working for varying periods of time. In several instances it had been difficult to proceed with higher levels of inbreeding thus resorting then to use of early generation lines. Even today some of the commercial hybrids developed by the public sector use lines that have only a few generations of inbreeding. It may be pointed out that inbreeding or selfing alone is not enough to develop good lines. Much will depend on the source germplasm and its ability to withstand inbreeding depression. It should be remembered that maize species in general is moderately tolerant to inbreeding. There are, however, variations among materials. As a general rule, unimproved materials from the germplasm bank succumb to inbreeding pressure more readily than improved germplasm. Further, materials that have been improved using schemes that involve inbreeding are more likely to be tolerant to inbreeding pressure.

Though inbred lines can be developed by several different ways, the pedigree method is used more commonly by the maize breeders. CIMMYT maize program, in general, uses this method for developing inbred lines. In this method, the inbred lines are developed by selfing in each successive generation of inbreeding and a proper record of the pedigree of each line is kept in each generation. Most CIMMYT inbreds are developed from ongoing population improvement programs, recycling of advanced and early generation lines, and very rarely, if necessary, inbreeding is practiced in populations, experimental varieties and synthetic bulks. Some important features in inbred line development include high population density, keeping records on pollen-shedding and silking, and reserving one-half of the row for observation and the other half for inbreeding purposes. The observation part is harvested and rated for yield, ear aspect, and ear rots. To reduce volume of material, at times, lines are carried forward as bulk. In other words, ears selected at harvest time from each line are shelled as a bulk. Resampling of exceptionally good lines is also occasionally done.

Recycling of good lines also can be practiced to develop new lines. Recycling is often done between lines from population(s) within the same heterotic group. There are no set guidelines for the recycling of lines. Much depends also on how a breeder is handling his germplasm and what kinds of difficulty(ies) he is encountering in developing good lines. From ongoing population improvement programs involving S1 or S2 as a procedure or as a step in the breeding process, one can always resort to recycling of early generation lines. Also, for germplasm/materials known to be notably poor for line development, it would be advisable to re-initiate recycling of early generations to increase the possibility of developing good lines. This will be a good strategy at least in the early maturing germplasm where inbreds with high degree of inbreeding are much more difficult to obtain. Information on combining ability of early generation lines is often obtained from the ongoing population improvement programs. Systematic combining ability tests are often conducted at S4 or past S4 stage. By this time one will have a fairly good idea as to whether or not the line is usable. Promising lines are also evaluated in line evaluation trials (LETs). Lines in these trials are characterized more thoroughly and sometimes one or two replications are planted under high plant density and artificial disease stress conditions. Data collected in these trials is of great help in planning crossing program to develop single and three-way crosses.

8. **Development of non-inbred progenitors.**

Non-inbred progenitors or materials of an OPV can be used in developing non-conventional maize hybrids. Most breeders in the past have used bulks of populations and varieties as parent(s) of a non-conventional hybrid. As one would expect, if the parents are variable, the hybrids would also be veriable. To obtain uniformity and appeal in such hybrids, it is therefore quite important that such non-inbred progenitors should be created specifically for the purpose of using parents of a non-conventional hybrid. It will be preferable to use experimental varieties, elite line synthetics, and narrow genetic base synthetics which have been reconstituted using only a few relatively uniform families and lines. There are great opportunities for developing such progenitors from the ongoing intrapopulation and interpopulation improvement programs. Interpopulation improvement programs permit development of cross-performance synthetics using test cross data to maximize heterosis manifestation in intersynthetic hybrids.

9. **Identification of testers.**

Testers, inbreds as well as non-inbreds, serve exceedingly useful functions during various phases of population and hybrid breeding programs. Non-inbred testers for population improvement programs, evaluation of combining ability, and when used as a parent of a hybrid, should be developed with some resource effort. These testers could be of narrow genetic base involving a few lines or families and can be reconstituted using data from population improvement programs, topcross tests, and from any other data which permits forming such progenitors. Perhaps, it may also be more appropriate to develop such non-inbred testers using various groups/pairs of heterotic population undergoing improvement or use in hybrid breeding program.

Identification of inbred testers will be of immense help in any hybrid breeding program. In fact it is a priority item to identify a set of testers which will serve as a reference point for meeting various objectives in a hybrid breeding program. Unfortunately, such tester lines are not freely available, if at all they exist, to maize scientists of the developing countries for the lowland tropical and subtropical germplasm. Such tester lines could be identified using special mating designs such as diallels and design-2. Once such first-set of testers are identified, they can be continuously replaced by new and superior lines resulting from the same heterotic group. Though CIMMYT's effort in hybrid development was initiated with a modest effort, we made special effort to identify tester lines for different classes of germplasm. These lines have been successfully used in developing hybrid combinations and to sort out heterotic patterns of lines. Separation of lines by heterotic pattern(s) facilitates breeder's job in developing hybrid combinations and to form and/or to broaden the already known heterotic groups. Inbreds from the same heterotic group could also be used to develop and identify single cross testers. In the near future, CIMMYT will announce lines that can be used as tester by the NARS and the private sector breeders.

c. **Integration of population improvement and hybrid research**

The population improvement and hybrid research are in fact two sides of a coin and one cannot be divorced from the other. There is enough complementary in both types of germplasm products and approaches that a breeder should try to integrate both aspects to increase resource efficiency and effectiveness of both programs. Both programs have enough information and germplasm that can be shared and used. Several aspects of the population improvement program can be easily integrated with hybrid research. By affecting sensible modifications in important breeding schemes, one can easily identify early generation lines with good combining ability. Some of the recurrent selection schemes such as recurrent selection for GCA and recurrent selection for SCA do have built-in procedure to identify early generation products for the hybrid program. Interpopulation schemes such as reciprocal recurrent selection and reciprocal full-sib selection allow integration between the two approaches in a more natural way. Population improvement programs involving testers greatly facilitate identifying potential hybrid combinations which could be single crosses, three-way, crosses and/or topcrosses depending upon the tester parent used.

Inbreeding process is often used to develop inbred lines. It is erroneous to think solely of this objective alone. During inbreeding process one can in fact perform several other important activities including improvement of source populations, development of narrow genetic base synthetics for further inbreeding work, and/or to serve as non-inbred tester or as a parent of a non-conventional hybrid. Combined with GCA evaluation, the inbred line program provides enormous opportunities for improving source germplasm and to develop hybrid-oriented source F2 populations for further inbreeding work.

At CIMMYT, we have used modified full-sib (FS) recurrent selection for a long time. More recently we have made some modifications in this scheme to obtain more information for hybrid-oriented work. This scheme is currently known as Modified FS1. Modified FS2 was introduced a few years ago, where FS progenies are generated from S1 x S1 or S2 x S2 crosses. This scheme permits identification of potentially useful intrapopulation inter-line hybrids. Identification of early generation lines and combining ability information can be obtained by arranging pre-planned systematic mating among systematic progenies. Two new schemes-Modified HS1 and Modified HS2 have been recently introduced. Both of these schemes involve use of a tester which is a bulk of selected S1 lines in the former and S2 selected lines bulk for the latter. The fifth scheme involves two heterotic populations 21 and 32 currently under improvement using modified reciprocal recurrent selection.

Introducing inbreeding and combining ability evaluation will make populations more geared for hybrid work in the long run. Cooperators testing progenies can request seed of early generation lines for inbreeding purposes and to develop synthetics to meet needs of OPVs. Regular topcross trials as part of the hybrid research program will perform essentially the same role.

d. **Hybrid development and performance**

Hybrids are placed under two broad classes namely conventional and non-conventional hybrids. Conventional hybrids involve inbred parents. The non-conventional hybrids on the other hand involve at least one non-inbred parent. The conventional hybrid mostly consists of single, 3-way, double, modified singles, and double modified singles. Similarly, the non-conventional category includes intervarietal, family, topcross, and double topcross hybrids. Advantages and disadvantages of each class of hybrids were presented in earlier publications (Vasal and Srinivasan 1991). Rather than presenting voluminous information from such trials, a summary of performance of different kinds of hybrids are presented in **Tables 6** and 7. Conventional hybrid trials data agree with information already known from past experience. The best double crosses showed a yield superiority of 20-26%, three-ways 26-33% and single crosses 40-53% over the best experimental variety (EV). The percent superiority over EV was 15-18% for varietal, 20-30% for family hybrids, 25-30% for double topcrosses and 33-40% for topcross hybrids. It is obvious that in both types, the two-parent hybrids gave the highest performance. Data on the performance of modified singles involving one highly inbred line and the other early generation 'FRIP' line is quite interesting. The 'FRIP' lines refer to early generation lines developed through a forward and reverse inbreeding process. Advanced sublines originating from a common early generation line, (say S3) can be recombined to develop an early generation 'FRIP' line. Several hybrids gave outstanding performance outyielding commercial hybrids and OPVs as check entries (Srinivasan *et al.* 1992).

Table 6. Top performing non-conventional hybrids.

Hybrid type	Superiority (% over check)
Intervarietal hybrids	15-18 %
Family hybrid	20-30 %
Double topcross	25-30 %
Topcross	33-40 %

Table 7. Top performing conventional hybrids.

Hybrid type	Superiority (% over best EVs)
Double cross	20-26 %
Three-way cross	26-33 %
Single cross	40-53 %

So far, CIMMYT has restrained from distributing international hybrid trials. It seems that there is demand for such trials which would greatly benefit certain national programs who have little or no effort on hybrid development. The small seed companies will equally benefit from such trials in absence of enough resources that could be devoted to hybrid research. Beginning in 1994, CIMMYT will be distributing international hybrid trials from lowland tropical, subtropical, and highland programs.

e. **Announcement of CIMMYT inbreds**

In the past 3 years, CIMMYT maize program has made three announcements/releases of maize inbred lines. CIMMYT lines are designated as 'CML' referring to CIMMYT maize lines. The first announcement consisted of 74 tropical (CML 1-74) and 65 subtropical (CML 75-139) lines developed at CIMMYT headquarters in Mexico. The second announcement was made in 1992 and it consisted of 99 CML lines (CML 140-238). The lines represented 33 tropical QPM (CML 140-172), 22 subtropical QPM (CML 173-194), 22 mid-altitude (CML 175-216), and 22 lowland tropical (CML 217-238). CML lines 140-194 were developed in Mexico and the rest (CML 195-238) were developed at Harare, Zimbabwe with special emphasis on resistance to maize streak virus. The third announcement was made in 1993 and it comprised 8 highland lines (CML 239-246).

The announced lines are freely available to everyone on request. Lines are being tried in hybrid combinations both by public and private company breeders. More information on the use of these lines will become available in the near future. These lines will be useful to all institutions concerned but will be particularly helpful to breeders of small companies and national programs with insufficient resources for hybrid work. It may be pointed out that in some populations enough lines have been announced. Lines from the same population which adapt well in a specific location could be recycled to generate new lines. The good performing CIMMYT lines could also be recycled with locally adapted lines. At least 50 more tropical lines are expected to be announced in the near future. The announcement of new and diverse lines will continue periodically to accelerate hybrid maize breeding programs in the developing world.

Table 8. Announced CIMMYT lines 1991-1993.

Year announced	Adaptation	CML No.	No. of lines
1991	Lowland tropical	1-58	58
		59-74	16
	Subtropical	75-116	42
		117-139	23
1992	QPM tropical	140-172	33
	QPM subtropical	173-194	22
	Mid-altitude (Harare)	195-216	22
	Lowland tropical	217-238	22
1993	Highland	239-246	8
	Total246		246

References

Beal, W.J. 1880. Indian Corn. Rep. Mich. Board Agric. 19: 279-80.

Beck, D.L., S.K. Vasal and J. Crossa. 1990. Heterosis and combining ability of CIMMYT's tropical early and intermediate maturity maize germplasm Maydica 35: 279-285.

Beck, D.L., S.K. Vasal and J. Crossa. 1991. Heterosis and combining ability among CIMMYT's subtropical and temperate intermediate maturity maize germplasm. Crop Sci. 31: 68-73.

Comstock, R.E., H.E. Robinson and P.H. Harvey. 1949. A breeding procedure designed to make maximum use of both general and specific combining ability. Agron. J. 41: 360-67.

Crossa, J., S.K. Vasal and D.L. Beck. 1990. Combining ability study in diallel crosses of CIMMYT's tropical late yellow maize germplasm. Maydica 35: 273-278.

Davis, R.L. 1927. Report of the plant breeders. Puerto Rico Agric. Exp. Sta. 14-15.

Duvick, D.N. 1977. Genetic rates of gain in hybrid maize yields during the past 40 years. Maydica 22: 187-196.

East, E.M. 1908. Inbreeding in corn. Conn. Agric. Sta. Bull. 1907: 419-428.

Jenkins, M.T. 1934. Methods of estimating performance of double crosses in corn. J. Am. Soc. Agron. 26: 199-204.

Jones, D.F. 1918. The effects of inbreeding and cross breeding upon development. Conn. Agric. Exp. Sta. Bull. 207: 5-100.

Lonnquist, J.H. 1964. A modification of the ear-to-row procedure for the improvement of maize populations. Crop Sci. 4: 227-228.

Meghji, M.R., J.W. Dudley, R.J. Lambert and G.F. Sprague. 1984. Inbreeding depression, inbred and hybrid grain yields, and other traits of maize genotypes representing three eras. Crop Sci. 34: 545-549.

Russell, W.A. 1984. Agronomic performance of maize cultivars representing different eras of breeding. Maydica 29: 375-390.

Shull, G.H. 1908. The composition of a field of maize. Am. Breeder's Assoc. 4: 296-301.

Shull, G.H. 1909. A pure line method of corn breeding. Am. Breeder's Assoc. 5: 51-59.

Srinivasan, G., S.K. Vasal, F. Gonzalez C., H. Cordova, S. Pandey and N. Vergara. 1992. Rendimiento y estabilidad de hibridos de maiz de cruzas simples evaluados en Colombia, Mexico y Centro America. Agron. Mesoamericana 4: 23-29.

Vasal, S.K., D.L. Beck and J. Crossa. 1986. Studies on the combining ability of CIMMYT maize germplasm. CIMMYT Res. Highlights 1986. CIMMYT, El Batan, Mexico.

Vasal, S.K. and G. Srinivasan. 1991. Breeding strategies to meet the changing trends in hybrid maize development. *In* Special Issue commemorating the Golden Jubilee Celebration Symposium of the Indian Soc. of Genetics and Plant Breeding, New Delhi. 12-15 Feb. 1991. Indian J. Genet. (in press).

Vasal, S.K., G. Srinivasan, D.L. Beck, J. Crossa, S. Pandey and C. De Leon. 1992a. Heterosis and combining ability of CIMMYT's tropical late white maize germplasm. Maydica 37: 217-223.

Vasal, S.K., G. Srinivasan, J. Crossa and D.L. Beck. 1992b. Heterosis and combining ability of CIMMYT's subtropical and temperate early-maturity maize germplasm. Crop Sci. 32: 884-890.

Vasal, S.K., G. Srinivasan, J. Crossa and D.L. Beck. 1992c. Heterosis and combining ability of CIMMYT's tropical x subtropical maize germplasm. Crop Sci. 32: 1483-1489.

Vasal, S.K., G. Srinivasan, S. Pandey, H.S. Cordova, G.C. Han and F. Gonzalez C. 1992d. Heterotic patterns of ninety-two white tropical CIMMYT maize lines. Maydica 37: 259-270.

Vasal, S.K., G. Srinivasan, G.C. Han and F. Gonzalez C. 1992e. Heterotic patterns of eighty-eight white subtropical CIMMYT maize lines. Maydica 37: 319-327.

Vasal, S.K., G. Srinivasan, S. Pandey, F. Gonzalez C., J. Crossa and D.L. Beck 1993a. Heterosis and combining ability of CIMMYT's quality protein maize germplasm: I. Lowland tropical. Crop Sci. 33: 46-51.

Vasal, S.K., G. Srinivasan, F. Gonzalez C., D.L. Beck and J. Crossa. 1993b. Heterosis and combining ability of CIMMYT's quality protein maize germplasm: II. Subtropical. Crop Sci. 33: 51-17.

Questions to the author:

FROM : S. J. Patil

Q : How can the heterotic pattern be identified? What should be the base materials (testers)?

A : The heterotic patterns can be identified through several ways using special mating designs such as diallels, design-2 mating, etc. Once heterotic patterns of potentially useful materials are determined, these then can be used as testers to determine their relationship with other materials.

FROM : C. Chutkaew

Q : Breeding corn for industrial use, e.g. protein, oil, popping quality, sweet-corn, young ear corn, what will be your recommendations on breeding procedures?

A : Recurrent selection procedures in general have been quite effective in increasing protein content and oil content. In other specialty corns such as popcorn and sweet corn, recurrent selections procedures will also be useful to correct deficiencies, provided populations are homozygous for gene(s) which control specialty corn character. I have no experience with baby corn but would expect prolificacy, early maturity, along with hybrid development important considerations for economical reason and to have high uniformity.

HYBRID MAIZE AND THE SMALL-SCALE FARMER: ECONOMIC AND POLICY ISSUES FOR ASIA.

Derek Byerlee [1/], Michael Morris [2/], and Miguel Lopez-Pereira [3/]

Abstract

Many consider that hybrid maize is an inappropriate technology for small farmers who dominate in maize production in Asia. The aim of this paper is to provide guidelines for research and seed production for the successful development of hybrid maize programs to serve the needs of small farmers. The paper first assesses the evolution of, and current status of adoption of hybrid and improved open pollinated varieties of maize in commercial and small farmer agriculture, with particular reference to Asia. The factors influencing the adoption of hybrid maize by small farmers, especially seed costs, yield gains and capital costs are then reviewed. Finally, policy issues in promoting dynamic research and seed production programs for hybrid maize are discussed with particular emphasis on the complementary roles of the public and private sectors.

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1. Introduction

1.1. Rapidly increasing demand for maize in Asia

Throughout most of Asia, rapidly growing incomes are increasing the consumption of livestock products, which is being translated into higher demand for feed grains, especially maize. Demand for feed maize is projected to rise by nearly 7% per year over the next 15 years, compared to zero projected growth in demand for food maize. By 2005, total demand for maize in Asia is expected to reach nearly 275 million tons, approximately 80% of which will be used as animal feed (Table 1). While these projections may slightly overestimate future growth in demand, since gains in feed conversion efficiency will probably be realized (Garnaut and Ma, 1992), there is little doubt that demand for maize in Asia will rise rapidly relative to other cereals. [a/]

Maize production in Asia will have to increase at an unprecedented rate over the next 15 years if maize supplies are to keep pace with these projected rapid increases in pro-production. However, expansion in maize area is now negligible throughout most of Asia (with the exception of a few countries in Southeast Asia), and given limited prospects for additional area expansion, the main engine of future growth will have to be yield increases. Over the past decade, maize yields for Asia as a whole rose at a rate of 2.7% annually. In South and Southeast Asia, yield increases acceler during the 1980s compared to previous decades; in East Asia, yield increases slowed during the 1980s following several decades of very rapid growth (Table 2). With maize production increasing slowly relative to demand in all regions, these historical rates of yield gain will have to be increased to avert a politically undesirable production shortfall.

1.2. The potential role of hybrid maize

Although a number of avenues are open for increasing maize yields, expanded use of

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a/ Even with an acceleration in the growth rate of maize production, it is unlikely that domestic supplies will be able to meet all of this increased demand. Thus, maize imports are expected to increase.

Table 1. Projections of demand for maize for food and feed in Asia, 1990-2005.

	Food use	Feed use	Total
Total demand		(million t)	
1990	53	81	134
2005	53	221	274
Projected growth in demand, 1990-2005 (% per year)			
Maize	0.0	6.9	4.9
Rice	2.0	na	2.0
Wheat	2.9	na	3.1

Source: CIMMYT Economics Program, based on Byerlee and Saad (1993).

improved germplasm offers one of the most effective and cheapest opportunities. In many Asian countries, use of improved maize varieties and hybrids is still modest. Not including China, about 6.8 million ha are sown to improved materials (**Table** 3).[1] Only about 2 million ha are sown to hybrids, while about 5.8 million ha are sown to improved open-pollinated varieties (OPVs). Expansion of the area under hybrid maize thus represents a major potential source of future yield increases.

This paper addresses a number of economic and policy issues that will influence the success of a strategy to expand the area under hybrid maize in Asia. While the benefits of hybrid maize have been convincingly demonstrated in commercial maize producing countries, especially the USA, it is not so clear that a hybrid-based strategy can be equally effective in the small farm agriculture that characterizes most of Asia (**Table 4**). Indeed, two arguments have frequently been advanced to support the view that hybrid maize may **not** be an appropriate technology for small-scale farmers: 1) new seed must be purchased every year, creating an expense which small-scale farmers may not be able to afford, and 2) the yield advantage of hybrid maize is expressed only with good management and high levels of purchased inputs, which may be beyond the reach of small-scale farmers.

The next section briefly describes the evolution of maize breeding strategies in developing countries and reviews the range of experiences with improved OPVs and hybrids. We then examine the farmer's decision whether or not to adopt hybrid maize, identifying key factors that most influence the adoption decision. The final section addresses the question of the appropriate mix of private and public sector involvement in hybrid maize research, seed production, and seed marketing, focusing especially on the ways in which public policy can influence the success of a strategy to promote hybrid maize technology.

2. Brief history of the evolution of OPVs and hybrids

Hybrid maize was first introduced in the USA beginning in 1933. Ten years later, nearly all of the American "Corn Belt" was planted to hybrid seed, and hybrids were being

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[1] Since data on use of improved OPVs and hybrids in China are still being compiled, the figures cited here do not include China. However, most maize in China is planted in temperate regions, so inclusion of the data for China's tropical and highland production zones will have only a modest effect on the regional aggregates for Asia.

Table 2. Growth rate of maize area and yields for different periods, and regions in Asia.

Period	South Asia	Southeast Asia	East Asia	All Asia*
Area growth		(% per year)		
1951-60	2.4	4.8	3.5	3.6
1961-70	3.1	2.0	1.9	2.2
1971-80	0.0	2.5	2.9	2.1
1981-91	0.5	1.9	0.6	0.9
1951-91	2.4	3.5	1.2	1.9
1971-91	0.5	1.7	0.9	1.0
1951-91	1.4	2.3	1.2	1.5
Yield growth		(% per year)		
1951-60	2.3	0	2.4	2.1
1961-70	0.4	1.7	5.6	4.0
1971-80	-0.4	1.9	3.9	3.4
1981-91	1.8	2.9	2.9	2.7
1951-70	1.4	1.8	2.5	2.1
1971-91	1.8	2.8	3.9	3.5
1951-91	1.2	2.2	3.6	3.0

Source: Calculated from FAO data.
* Excludes West Asia.

Table 3. Maize area in Asia planted to improved OPVs and hybrids, 1990.

	Improved OPVs	Hybrids	Total improved
		(% of total maize area)	
South Asia	24	14	37
Southeast Asia	39	10	49
East Asia (China)	5	90	95
Total Asia (minus China)	32	11	43
Sub-Saharan Africa	20	21	41
West Asia/North Africa	27	12	39
Latin America	10	36	46
All developing countries	16	39	55
All developing countries (excluding China and Southern Cone of Latin America)	24	17	41

Source: CIMMYT survey.

Table 4. Distribution of farm sizes in selected countries of Asia, late 1980s.

	Year	Average farm size	Farms with < 2 ha
South Asia		(ha)	(%)
India	1976	2.0	73
Nepal	1981	1.1	84
Pakistan	1980	2.4	37
Southeast Asia		(ha)	(%)
Indonesia	1983	1.0	85
Philippines	1980	2.8	51
Thailand	1983	4.2	27

Source: IRRI (1991).

adopted in other less productive maize-producing areas of the USA, especially the southern states. Adoption of hybrids was the main factor leading to the takeoff in maize yields which occurred in the USA during the 1930s, some 20 years before chemical fertilizer and pesticides were widely adopted (**Figure** 1). During the late 1940s and early 1950s, hybrid maize technology spread to other commercial maize producing countries. In Western Europe and parts of South America where maize is produced under temperate conditions similar to those found in the USA, adoption of hybrids proceeded rapidly in the post-War years. Meanwhile, commercial farmers in other regions characterized by warmer, non-temperate climates also began to take up hybrid maize technology, especially in Eastern Africa (Kenya), Southern Africa (Zimbabwe), and South America (Brazil). Zimbabwe's commercial farmers were among the pioneers in the use of single-cross hybrids, extensively adopting the locally developed hybrid SR 52 during the early 1950s.

During the period when hybrid maizes were first being taken up by large-scale commercial farmers, efforts were also made to introduce hybrid maize technology into small farm agriculture in developing countries. Many of these efforts were stimulated by foreign assistance programs inspired by the success of hybrid maize technology in the USA. Among the earliest were programs sponsored by the Rockefeller Foundation in Mexico (beginning in the 1940s) and in India (beginning in the 1950s). In spite of high expectations, these programs met with limited success, and in most developing countries the proportion of maize area sown to hybrids remained modest. One major reason for the relative lack of success in achieving widespread adoption of hybrids was the lack of viable seed industries; attempts to produce and distribute hybrid seed through public agencies and/or by means of *ad hoc* arrangements with private companies generally failed to develop a market for hybrid seed.

At the time of CIMMYT's establishment in 1965, international maize breeding efforts were focused primarily on the development of hybrids. However, during the late 1960s the attention of CIMMYT maize breeders shifted to OPVs. The shift in emphasis from hybrids to OPVs appears to have been stimulated by several widely held beliefs:

- hybrid seed technology is not appropriate for small farmers, especially since it requires annual seed purchases
- hybrids cannot succeed without the support of a sophisticated seed industry
- seed of OPVs can be produced with simple technology, and once distributed to farmers, will travel from farmer to farmer (as had recently occurred with the high-yielding varieties of rice and wheat)
- improved breeding methods for population improvement offer the opportunity for OPVs to match yields of hybrids.

At the same time that CIMMYT was shifting its germplasm improvement efforts to focus on OPVs, several national maize research programs were also beginning to concentrate on population improvement activities, with the ultimate objective of producing improved OPVs for small-scale farmers. Among these was the Rockefeller-led regional effort based in Thailand. The widespread shift in breeding focus was reflected at the global level in a marked increase in the proportion of OPVs released during the 1970s. The emphasis on OPVs was especially pronounced in tropical maize, to which CIMMYT devotes most of its breeding efforts.

The results of this OPV-led strategy were mixed. A few outstanding successes were realized, as in Thailand, where improved OPVs were adopted on most of the maize area, and where a combination of public and private efforts to produce and market seed led to the emergence of a dynamic seed industry that enabled most farmers to replace seed annually. More commonly, however, the adoption of improved OPVs was less extensive than expected. Seed supply and quality were often inadequate, in many cases because seed production was left to inefficient parastatal seed companies or assigned to community development projects lacking in technical expertise. Even where improved OPVs were initially adopted, few farmers replaced seed on a regular basis. Edwin Wellhausen, the first director of the CIMMYT Maize Program, summed up his frustrations with OPV seed production efforts:

> During my 32 years of promotion of maize production in the tropics, I have been unable to interest either the public sector or the private sector in the production of large volumes of seed of OPVs. Where [OPV seed] is produced, it is produced by individual farmers, or as a stopgap by commercial seed producers, until some kind of hybrid can be developed. (Wellhausen, 1978).

Meanwhile, as efforts to promote improved OPVs faltered, a number of success stories emerged to show that hybrid maize could be adopted profitably by small-scale farmers. In Kenya, Zambia, and Zimbabwe, adoption of hybrids by small-scale farmers resulted from a "spillover" out of the commercial farming sector (Figure 2). In all three of these countries, hybrids were initially targeted at large-scale commercial farmers, but when the superior performance of the commercial hybrids caused them to be sought out by small-scale farmers, seed companies recognized a potential new market and adjusted their packaging and marketing strategies accordingly. Other countries in which hybrids were widely adopted by small-scale farmers included El Salvador, Venezuela, China, and India.

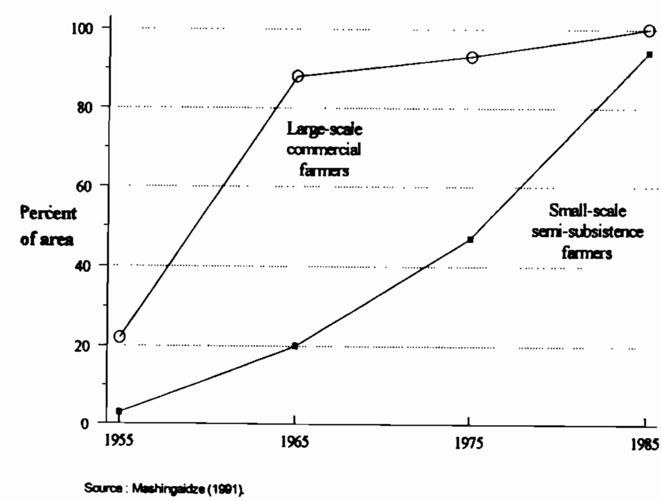
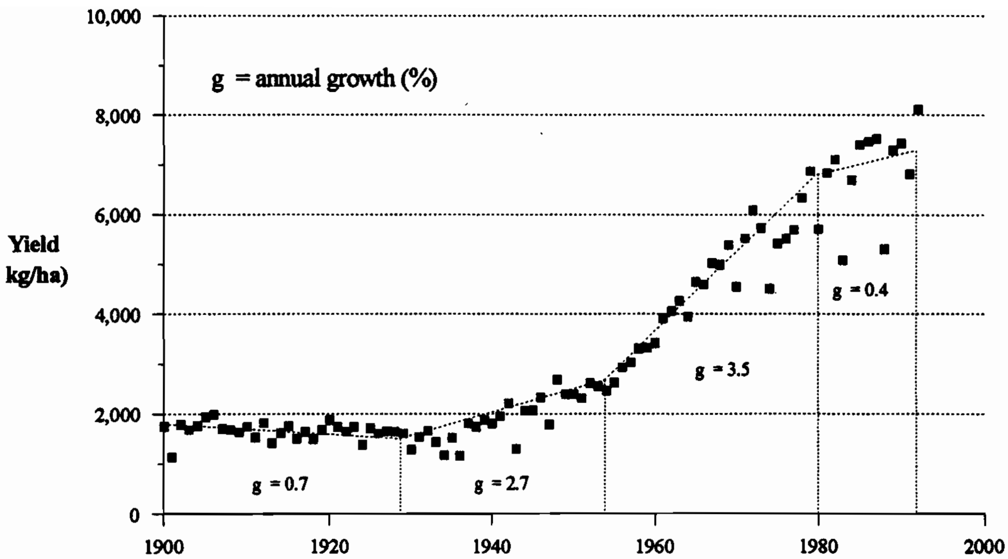


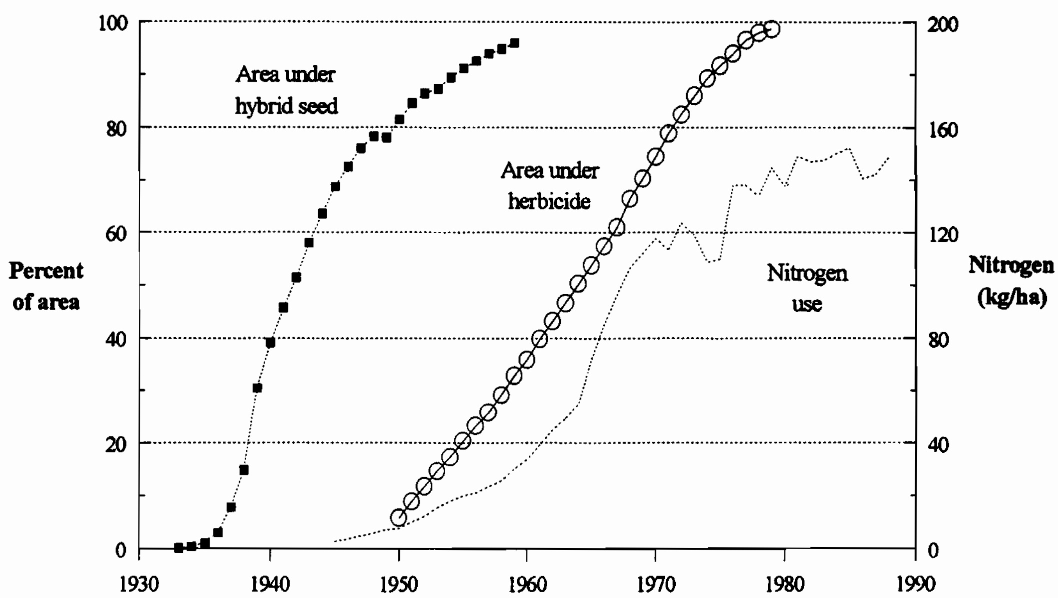
Fig. 2. Adoption of hybrid maize in Zimbabwe.

Most of the early success stories featuring adoption of hybrid seed by small-scale farmers had several features in common:



Source: Brown (1966), and FAO data.

Fig. 1a. Maize yields in USA, 1990-92.



Sources: Hybrid seed - USDA Agricultural Statistics (various years).
Herbicide, nitrogen - Sunquist et al. (1982), updated in Munson and Runge (1989).

Fig. 1b. Trends in hybrid seed adoption, herbicide adoption, nitrogen use on maize in USA, 1933-89.

- when grown under farmers' conditions, hybrids developed by public sector research institutions provided a large yield advantage (as well as other desirable characteristics) compared to local varieties.
- private seed companies or cooperatives (public seed companies, in the case of China) were able to produce and market quality seed at affordable prices
- public extension services played an important role in widely demonstrating the technology in farmers' fields and in educating farmers about the need to replace seed annually.

Perhaps the single most important lesson emerging from the early success stories was that hybrid maize can be appropriate under a wide range of production conditions and levels of management. The realization that hybrids could be suitable for less than optimal production conditions soon led to a significant change in hybrid development strategies. Although many researchers and policy makers previously had argued that hybrids should be promoted only when average yields reach a threshold level of about 2.5 - 3.0 t/ha, these success stories demonstrated that small-scale farmers can profitably adopt hybrid seed in situations where average yields are still quite low. For example, Cutié (1975) documented the successful adoption of hybrids in El Salvador, where yields averaged only 1 - 1.5 t/ha, and Rohrbach (1989) described adoption taking place in dry areas of Zimbabwe where average yields average only about 0.6 t/ha.

With the realization that hybrid maize technologies can be appropriate even for small-scale farmers, attention within CIMMYT and in many national breeding programs shifted back to hybrids. This shift in focus was subsequently reflected in the mix of products coming out of national breeding programs (**Figure** 3). Since 1985, the number of hybrids released has increased relative to the number of OPVs, and sales of hybrid seed have risen dramatically. Hybrid seed sales have risen even in countries where improved OPVs had been very popular, such as Thailand and India.

Although the success stories described above no doubt played a role in the shift in attention back to hybrids, institutional and policy changes have also contributed to the surge in hybrid use. Particularly during the 1980s, many countries enacted laws designed to encourage greater participation by the private sector in seed production and marketing activities. These changes were often supported by the implementation of policies designed to promote foreign investment in seed industries, leading to the entry of multinational seed companies into many markets.

3. Economics of adopting hybrid maize

Economic as well as non-economic factors influence the farmer's decision whether or not to adopt hybrid maize (**Figure 4**). Economic factors affect the profitability of growing hybrids, while non-economic factors affect the farmer's knowledge of the technology, access to the technology, and the perceived riskiness of adopting the technology. The main economic factors influencing the adoption of hybrid maize are discussed below.

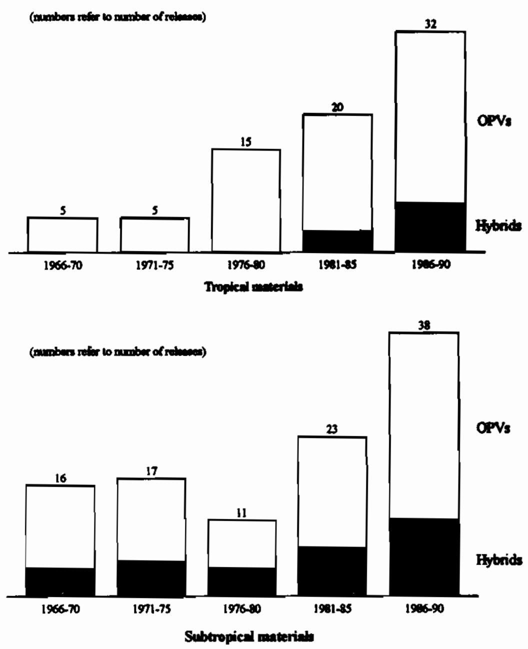
3.1. Price of hybrid seed

Since hybrid seed must be purchased annually, the price of seed is potentially important in the adoption decision, especially in the case of small-scale farmers for whom cash availability is usually a constraint. The price of hybrid seed varies tremendously from one country to another (**Figure 5**), depending on various factors:

- **the type of hybrid.** The seed yield of parental inbred lines varies depending on the type of hybrid, resulting in large differences in production costs. Seed of single-cross hybrids is generally the most expensive to produce, while seed of non-conventional (top-cross) hybrids is usually the least costly (**Figure 6**).

6. Maize seed-to-grain price ratios, by seed type.

- **net seed yields.** Even for a given type of hybrid, the cost of



Source: CIMMYT Maize Impact Study.

Fig. 3. Number of maize OPVs and hybrids released in Asia, 1966-90.

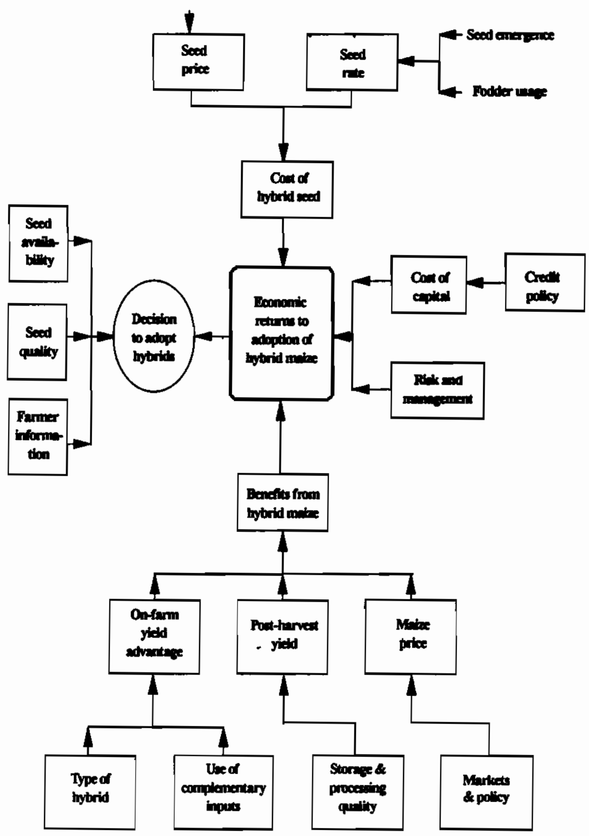


Fig. 4. Factors influencing the decision to adopt hybrid maize seed.

seed often varies substantially because of differences in net seed yield. For example, in Mexico an important factor determining net seed yields is the proportion of usable seed, since varying amounts of seed of unacceptable size must be discarded (Table 5).

- **the costs which must be covered by the price of hybrid seed.** If hybrid seed is produced from inbred lines developed by the public sector, research and development costs do not have to be reflected in the price of seed.[1/] Likewise, if hybrids are promoted extensively through public sector extension programs, marketing and promotion costs borne by private companies are generally low.

Table 5. Seed yield of parent inbreds, single-cross parents, and commercial double-cross hybrid in Mexico, 1991.

	Gross seed yield	Net seed yield	Net seed yield
Parent lines	(t/ha)	(t/ha)	(%)
M15*	2.33	0.13	5
M16	2.27	0.32	14
M17*	2.48	0.39	16
M18	2.36	1.04	44
M17 x M18*	0.67	0.54	80
M15 x M16	5.86	2.00	34
Commercial hybrid	(t/ha)	(t/ha)	(%)
H-28**	6.50	4.73	73

Source: Lopez-Pereira and Espinosa C. (1993).
* Male parent of cross.
** (M17 x M18) x (M15 x M16).

- **the structure and competitiveness of the seed industry.** A seed industry characterized by many companies actively competing for a share of the market is likely to be more efficient than one characterized by only one or two companies. Although there are probably significant economies of scale in hybrid R&D, as well as in seed marketing and promotion, there appear to be few economies of scale associated with hybrid seed production. Therefore, competitive small-scale seed companies can develop if the public sector provides a source of improved germplasm and supports extension and promotion activities. The presence of small-scale companies increases competition in the seed market and helps to keep seed prices low.
- **general economic policies.** These influence the profitability of commercial maize production (e.g., commodity price support policies, input price policies, credit policies). In Mexico, for example, high guaranteed prices for maize in the 1990s have made maize production very attractive, resulting in an increased demand for hybrid seed.

Table 6 presents information on prices of hybrid maize seed in selected countries. In order to facilitate comparisons, seed prices are expressed in terms of the number of

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1/ In some cases, public breeding programs charge private companies for basic seed, but these charges are usually less than needed to recover research and development costs.

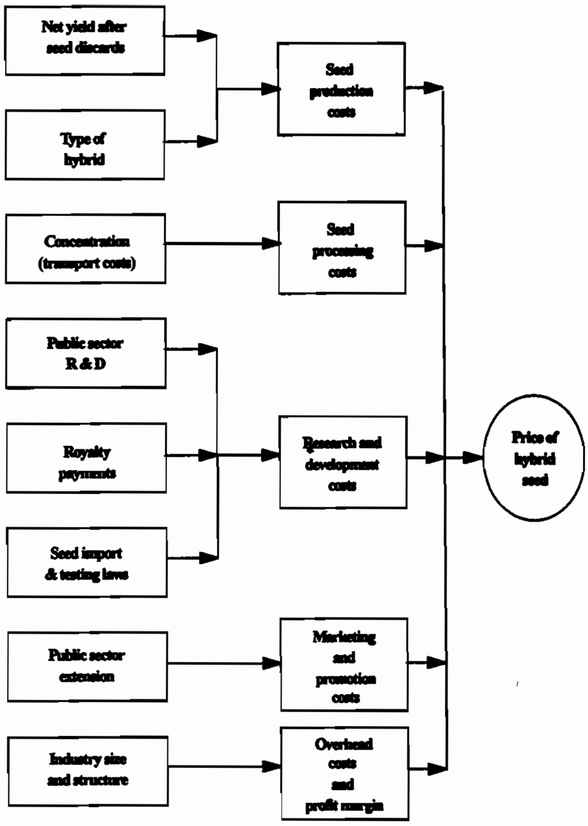


Fig. 5. Factors influencing the market price of hybrid maize seed.

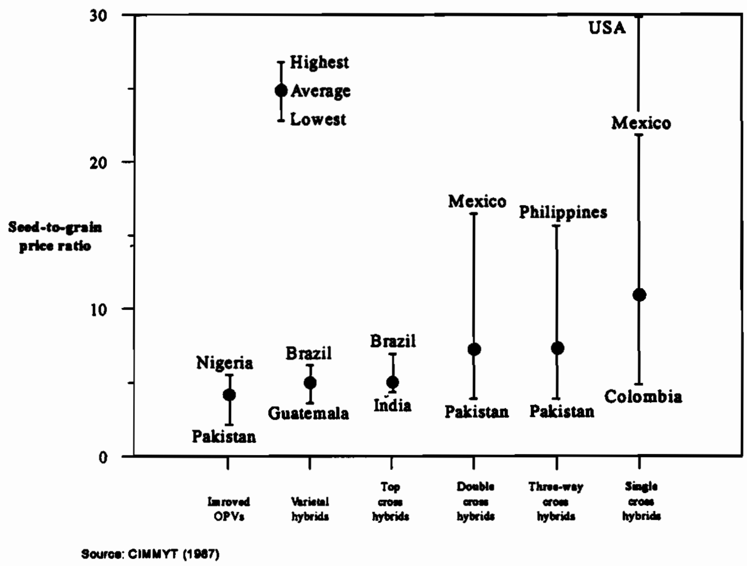


Fig. 6. Maize seed-to-grain price ratios, by seed type.

kilograms of maize grain that must be sold to pay for one kilogram of seed (known as the **seed-to-grain price ratio**). In the USA, this ratio is now close to 30:1, but during the 1930s when hybrids were initially adopted, it ranged from 5:1 to 8:1 (Figure 7). In a number of developing countries where hybrid seed has been widely adopted by small-scale farmers, seed-to-grain price ratios currently range from 4:1 to 6:1.

Table 6. Seed-to-grain price ratios and adoption of hybrid seed in selected developing countries, 1990.

Country	Seed-to-grain price ratio for a common hybrid*	Percent of maize area sown to hybrid seed
Zambia	2.8	72
India (Bihar)	4.2	75
Kenya	4.3	62
Venezuela	4.4	91
El Salvador	4.6	55
Zimbabwe	6.5	96
Mexico	7.1	8
Indonesia	11.3	13
Thailand	15.1	20
Philippines	16.7	5

Source: CIMMYT survey.

* Ratio of price of hybrid seed (usually a double cross) to commercial price of maize grain.

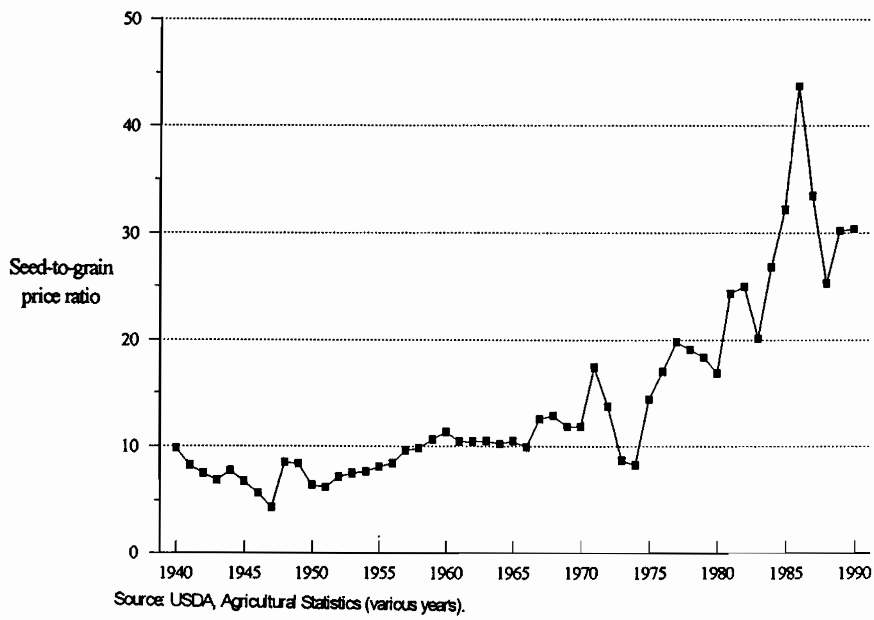


Fig. 7. Hybrid maize seed-to-grain price ratio, USA, 1940-90.

Differences in seed prices can be explained partly in terms of differences in production costs. For example, today's high seed prices in the USA reflect the widespread use of single-cross hybrids, which are more expensive to produce than other types of **per se** can also contribute to high seed prices. In the USA, seed production costs comprise only about 30% of the final sales price; the remaining 70% consists of R&D, marketing, and promotion costs (**Table** 7). By contrast, over 80% of the final sales price in Zimbabwe consists of production and on-farm processing costs; until recently, R&D, marketing, and promotion costs borne by the seed companies were negligible, since these services were provided largely by the public sector. In Mexico, where seed prices are somewhat higher than in Zimbabwe, seed production and processing costs account for about 60% of the final sales price (**Table** 8).

It is interesting to note that wherever hybrid maize has been widely adopted by small-scale farmers, seed-to-grain price ratios have been in the range of 4:1 to 6:1. This would appear to indicate that low seed-to-grain price ratios (probably on the order of 10:1 or less) are necessary to encourage farmers to adopt hybrids during the development phase of the seed industry, when the market for hybrid seed is first established. At these low seed-to-grain price ratios, seed costs contribute only a small share of the variable cost of production. As will be discussed in the next section, various policy measures are available to stimulate a competitive hybrid seed market with prices at these levels.

Although low seed prices may be necessary to encourage farmers' initial adoption of hybrids, it is important to recognize that low seed prices can be undesirable if they discourage private companies from investing in seed production activities. For example in India, public and parastatal seed corporations produce and market OPVs and hybrids, which they are able to sell at low prices with the help of government subsidies. Many private seed companies in India are reluctant to produce and market seed of the public materials,

Table 7. Breakdown of hybrid maize seed price, USA.

	Percent of sale price
Seed production	30
Processing	15
Marketing	15
Research and development	10
Overhead	15
Gross profit	15
Sale price	100

Source: Based on Pioneer (1992) and Seghal (1992).

because profit margins are negligible. Although most private companies continue to produce and sell seed of the more popular public OPVs and hybrids, these materials are often carried as "loss leaders," i.e., products sold for little or no profit in order to attract and retain customers who will purchase other more profitable products such as fertilizer and agricultural chemicals.

3.2. Seed rate

Another important variable which can greatly affect the cost of using hybrid seed is the seed rate. Although seed rates for monocropped maize average around 25 kg/ha across Asia as a whole, in some instances they are much higher. In East Java, for example, seed rates average over 40 kg/ha because farmers overplant in order to compensate for expected losses from insect attacks during the seedling stage (Krisdiana *et al.* 1991). In hill areas of northern Pakistan, farmers frequently sow 80-100 kg/ha of seed in order to provide both grain and fodder from thinnings (Byerlee *et al.* 1991). In some parts of India and Thailand, early season drought can lead to poor emergence, creating the need to

Table 8. Cost of producing, processing and marketing seed of a double-cross hybrid in Mexico, 1992.

	Unit	Value	Percent of sale price
Seed production and processing costs:			
Gross seed yield	kg/ha	3,000	
Net seed yield	kg/ha	2,250	
Total production cost	US$/ha	1,878	38
Seed processing	US$/ha	420	
(sale value of discarded seed)	US$/ha	(183)	
Net processing cost	US$/ha	237	19
Total cost of production and processing			
Per ha	US$/ha	2,115	
Per kg of seed	US$/kg	0.94	
Cost breakdown per kg of hybrid seed:			
Production and processing	US$/kg	0.94	57
Promotion and sales	US$/kg	0.38	23
Overhead	US$/kg	0.09	5
Subtotal	US$/kg	1.41	85
Net margin	US$/kg	0.25	15
Final sale price	US$/kg	1.66	100
Seed-to-grain price ratio = 6.8			

Source: Lopez Pereira and Espinoza C. (1993).

replant one or more times. In all of these situations, the use of hybrid seed may be unprofitable unless ways are found to reduce the need for high seeding rates (e.g., use of soil insecticide in East Java, introduction of materials in Pakistan which can withstand leaf stripping, development of improved planting equipment in Thailand).

3.3. Yield gains from hybrids

On the benefit side, the most important variable determining the attractiveness of maize hybrids is the yield advantage they offer compared to the farmer's current material. Depending on the type of material currently being grown, the relevant comparison may be with an unimproved local variety, with an improved OPV, or even with another, older hybrid. In areas where hybrids are replacing unimproved local varieties (e.g., parts of Eastern and Southern Africa, Central America), yield increases on the order of 40-50% are quite realistic (**Table 9**). In areas where hybrids are replacing improved OPVs (e.g., Thailand, parts of India), it may be difficult to achieve yield increases of more than 20-25% over the levels currently being achieved by farmers. In areas where the use of hybrids is already extensive (e.g., China, northern Mexico, parts of Brazil), yield increases associated with adopting the latest hybrid may be as low as 8-15%.

Table 9. Yields of hybrids and local maize in on-farm demonstrations without fertilizer application in Malawi, 1990-92.

	Normal years	Drought year	All years
Number of sites	110	102	212
Yield of local variety (kg/ha)*	950	385	678
Yield of hybrid (kg/ha)*	1,409	680	1,058
Yield advantage of hybrid (kg/ha)**	459	295	380
Yield advantage of hybrid (%)	(48)	(77)	(56)

Source: Byerlee and Heisey (1993).
* Yield in unfertilized plots.
** Yield increase of 150 kg/ha required to cover the additional cost of hybrid seed.

Although it is widely believed that the yield advantage of hybrids will be expressed only with good management, plentiful water, and high levels of purchased inputs (especially fertilizer), recent evidence suggests that hybrids can be profitable even in marginal environments and under low management. Given the paucity of on-farm studies, it is difficult to draw firm conclusions about the conditions under which hybrids are likely to outperform farmer's current materials. Clearly there is a need for more extensive testing of hybrids under farmers' conditions in order to assess their yield advantage at the farm level.

In comparing the performance of hybrids to those of the farmers' current material, it is important to keep in mind that the criteria used by farmers to measure performance may differ from those of researchers. For example, farmers usually think of grain yields in terms of **net yields**, i.e., after deducting processing and storage losses. In some cases, processing and storage losses in hybrids have been sufficiently large to offset advantages of 40% or more in gross grain yields (Smale *et al.*, 1991). When maize is produced for the market, quality differences reflected in price discounts must also be taken into account when estimating the yield advantage of hybrids. Price discounts applied to hybrids because of undesirable characteristics having to do with grain texture, grain color, storage quality, difficulty of processing, or eating quality may fail to compensate farmers for a simple yield advantage.

3.4. Cost of capital and risk

To be attractive to farmers, hybrid maize must not only generate additional income sufficient to repay the higher cost of the seed, but it must also provide an extra return to compensate the farmer for the risk taken in planting an unfamiliar material. Small-scale farmers, particularly those who rely on their own production for an important share of household consumption needs, often place a high value on food security. Studies have found that a marginal return of at least 100% often is needed to make investment in a new technology attractive to farmers, meaning that for every dollar (or peso or rupee) invested in seed, the new technology will have to generate at least two dollars (or pesos or rupees) in additional profits. Some seed companies figure on a much higher marginal return of at least 300% in setting prices for hybrid seed (McMullen, 1987). Under such a pricing strategy, at least three quarters of the additional benefits associated with the new hybrid are captured by farmers.

Table 10 illustrates how partial budget analysis can be used to compute the marginal rate of return (MRR) associated with the adoption of hybrid maize. Two scenarios are depicted: 1) a case in which the hybrid replaces an unimproved local variety, and 2) a case in which the hybrid replaces an improved OPV. Note that the maize price used in this analysis is the "field price," which has been adjusted for harvesting, shelling, bagging, and post-harvest transportation costs. Use of the field price is important in order to take into account the additional costs of harvesting higher-yielding hybrid maize. In this example, switching to hybrid maize would be particularly profitable for farmers who are currently growing the unimproved local variety, as the MRR exceeds 475%. Switching to hybrid maize would be somewhat less profitable for farmers who are already growing the improved OPV, in which case the MRR equals 260%. However, even the latter MRR is likely to be considered attractive by most farmers.

3.5. Break-even yield gain curves for hybrid adoption

Putting together all of these variables -- seed price, seed rate, yield gains, cost of capital and risk -- we can derive break-even yield gain curves to show the likely profitability of adopting hybrid maize. Break-even yield gain curves depict the set of minimum percentage yield increases (computed across a range of yield levels) which a hybrid must generate in order to compensate the farmer for the higher seed cost and increased risk. Figure 8 shows break-even yield gain curves for three alternative seed-to-grain price ratios. At a high seed-to-grain price ratio of 20:1, the yield increase generated by the hybrid must be very large in order for adoption to be attractive, especially if current yields are low. At a low seed-to-grain price ratio of 5:1, the yield increase generated by the hybrid can be much smaller, especially if current yields are relatively high.

Table 10. Partial budget analysis for the use of improved maize seed.

	Local variety	Improved OPV	Double-cross hybrid
Yield (kg/ha)	1,500	2,000	2,500
Adjusted yield (minus 10%)	1,350	1,800	2,250
Field price of maize grain (US$/kg)	0.12	0.12	0.12
Gross revenues (US$/ha)	162	216	270
Price of seed (US$/kg)	0.15	0.30	0.90
Total costs that vary (US$/ha)*	3.75	7.50	22.50
Net revenue (US$/ha)	158	208	247
Additional costs (US$/ha):			
Change from local variety to hybrid			18.75
Change from improved OPV to hybrid			15.00
Additional net benefits (US$/ha):			
Change from local variety to hybrid			89.25
Change from improved OPV to hybrid			39.00
Marginal Rate of Return (%)**			
Change from local variety to hybrid			476
Change from improved OPV to hybrid			260

* Based on a seed rate of 25 kg/ha for all types of seed.

** The marginal rate of return (MRR) is calculated by dividing the additional net benefits by the additional costs, and expressing the result in percentage terms.

The relationships depicted in **Figure 8** are consistent with historical experience. As discussed earlier, widespread adoption of hybrid maize by small-scale farmers has occurred most frequently when seed-to-grain price ratios have been around 5:1; as farmers' yield levels rise, smaller yield gains are needed to induce adoption of hybrids. These break-even yield gain curves illustrate why farmers producing maize under better growing conditions and with good management are likely to adopt hybrids more readily than those producing maize under marginal growing conditions and with poor management.

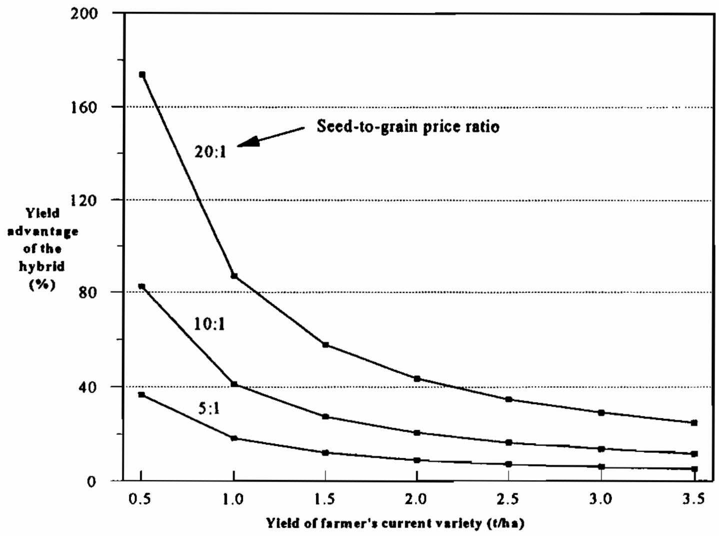


Fig. 8. Yield advantage over farmer's current variety required to compensate additional cost of hybrid seed and generate 100% marginal return to investment.

4. Policy and institutional issues in hybrid seed promotion

With certain notable exceptions, public and parastatal seed companies in developing countries have not been particularly proficient at developing, producing, and distributing adequate quantities of high quality maize seed. Therefore, if future efforts to increase maize production in Asia are to involve greater use of hybrid technologies, the private sector probably will have to assume a more active role in the seed industry. Private sector involvement can potentially involve one or more types of activities. At a minimum, all private seed companies produce and market seed. In addition, many larger companies also support their own in-house R&D programs in order to carry out the applied research needed to develop new hybrids. Some of the largest companies (often multinational corporations) even undertake basic research, such as biotechnology research.

Figure 9 summarizes potential links between public and private participants in the hybrid maize seed market. Experience from many countries suggests that private companies have a comparative advantage in producing and marketing seed, which means that they tend to be most active in the activities which appear in the right-hand side of the figure.

Since private companies by definition are in business to generate profits, they will become active in the seed industry only if it is economically attractive to do so. Several key factors that can influence the profitability of the seed industry are discussed in this section. Because profit opportunities change depending on the maturity of the seed market, it is useful to organize the discussion around two types of seed markets representing different stages of development: (1) **emerging markets**, in which farmers are adopting hybrid seed for the first time, and (2) **mature markets**, in which most farmers

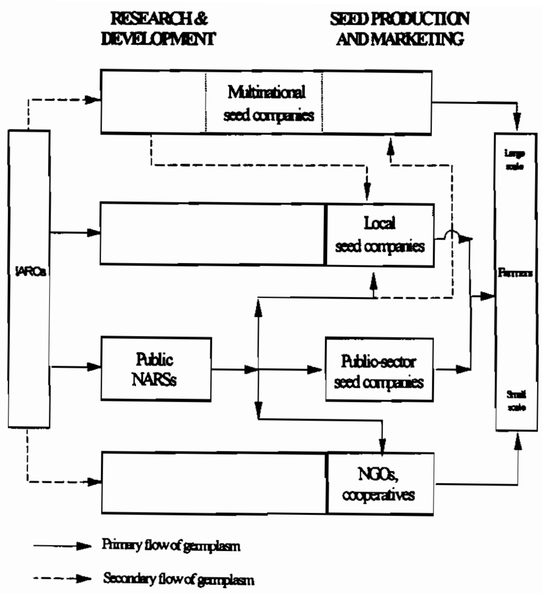


Fig.9. Framework for viewing interactions between the public and private sectors in the maize seed industry.

already use hybrid seed and periodically replace older hybrids with newer hybrids.

4.1. Emerging seed markets

In emerging seed markets, public breeding programs carry out most of the basic research needed to develop the source germplasm used to produce improved OPVs and hybrids. This was true even in the world's largest hybrid maize seed market, the USA, where up until 1950 most of the inbred lines used in producing commercial hybrids were developed by breeders working at public universities. Rather than concentrate on research, the first successful seed companies in the USA placed most of their effort in seed production and marketing. Similar alliances involving public sector R&D and private sector seed production and marketing were instrumental in the emergence of thriving hybrid maize seed markets in El Salvador, Zimbabwe, Kenya, Malawi, Venezuela, and India. Significantly, in nearly all of these countries public support to research was accompanied by public support to education, as government extension services played a major role in publicizing the benefits of hybrids and promoting their use.

In emerging seed markets, public policies have often been important in providing incentives for private companies to become involved in seed production activities. These incentives have typically included:

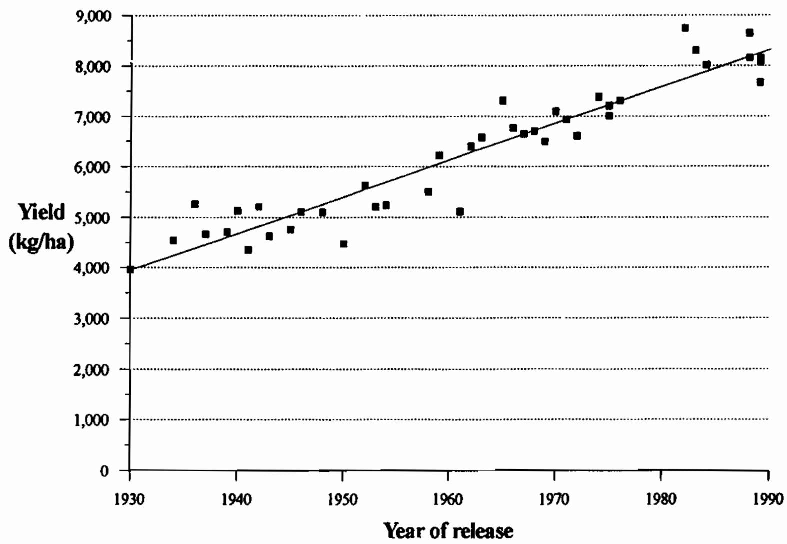
- provision of free access to improved populations and inbred lines generated by public research institutions, as well as information about the performance of these materials
- provision of credit and technical assistance to companies to invest in seed production (since hybrid seed production is skill intensive, technical training programs are often important for successful seed production)
- introduction of realistic policies governing seed certification that do not restrict the availability of quality seed to farmers
- establishment of liberal foreign investment laws and seed import policies to facilitate foreign participation in the seed industry (multinational seed companies are often an important source of new technology for seed production)

We have not included in this list plant varietal protection (PVP) laws and other forms of intellectual property rights (IPR) legislation. In our experience, these have not been very important in stimulating the emergence of seed markets during their initial stages of development.

It is important to recognize that there is no single "best" institutional framework to encourage the emergence of a flourishing seed industry. Hybrid maize success stories have been realized under a variety of institutional arrangements. In many cases, a single seed company or cooperative has played a leading role in launching a hybrid maize seed industry. Examples include the National Seed Cooperative in Zimbabwe, the Kenya Seed Company (originally owned by commercial maize producers but now with a majority ownership by the Kenyan government), and a locally owned private seed company in El Salvador. At the other extreme, in India a combination of public institutions and locally owned private seed companies have stimulated a very competitive seed industry.

4.2. Mature seed markets

In mature seed markets, incentives are often substantial for private companies to assume a larger role in R&D activities. In mature markets, most farmers are already familiar with hybrids and are willing to pay higher prices for quality seed. Furthermore, farmers expect that new, superior hybrids will be released periodically, leading to steady increases in yields (**Figure 10**). Thus, there is more scope for private companies to invest in R&D in order to develop branded products, as well as to invest in marketing and promotion in order to differentiate their products in the marketplace.



Source: Duvick (1992).

Fig. 10. Yields of US maize hybrids, by year of release.

In countries with well-established and dynamic private seed industries, public breeding programs must redefine their role so as to complement the activities of the private sector. The experience of many industrialized countries suggests that if public breeding programs do not redefine their roles, they will be left trying to compete with private companies in a contest in which the rules inevitably favor those who pay greatest attention to the bottom line. Although public breeding programs may be able to adopt some of the practices of private companies (including charging fees for their products), there is usually a limit to the degree to which this will be possible. Thus, public breeding programs must be willing to cede responsibility for some of their former functions and to concentrate on activities which private companies are unlikely to undertake. Activities which the public sector can perform in a mature seed market include:

- concentrating on the development of OPVs or hybrids for farmers and regions which do not allow a sufficient profit to interest the private sector (usually these farmers are located in marginal production regions)

- providing special trait materials (e.g., materials with resistance to specific abiotic and biotic stresses) that require a considerable investment in plant breeding over time and that enhance the stability and social benefits from private sector hybrids developed from using these special trait populations.
- providing information (based on multilocational testing) about yields and other traits of private sector hybrids.

Other potential roles of the public sector are more controversial. Possible activities include:

- evaluation and approval for release of private sector hybrids. Although responsibility for this important function is usually assigned to government-appointed varietal certification boards or agencies, in cases where public breeding programs are seen as competing with the private sector, government-appointed agencies often are charged of favoring materials produced by public breeding programs and discriminating against materials submitted by private companies.
- charging royalties for the use of public sector inbreds and hybrids. Some countries in Latin America are now actively experimenting with this approach, but there is a danger that a "profit driven" public sector will target its research to compete with the private sector, rather than play a complementary role as discussed above.
- implementation of IPR legislation to provide greater protection to private sector R&D. Intellectual property rights are more important in mature seed industries than in emerging industries and may be especially important in facilitating the transition to single-cross hybrids. However, the real importance of IPR laws is not that they stimulate investment by the private sector in R&D, but rather that they facilitate the transfer of new technologies from other countries (especially technologies produced using biotechnology methods).

4.3 Structuring incentives to ensure satisfactory market performance

In order to establish and maintain competitive hybrid seed industries in Asia, it will be necessary to balance a number of conflicting goals. Policies will have to be enacted which enable large seed companies to protect their products and thus generate reasonable returns to their R&D investment, while at the same time allowing small seed companies to remain in the market as active players. By implication, public breeding programs will have to concentrate on the development of basic germplasm (improved populations and inbred lines). A major challenge will be to devise policies which provide fair access to this basic germplasm to all potential users. Although some have argued that small seed companies need special assistance in the form of preferential access to germplasm produced by public breeding programs, administrators of public programs probably do not want to get involved in attempting to provide access to one set of companies while denying access to another, because of the difficulties inherent in enforcing any sort of discriminatory germplasm distribution policy.

While it may be true that large seed companies can sometimes capture economies of scale, allowing them to operate more efficiently than small companies, policy makers should not be unduly influenced by the exaggerated rhetoric heard in many countries alleging that large companies will inevitably come to monopolize the market. In attempting to assess the competitiveness of the seed industry, it is important to establish appropriate performance measures. The fact that a small number of firms may be present in a given market does not necessarily indicate poor performance, as long as the firms compete. In this respect, it is instructive to look to the experience of the USA and the EC, where maize seed industries have become concentrated in the hands of a small number of companies, but where the battle for market share is intense. It would be fair to say that maize farmers in the USA and the EC are generally well served by the private seed industry, if performance is measured by the availability of superior products at remunerative prices. Although the high seed-to-grain price ratios prevailing in the USA and the EC do in part reflect heavy promotion and advertising costs (which some might view as wasteful), the fact that most farmers in these countries achieve extremely high yields means that the cost of seed as a proportion of total purchased input costs is still very modest (about 10%).

Providing incentives for private sector investment may entail the enactment of IPR laws. No effort will be made here to review comprehensively all of the IPR alternatives available. However, it is worth distinguishing between two basic options:

1) **plant varietal rights (PVRs)**: Many countries seem to be opting for some form of PVRs, which help private companies establish proprietary rights to the products they develop. Most forms of varietal registration confer the right to produce and sell commercial seed of the protected variety for a fixed number of years; researchers are usually allowed to use protected materials as inputs into their own breeding programs (although recent revisions of PVR laws in some countries will restrict research uses). The emergence of DNA fingerprinting techniques will facilitate definitive identification of materials, thus making more practical the enforcement of PVR laws. However, a major problem is the difficulty of devising an operational definition of what constitutes a "significantly different" variety.

2) **plant patenting**: A few countries have granted patents on plant varieties, conferring a much stronger claim to the patentee than PVRs and often preventing the free use of the material by other researchers. Since plant patents are often expensive to obtain, and since their legality has not been established conclusively in many court systems, patents have not been used extensively for maize germplasm. Some of the strongest opposition to plant patenting has come from critics who have raised ethical objections to the idea of patenting living materials.

The need for legal protection of intellectual property generated by plant breeding programs tends to vary as a function of the maturity of the seed market. In emerging markets characterized by weak demand for seed and large numbers of relatively small seed companies, demand for IPR tends to be modest, largely because small seed companies do not invest extensively in R&D. The small seed companies typically found in emerging markets tend to rely on germplasm obtained from public breeding programs, as well as on materials "pirated" from other companies (a practice which is rarely admitted, but which is generally recognized to be widespread). Because they do not invest heavily in R&D, small companies naturally favor a system which affords the freest possible access to germplasm, and they are usually content to protect their own products by preserving the confidentially of parent lines. This so-called "trade secrets" strategy is feasible if the company is small and careful vigilance of materials is practical. Arguments made by small seed companies against enactment of IPR legislation are often couched in terms of "preserving biodiversity" and "protecting farmers' rights," when in fact the companies' real interest is to protect their ability to act as free riders in the system (i.e., those who profit from the investment of others without contributing to R&D costs).

As seed markets mature and larger companies find it profitable to invest in R&D, stronger IPR laws for plants may become necessary. It is difficult to generalize about the stage of seed market development at which investment in R&D becomes an attractive option, in part because the cost structure of research varies from country to country, and in part because private seed industries are only now emerging in many developing countries (so that there have not been many empirical examples upon which to base conclusions). Another key factor alluded to earlier is the prevailing policy environment regarding foreign participation; where foreign companies are welcome, often they are able to import products developed elsewhere and to adapt them to local production conditions (as opposed to developing new products from scratch). Larger companies with their own R&D programs strongly support plant varietal protection laws. It is important to note that the support for plant varietal protection comes from both national and multinational companies; the key factor is not where they are incorporated, but rather how large they are and the extent to which they are investing in R&D.

5. Conclusions

Most countries of Asia are now (or will soon be) witnessing an unprecedented surge in the demand for maize, stimulated in large part by rapidly rising consumption of livestock products. One of the major potential sources of future growth in maize production to meet this demand will be hybrid technology. In South and Southeast Asia, where use of hybrid maize is still very low, initial adoption of hybrid seed has the potential to make a particularly dramatic impact. In China, on the other hand, where adoption of hybrids is already well advanced and where there is a mature market for hybrid seed, replacement of old hybrids by newer, higher yielding hybrids will be the major source of future yield growth.

It is now well established that hybrid maize can and will be profitably adopted by small-scale farmers, provided good quality seed is readily available at reasonable prices. We have noted in this paper the wide variation in prices of hybrid seed, even seed of the same type of hybrid. Since evidence from a number of countries suggests that seed-to-grain price ratios on the order of 10:1 or less (for double-cross hybrids) may be necessary to encourage widespread adoption of hybrid maize, it is important to understand the factors which affect seed pricing strategies. Maintaining low seed-to-grain price ratios apparently requires an efficient seed industry, strong support from public-sector R&D in the form of inbreds and finished hybrids, and active promotion of hybrid technologies by the public extension service.

A variety of institutional arrangements involving different degrees of public and private sector participation have proven to be effective in fostering the emergence and establishment of hybrid seed markets. Generally speaking, during the initial stages of market development private companies have a comparative advantage in seed production and marketing activities, while public institutions have a comparative advantage in R&D. However, incentives to invest in research change as seed markets mature. In emerging seed markets, potential returns to R&D are limited, and public breeding programs must be expected to take the lead in developing not only basic germplasm, but also more finished products suitable for immediate distribution. As seed markets evolve and mature, however, incentives for private sector investment in R&D increase, and private seed companies can be expected to assume a greater role in developing products specifically designed for well-identified niches. When this happens, institutional arrangements must evolve to accommodate the changing role of the private sector, and changes will usually be required in IPR laws, as well as in procedures for varietal testing and release. As private companies assume a greater role in R&D, public research organizations frequently will have to reorient their activities to place greater emphasis on the development of basic germplasm, rather than finished products. But whatever the stage of market development, each country must develop a strategy that exploits the complementarity between the public and private sector. Too often these two sectors have been viewed as competitors in the seed industry.

Finally, while this paper has focused on hybrids, it should be emphasized that improved OPVs will continue to play an important role in some regions, such as the mountainous areas of northern Pakistan, northern India, and Nepal. The major challenge in promoting OPVs more widely in these areas is to find innovative ways to stimulate seed production. This will require government collaboration with non-governmental organizations, farmer cooperatives and individual farmer-seedsmen.

References

Brown, L.R. 1966. Como Aumentar la Produccion Mundial de Alimentos. Problemas y Perspectivas. Manuales UTEHA Numero 344/344a. Mexico, D.F.Union Tipografica Editorial Hispano-Americana.

Byerlee, D. and P. Heisey. 1993. Performance of Hybrids under Low-Input Conditions in Eastern and Southern Africa. Draft Paper, Mexico, D.F.: CIMMYT.

Byerlee, D., K. Khan, and M. Saleem. 1991. "Revealing the Rationality of Farmers' Strategies: On-farm Maize Research in the Swat Valley, Northern Pakistan." In R.Tripp (ed). Planned Change in Farming Systems: Progress in On-farm Research. Chichester: John Wiley and Sons.

Byerlee, D. and L. Saad. 1993. CIMMYT's Economic Environment to 2000 and Beyond: A Revised Forecast. Draft Paper, Mexico, D.F.: CIMMYT.

CIMMYT. 1987. 1986 CIMMYT World Maize Facts and Trends. The Economics of Commercial Maize Seed Production in Developing Countries. Mexico, D.F.: CIMMYT.

CIMMYT. 1988. From Agronomic Data to Farmer Recommendations: An Economics Training Manual. Completely Revised Edition. Mexico D.F.: CIMMYT.

Cutie, J.T. 1975. Diffusion of Hybrid Corn Technology: The Case of El Salvador. Mexico, D.F.: CIMMYT.

Duvick, D.N. 1992. "Genetic contributions to advances in yield of U.S. maize." Maydica 37: 69-79.

Garnaut, R. and G. Ma. 1992. Grain in China. Canberra, Australia: Commonwealth Information Services of Australia.

IRRI. 1991. International Rice Statistics, International Rice Research Institute, Los Banos.

Krisdiana, R., M. Dahlan, Herianto, C. van Santen, and L.W. Harrington. 1991. "From diagnosis to farmer adoption: MARIF's maize on-farm research programme in East Java, Indonesia." In R.Tripp (ed). Planned Change in Farming Systems: Progress in On-farm Research. Chichester: John Wiley and Sons.

Lopez-Pereira, M. and A. Espinosa C. 1993. "Analisis Economico de la Produccion y Uso de Semilla Mejorada de Maiz: El Caso de Mexico." Paper presented at the XXXIX Annual Meetings of the Programa Cooperativo Centroamericano para el Mejoramiento de Cultivos y Animales (PCCMCA), March 28-April 3, Guatemala City, Guatemala.

Mashingaidze, K. 1991. "Maize Research and Development." Paper prepared for the conference Zimbabwe's Agricultural Revolution: Implications for Southern Africa. Victoria Falls Hotel, Zimbabwe, 7-11 July, 1991.

McMullen, N. 1987. Seeds and World Agricultural Progress. Washington, D.C.: National Planning Association.

Munson, R.D., and C.F. Runge. 1989. Agricultural Competitiveness, Farm Fertilizer and Chemical Use, and Environmental Quality: A Descriptive Analysis. St. Paul, Minnesota: Center for International Food and Agricultural Policy at the University of Minnesota.

Pioneer Hi-Bred International. 1992. Annual Report. Iowa, Johnston City.

Rohrbach, D. 1989. The Economics of Smallholder Maize Production in Zimbabwe: Implications for Food Security. MSU International Development Paper No. 11., East Lansing: Michigan State University.

Sehgal, S. 1992. "Opportunities in Hybrid Rice Development." Seed World, 20-23, December 1990.

Sundquist, K., K. Menz, and C.F. Neumeyer. 1982. A Technology Assessment of Commercial Corn Production in the United States. Station Bulletin 546. St. Paul: Experiment Station, University of Minnesota.

Smale, M., with Z.H.W. Kaunda, H.L. Makina, M.M.M.K. Mkandawire, M.N.S. Msowoya, D.J.E.K. Mwale, and P.W. Heisey. 1991. Chimanga Cha Makolo, Hybrids, and Composites: An Analysis of Farmers' Adoption of Maize Technology in Malawi, 1989-91. CIMMYT Economics Working Paper 91/04. Mexico, D.F.: CIMMYT.

Wellhausen, E.J. 1978. "Recent Developments in Maize Breeding in the Tropics." In D.B. Walden (ed.) Maize Breeding and Genetics. Chichester, U.K.: John Willey & Sons.

Questions to the author:

FROM : E. R. Bautista

Q : When you say "small-scale farmer", how do you translate such idea into some definite area cultivated by farmers? Do you have some suggestion as to the minimum area for a farmer to work on for which hybrid production would be profitable?

A : In Asia, I think of small scale farmers as having less than 2 ha and who consume much of the maize they produce. There is no minimum size for adoption of hybrid maize. In China and India many farmers with less than 0.5 ha of cultivated area use hybrid seed.

FROM : F. Kasim

Q. : 1) You mentioned about the success story of Malawi as an example of hybrid in marginal environments, and then Dr. Pandey mentioned about the drought tolerant hybrids in Peru. Related to the roles that public sectors should play in development of markets for hybrid seed, I do not see your point. There is a situation where low prices of grain often occur at harvest time. We're talking about price certainty. In most marginal environments, farmers do not have bargaining powers dealing with buyers. Infrastructu-reare often poor in these environments. So, the buyers come to the farmers because they have money (cash) and can set up their own price to buy grain. These situations discour-age maize production in the environment besides other physical constraints.

2) Could you elaborate more on the role of the public sector in the market develop-ment stage?

A. 1) I agree that price uncertainty may be an additional risk in using hybrid seed.

2) In successful cases of adoption of hybrid seed use by small scale farmers,the public sector has provided in the market development stage:

a) hybrids developed by public sector research

b) strong extension support to popularize hybrids.

In some cases, the public sector has provided credit and technical assistance for establishment of local seed companies.

PROSPECTS FOR THE HYBRID SEED INDUSTRY IN DEVELOPING COUNTRIES

Suri Sehgal and Jan Van Rompaey [1]

Abstract

There are at least four basic principles by which the private seed sector operates:

1.Breeding and associated technologies must create significant value.

2.Protection of the products must be possible.

3.Industry must be able to recover added value through adequate pricing.

4.Farmers must significantly benefit if they are to pay higher prices for hybrid seeds.

Value creation can be in the form of cost savings, or extra earnings. For example, if a hybrid has a built-in tolerance to insects, it needs minimal or no application of expensive insecticides and therefore results in cost savings. An increase in harvestable yield of a hybrid results in extra earnings.

Irrespective of whether there are savings or extra income, both lead to extra value which has been created through breeding or associated technologies. The magnitude of value creation should eventually be reflected in the price at which seed of the new variety can be sold. This value-added pricing concept is new in the seed industry, but it is rapidly catching on.

In those countries where Intellectual Property Laws (IPR) exist, new plant varieties can be legally protected. IPR includes trade secrets, plant variety rights (PVR), and patents.

Plant varieties protected by PVR must comply with internationally recognized criteria for distinctness, uniformity, stability, and novelty. Two important principles of PVR protection are "breeder's exemption" and "farmer's privilege".

The breeder's exemption clause of PVR allows a protected variety to be freely used for further breeding after commercialization by its owner. Partly because of the advent of biotechnology and its reliance on patents, this clause of PVR has come under critical evaluation in recent years. Patented genes introduced through genetic engineering into the plant genome cannot be incorporated in other varieties through classical breeding or otherwise without permission from the patent holder.

The farmer's privilege (right to save seed) clause has come under attack from the seed industry in recent years because of exploitation of this privilege by farmers and by some small seed traders. Amendments to tighten farmer's privilege and breeder's exemption are being sought by the seed industry.

Most industrialized countries have well developed patent legislation. Although there are differences among countries, the general principles are similar. Patent protection can only be obtained for inventions : a) that are novel, that is, inventions not available to the public before the date of application for the patent; b) that are non-obvious and contain an inventive step; c) and that have industrial utility. In addition, the patent application should contain what is called an enabling disclosure, that is, a detailed description of the invention that enables any person familiar with the technical field of the invention to understand and reproduce the invention.

A detailed comparison of European and American Patent and PVR laws, and the proposed amendments to these laws currently being sought is presented.

The enactment of strong PVR and patent legislation, similar to that in the industrialized countries, is probably not appropriate for the developing countries, at least in the short term.

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[1] Director General and Scientist, respectively, Plant Genetic Systems N.V., Jozef Plateaustraat 22, 9000 Gent, Belgium.

To recover value, seed companies can theoretically charge an amount up to, but not exceeding, the value they add. Farmer benefit is a function of the value added to improved seed. The farmer should not get less than 3 times (preferably 5 to 6 times) the return on his investment in seed. Depending upon the complexity of the cross and the amount of value added, hybrid seed is generally priced at 10 to 30 times the value of the crop's commodity price.

If a seed company is to become successful, farmers must share in the value added (farmer's benefit). The seed grower must benefit by earning more than what he would from a commercial crop. And, the seed company must benefit by earning an acceptable return on investment. Farmers will pay for hybrid seed if it benefits them regardless of its price premium. Farmers in the developing world have centuries of crop growing experience, even if they may lack the formal education of their colleagues in the developed world. Higher input levels are no disincentive to use of hybrids.

Key words: Hybrid - Seed - Industry, IPR, PVR, UPOV convention.

Introduction

The seed industry in the developing countries is in an embryonic growth stage. Seed companies in those countries are typically small family-owned businesses. They generally focus on multiplying and distributing seed originating from the National Agricultural Research Systems (NARS) and/or the International Agricultural Research Centers (IARCs).

By contrast, the seed industry of the developed world is mature. It is going through a period of transition involving globalization, restructuring and consolidation. New technologies, particularly biotechnology have, in recent years, driven this structural change. These technologies have led to shifting alliances between established seed companies and to links with complimentary industries. The acquisitions of seed firms by agrichemical companies, and the strategic alliances being forged between them and food processors and biotechnology firms are notable examples.

In the late 1970's and early 1980's, many multinationals (MNCs) determined that seed would be the primary carrier of new technologies and therefore began to aggressively acquire seed businesses (**Table 1**). By acquiring those businesses, MNCs hoped to capture margins along the length of the agribusiness chain, from the laboratory to the farmer.

Table 1. Seed industry acquisition and merger mania - 1970s and 1980s (selected examples).

Multinational	Acquired company
Ciba-Geigy	Funk Seed International
Dow Chemical	United Agriseeds
Elf Acquitaine (Sanofi)	Dahlgren, King Agro, France Canada Semence
Hoechst	Nunhems, Canners, Hild
ICI	Garst, SES, Sinclair Mc Gill, Miln Marsters, Contiseeds, Edw. J. Funk
Lubrizol	Agrigenetics, (Jacques, McCurdy, Lynnville, Sigco)
Rhone Poulenc	Callahan, Clause (50%), Harris-Moran (50%)
Sandoz	Northrup King, Stauffer Seed, Vaughans, Hilleshog, Weibull, Sluis & Groot
Upjohn	Asgrow, O's Gold, Bruinsma

This strategy has not worked for many MNCs. Firstly, because the time element in converting technologies into products has taken much longer than originally envisioned. Secondly, there has been a conflict between the entrepreneurial management style of small companies vs. the hierarchial and in most cases bureaucratic style of most MNCs. Thirdly, the learning curve has been longer and more complex than expected and has lead to poor financial performance. Lately, MNCs have come to realize that the seed business is different than the chemical or pharamaceutical business. Unlike chemicals, a variety cannot be marketed globally, but only in agroclimatic regions similar to where it was developed. Most MNCs are dissatisfied with the payoff in the seed business to date. It is expected that as chemical companies exit from the seed industry, the acquired businesses are likely to revert back to the "genuine seedsmen". In the late 1980's and early 1990's, many multinationals began to divest their seed business and are still in the process of doing so (Table 2).

Table 2. The seed industry divestment mania - 1990s (selected examples).

Multinational	Divested company
Arco Chemical	Sunseeds
British Petroleum	Edward J. Funk
British Sugar	Germain's, W.L. Research
Pfizer	30% interest in Dekalb Plant Genetics
Shell	Nickerson International Seed Co., Ltd.
Orsan	Wilson Hybrids, Western Plant Breeders
Rohm & Haas	Rohm & Haas Seeds, Inc.
Elf Acquitaine (Sanofi)	Dahlgren, Rustica

Today there are essentially two broad divisions (Table 3) within the global seed industry, namely:

- the Hybrid seed sector, and
- the Non-Hybrid seed sector.

The hybrid seed industry is characterized by high R&D costs, high prices, high margins, and is primarily controlled by the private sector in both developed and developing countries. The non-hybrid seed industry is characterized by low R&D costs, low prices and low margins, and is primarily in the public domain in developing countries and in the private sector in developed countries.

Table 3. Seed industry characteristics in high, middle and low income countries.

Industry	High Income	Middle Income	Low Income
HYBRID			
. Volume	high	medium	low
. Value	high	high	high
. Margins	high	high	high
. Sector	private	private	public and private
. Stage of Development	mature	growth	embryonic
NON-HYBRID			
. Volume	high	high	high
. Value	low	low	low
. Margins	low	low	low
. Sector	private	public and private	public
. Stage of Development	growth	embryonic	embryonic

In recent years, many new companies have entered the seed business in developing countries. This can be attributed to:

- Greater availability of hybrids in several crop species.
- Easing of government policies pertaining to the private sector entering the seed business.

Availability of hybrids

A partial list of crops for which hybrids are available can be seen in **Table 4.** Historically, the seed industry in developed countries has expanded by developing and selling hybrids (**Table 5**). The industry generally shifts towards hybrids whenever they are technically and economically feasible. Nearly 40% of the total global commercial seed business of about US$15.0 billion is accounted for hybrid sales in various crops. Importantly, with hybrids breeders can protect their intellectual property in the form of trade secrets. The parent lines required to produce the hybrid are kept secret by the breeding company. Hybrids thereby enable companies to obtain an acceptable return on their investment either directly in the form of gross margins, or indirectly in the form of royalties, or both. With proper incentives, the private sector can become a dynamic force in hybrid seed industry development in the Third World. Recent activity by the private sector in developing countries in Asia and Latin America indicates that there are ample business opportunities in hybrids.

Table 4. Available hybrid systems and selected examples.

Hybrid System	Crops
Manual or mechanical emasculation	- Corn
	- Tomato
Chemical (Gibberellins, $AgNO_3$, Ethrel, etc.)	- Cucumber
	- Melon
Cytoplasmic male sterility (CMS)	- Sorghum
	- Rice
	- Millet
	- Sunflower
Self incompatibility (SI)	- Cabbage
	- Broccoli
Natural genetic male sterility (ms ms)	- Pigeon Peas
Engineered genetic male sterility (NMS)	- Oilseed Rape

Government deregulation

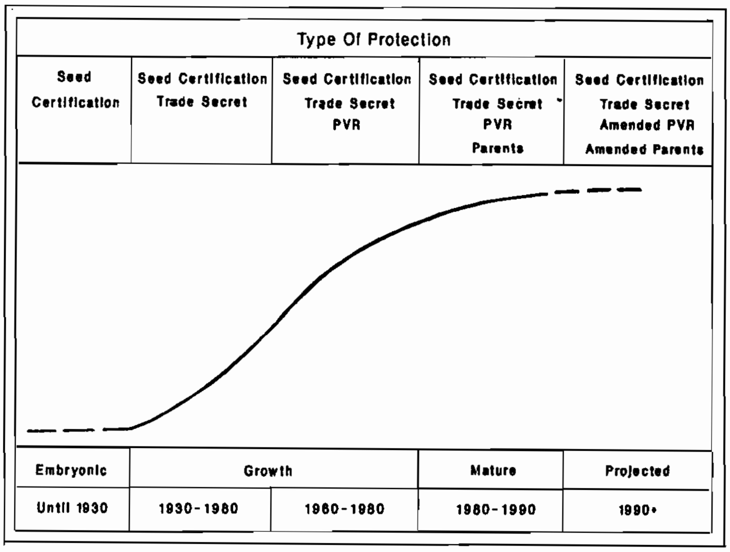
One of the most notable examples of deregulation in the developing world is India's "New Seed Policy", which was announced in 1988. As a result of the new policy, many new national and multinational companies entered the seed business in India. The newcomers include Indian Tobacco Co. (ITC), Sandoz, Cargill, Hoechst, Ciba-Geigy, ICI, SPIC, Bejo, Hindustan Lever, Harrisons Malayalam and JK Seeds. Similarly, deregulation in Thailand and Philippines has led to a sizable expansion in their hybrid seed industries over the past 5 years. Government policy makers can learn a lesson from this phenomenon. Even slight deregulation of the sort introduced in India can spur enormous development in a country's seed industry.

Policy makers can continue to create incentives for expansion, as is currently happening in several developing countries. The aim of any seed policy should be to ensure that elite seed is made available to farmers. Legislation that hinders this goal is counterproductive. If the private sector is to be a partner in the effort to develop, produce, and distribute hybrid seeds, the principles by which the industry operates should be considered in national policy making.

There are at least four basic principles by which the private seed sector operates:

1) Breeding and associated technologies must create significant value.
2) Protection of the products must be possible.
3) Industry must be able to recover added value through adequate pricing.
4) Farmers must significantly benefit if they are to pay higher prices for hybrid seeds.

Table 5. Historical representation of seed industry development in developed countries and type of protection available.



Creating value

Value creation can be in the form of cost savings, or extra earnings. For example, if a variety has a built-in tolerance to insects, it needs minimal or no application of expensive insecticides and therefore results in cost savings. The same is true of disease resistance. In the case of drought tolerant varieties, savings result from decreased costs incurred in irrigation.

An increase in harvestable yield results in extra income to the farmer. An increase in quality traits, such as high oil content or better quality oil, high quality protein (tryptophane or methionine), or high quality starch, etc. results in higher income to the farmer because of better prices.

Irrespective of whether there are savings or extra income, both lead to extra value which has been created through breeding or associated technologies. The magnitude of value creation should eventually be reflected in the price at which seed of the new variety can be sold. This value-added pricing concept is new in the seed industry, but it is rapidly catching on.

Protecting value

In those countries where Intellectual Property Rights (IPR) exist, new plant varieties can be legally protected. IPR includes trade secrets, plant variety rights (PVR) and patents. The importance of trade secrets has been discussed earlier under "Availability of Hybrids". The essential principles of PVR and patents are discussed below.

PVR

Plant varieties protected by PVR must comply with internationally recognized criteria for distinctness, uniformity, stability, and novelty. Two important principles of PVR protection are "breeder's exemption" and "farmer's privilege".

The breeder's exemption clause of PVR allows a protected variety to be freely used for further breeding after commercialization by its owner. Partly because of the advent of biotechnology and its reliance on patents, this clause of PVR has come under critical evaluation in recent years. Patented genes introduced through genetic engineering into the plant genome cannot be incorporated in other varieties through classical breeding or otherwise without permission from the patent holder.

The farmer's privilege (right to save seed) clause has come under attack from the seed industry in recently years because of exploitation of this privilege by farmers and by some small seed traders. Amendments to tighten farmer's privilege and breeder's exemption are being sought by the seed industry.

Patents

Most industrialized countries have well developed patent legislation. Although there are differences among countries, the general principles are similar. Patent protection can only be obtained for inventions; a) that are novel, that is, inventions not available to the public before the date of application for the patent; b) that are non-obvious and contain an inventive step; c) and that have industrial utility. In addition, the patent application should contain what is called an enabling disclosure, that is, a detailed description of the invention that enables any person familiar with the technical field of the invention to understand and reproduce the invention.

The scope of a patent is determined by the content of the claims. The patent system offers the possibility of protection for processes, such as plant transformation and for novel genes which can be expressed in plant cells and can confer useful properties on plants. The extent to which claims are allowed is determined by the competent patent office examining the application for requirements for patentability and sufficiency of disclosure. That examination takes into account everything known by the public at the time the application was filed.

An invention entitled to patent protection can consist of a product (or a series of products) or a process for making a product. In this respect it differs from plant variety rights which are only granted for a single product, namely, one specific plant variety. Patent legislation contains a provision known as the research exemption under which the use of a patented invention for experimental purposes does not infringe the patent. The experimentation is permissible only to satisfy research needs and not for commercial purposes. Unlike PVR, nothing like farmer's privilege is ever granted by patent protection.

An important feature of the patent system is the concept of dependency. For example a patent claim on a process to transform corn, although perfectly patentable in its own right, might fall within the constraints of claims of another independent patent directed towards a process to transform monocotyledonous plants in general. In that case, commercial corn transformation would require the consent of the owner of the patent on transformation of monocotyledons. Likewise, to apply his patent to corn, the monocotyledon transformation patent owner would require the consent of the patent owner of corn transformation.

Recent developments

Patents on plants, plant varieties, seeds, etc. are allowed in the U.S. whereas the situation in Europe is somewhat different. Recent decisions from the European Patent Office (EPO) make clear that claims on plants not conforming to the traditional criteria of plant varieties are allowed. The proposed Directive on the Legal Protection of Biotechnology Inventions of the Commission of European Communities aims at defining:

1) The patentable subject matter in the plant field.
2) The scope of protection conferred by a patent to a transgenic plant.
3) The relationship with the PVR system.

According to the current draft of the proposed Directive,plants, except plant varieties as such, are patentable subject matter. Furthermore the protection of a product consisting of a piece of genetic information extends to all products in which this piece of genetic information is incorporated. Similarly, a claim to a plant with particular properties covers any such plant and all its descendants. Moreover, protection of a biotechnological process for production of transgenic plants covers not only the product directly obtained by the patented process but also all its descendants.

The proposed Directive also addresses the relationship between the patent system and the PVR system through a compulsory licensing system. Any PVR holder is granted the right to a patent license if his variety infringes the patent and if the license would be considered to be in the public interest. Similarly a compulsory license on the PVR to the patentee is also provided for. Compulsory licensing has been seriously objected to by industry.

The proposed Directive contains an amendment which provides farmers the right to multiply and propagate on their own farms seeds obtained from crops cultivated on their farms which themselves were grown using seeds protected by patent. This amendment was introduced on demand of the European Parliament but is strongly opposed by industry.

The emergence of patent rights in the agricultural domain, as a result of biotechnology, has been generally perceived as an intrusion on the existing PVR system, and was initially rejected in agriculture circles. These and other developments led to an initiative to revise the UPOV Convention. The UPOV convention, a multinational treaty for the protection of plant varieties, has been ratified by most industrial countries. In Europe, a proposal to introduce Eureopean Community Plant Variety Rights has also come up for discussion.

The UPOV Convention was substantially revised in March 1991 in order to strengthen the rights of breeders. The revised text has not yet been ratified by the national parliaments of the UPOV member states. An important provision of the revised text is the extension of the scope of the PVR to *essentially derived varieties*. These are defined as varieties that are derived from a protected source variety, and which while clearly distinguishable therefrom, nevertheless retain all the essential characteristics of the source variety. This is aimed at safeguarding the original breeder's efforts in obtaining a specific combination of desirable characteristics in a plant variety against the simple introduction into his variety of a distinguishing characteristic either by means of mutation, repeated backcrossing, gene insertion or otherwise, without changing the overall genetic composition of the variety. The new variety will be dependent on the original variety and cannot be sold without the permission of the original breeder. How the principle of essentially derived varieties will be applied in practice still needs to be determined.

The scope of protection in the revised UPOV convention extends not only to the propagating material, but also to harvested material and products directly obtained from the harvested material. With respect to the farmer's privilege, a provision was introduced which stipulates that each contracting state may impose restrictions in the PVR pertaining to farmer's privilege as per its own requirements.

The seed industry in developed countries is seeking harmonization of PVR and patent legislation. In other words, a uniform and consistent interpretation of existing PVR and patent laws is being sought to ensure optimal protection of plant varieties and biotechnological inventions and to foster the overall innovatory potential and competitiveness of the seed industry. The seed industry expects to benefit from the proposed amendments to IPR.

A detailed comparison of European and American Patent and PVR laws, and the proposed amendments to these laws currently being sought, is given the **Table 6.**

Developing countries

The enactment of strong PVR and patent legislation, similar to that in the industrialized countries, is probably not appropriate for the developing countries, at least in the short term. Any legislation, if enacted, must take into consideration the following:

- Because of the budgetary constraints at both NARS and IARCs, it is important that private sector research in plant breeding is encouraged. Unless there is a mechanism to protect value through some IPR mechanism, such as PVR, it will be difficult to entice the private sector into varietal breeding, seed production, and distribution. The timing may not be right, but eventually if private breeding is to take-off and flourish, some mechanism to provide breeder's rights will have to be created.
- New technologies, such as biotechnology, are patent driven. Because of the high costs associated with their development, it is important that a mechanism is created to protect biotechnological inventions so as to encourage private sector

Table 6. Intellectual property rights in plants - present status and proposed amendments an overview - US and Europe.

	EXISTING LEGISLATION					PROPOSED AMENDMENTS		
	US - Utility Patent	US - PVR (PVPA)	US - Plant Patent (PPA)	UPOV - PVR	Europe - EPC [c]	Europe - Patents Proposed Directive EC [c]	Europe - CPVR Proposal Regulation	Proposal Revision UPOV
Subject matter	Inventions	Plant varieties	Asexually propagating plant varieties (no tubers)	Plant varieties	Inventions	Inventions incl. living organisms	Plant varieties	Plant varieties
Criteria for protectable subject matter [a]	Novel Non-obvious Utility Enabling disclosure	Novel Distinct Uniform Stable	Novel - Distinct Non-obvious Utility Enabling disclosure	Novel Distinct Uniform Stable	Novel Inventive step Industrial application Sufficient disclosure	See EPC	Novel Distinct Uniform Stable	Novel Distinct Uniform Stable
Scope	Claims	Reproductive material	Claim (only 1) Plant material	Reproductive material	Claims	Claims (for living matter extending to progeny)	Plants, material, products, essentially derived varieties	Plants, material, products, essentially derived varieties
Rights [b]	Negative	Negative	Negative	Negative	Negative	Negative	Positive	Negative
Limitations [d]	Dependency	See UPOV	See US utility patent	Farmer's privilege (implicit) Breeder's right	Dependency	See EPC Farmer's rights	Farmer's privilege Breeder's right Dependency for essentially derived varieties	Farmer's privilege Breeder's right Dependency for essentially derived varieties
Duration	17 years from date of grant	18 years from date of issue	17 years from date of grant	> 15 years	20 years from date of filing	See EPC	> 30 years	> 20 years
Interaction with other IPR	None	None	None	No double protection (exceptions, e.g. US)	No plant varieties	No plant varieties, Compulsory licenses	CPVR is excl. IPR for plants, No double protection	None

a) The novelty concept has a different meaning in patent law and PVR law
b) A negative rights means that the owner of the Intellectual Property Right has the right to prevent others from exploiting that which is protected (and does not automatically confer a positive right)
A positive right means that the owner is entitled to exploit the protected subject matter.
c) Currently all countries of the EC are member of the EPC
d) Most legislation restrict rights by including exhaustion provisions and by prohibiting abuse of monopoly by providing compulsory licenses in the public interest

Abbreviations used :
EPC - European Patent Convention; EC - European Community; PVPA - Plant Variety Protection Act; PPA - PLant Patent Act; UPOV - Union pour la protection des obtentions végétales; PVR - Plant Variety

research in biotechnology.

Transgenic varieties can involve several proprietary rights which will have to be considered before they can be commercialized. This may result in a complicated network of proprietary rights for some products. For example, a transgenic plant variety that is insect tolerant may involved the PVR for the variety, as well as several patents relating to various elements required for the transgenic variety, such as transformation technology, a gene serving as a selectable marker for plant transformation, a gene coding for an insecticidal protein, and various regulatory elements and modifications needed to adequately express genes in plant cells.

Table 7 shows how such a variety could be dependent on eight different proprietary rights, each possibly owned by a different party. Prior to commercialization of such a transgenic variety, all interested parties with IPRs on the variety will have to come to an understanding as to who is contributing what and how the variety's eventual profits will be shared.

Table 7. Insect tolerant plant variety with multiple intellectual property rights.

Subject	Components	Example	IPR
Plant variety	Germplasm	Protected Variety, e.g. potato	PVR
Selectable marker gene	promoter	35S	patent
	coding sequence	neo	patent
Trait	promoter	TR	patent
	coding sequence	bt2	patent pending
Transformation technology	Ti-plasmid	pGV2260	patent
Gene Expression technology	Transcription initiation	viral leader	patent pending
	Translation initiation	Joshi	-
	Codon usage	AT-> GC	parent pending
	Number of different IPRs		8

Since a new protected variety is likely to be dependent on IPRs owned by different parties, recognition that "value added" must be shared between the owners (seed companies, biotech companies, breeders and others) is beginning to evolve. with the enactment of patent legislation for plants we can expect that the complexity and the cost of doing seed business will increase significantly, as will the likelihood of litigation.

It is therefore important that proposals for IPR legislation in developing countries should consider the following:

- Progress in breeding has been possible because of free access to germplasm from all sources. Further progress in breeding will be based upon current germplasm, so that restricting its access will adversely affect overall breeding progress. Furthermore, restricted access can lead to loss of genetic diversity, whereas increase in genetic diversity is the desired and accepted goal worldwide of agriculturists and environmentalists. The breeder's exemption therefore should be maintained in any IPR legislation.
- Over centuries, the farmers in the developing countries have played a critical role in conserving land races, which after domestication have served as the basis

for crop improvement programs. It is fair that they are not denied the reward for their past efforts. Therefore, any legislation which restricts them in saving their own seed for future plantings should be avoided. The farmer's privilege should be maintained in any new or amended IPR legislation.

- The seed companies in developing countries are typically small family-owned businesses. Unless IPR legislation is kept simple, and its implementation cost effective and economical, small companies can be driven out of business by MNCs who have easy access to patent attorneys, a strong tradition of technology protection, and experience in litigation.
- Developing countries need technology and know-how. Development requires appropriate transfer and absorption of technology. IPR legislation can possibly hinder the flow of technology, particularly biotechnology, from IARCs. Some recent agreements between at least one private sector company and the IARCs stipulate royalty free rights to the IARCs for the developing countries where there is no patent law. The private company has exclusive rights for commercialization in countries where patent rights exist. This could be a model for future agreements.
- The seed business is in varied stages of development in different countries. Legislative proposals should take into consideration the technology level of the country, the availability of trained manpower, and the specialized institutions required to implement IPR laws. Without proper implementation, IPR legislation only leads to further bureaucracy.

Recovering value

Unless certain minimal requirements on costs and revenue are met, the private sector will have no long term incentive to stay in the seed business. The 1989 survey conducted by the American Seed Trade Association (ASTA) of the U.S. seed industry shows that if the cost of goods sold (COGS) for hybrid corn seed is over 60%, a seed company cannot be profitable or only marginally profitable. A private company needs at least 48-52% gross margin to be in business and show an acceptable return on sales.

The price, cost, and profit structure required by the private sector seed industry can be seen in **Table 8.** Payment to seed growers is a major seed production costs, accounting for approximately 45% of COGS (**Table 9**). To undertake seed production, growers must be assured of at least 25-30% more revenue than would be earned by producing and selling the crop as a commodity. If seed yields are low, growers are paid an even higher premium (the row ratio of female to male parents, and the yield of the male parent are taken into account when compensation to growers is fixed).

Table 8. Hybrid crop profit and loss structure desired by industry.

	%
Net sales	100.00
Cost of goods sold	48.00
Gross margin	52.00
Selling expenses	15.00
G&A	15.00
R&D	7.50
Net operating income	14.50
Non-operating income	1.50
Total income	16.50
Non-operating expenses	1.50
Profit before tax	15.00

Table 9. Average U.S. production cost per unit (50 lbs) of hybrid seed corn.

	COGS (%)
Field	
Grower	45
Parent Seed	10
Rouging, Detasseling	11
Oter	9
Plant	
Husk, Sort, Dry, Shell	9
Quality Assurance	2
Conditioning	9
Freight in	2
Other	3
Total	100

The other 50% of the COGS comprises parent seed costs, transportation, certification, seed conditioning, bags, tags, and other incidental costs. If rouging, quality control and inputs costs are high the resulting COGS can jeopardize the feasibility of the business. In order to reduce the COGS, an increase in the yield of the female parent through higher seed yields is essential. In corn, if the female parent is made male sterile through genetic engineering as demonstrated by Plant Genetic Systems of Belgium, or through the use of cytoplasmic male sterility (if it is not linked with disease susceptibility) then cost can be saved.

Farmer's benefit

Farmer benefit is a function of the value added to improved seed. Seed companies can theoretically change an amount up to, but not exceeding, the value they add. The farmer should not get less than 3 times (preferably 5 to 6 times) the return on his investment in seed. Depending upon the complexity of the cross and the amount of value added, hybrid seed is generally priced at 10 to 30 times the value of the crop's commodity price. This price structure can give acceptable gross margin to the seed company if COGS is kept at 48-52% of the net price.

Growth limitations

Major constraints to the hybrid seed industry in the developing countries include the following:

- Hybrid technology constraints. Technology for making some key crops hybrids may not be economically feasible;
- Low heterosis, low female yield, high input costs;
- Complicated variety notification and registration procedures;
- Complex seed legislation;
- Unfair competition due to seed subsidies to public sector;
- Restrictions on seed exports/imports;
- Restrictive quarantine laws;
- Restrictive investment laws;
- Inadequate sources of long-term financing;
- Inadequate refrigerated storage capacity;
- Infrastructure limits on markets for inputs and outputs.

Capabilities

Despite these constraints, there are opportunities for growth in the seed industry in developing countries. Growth could be optimized if unduly restrictive constraints are removed or modified. A few lessons can be gleaned from the history of the global seed industry over the past 25 years.

- Flexible dynamic management is critical to success;
- Success is more likely when building onto an existing successful program;
- Private sector commitment is directly related to a product's gross margin; the higher the margin, the greater the commitment;
- Seed growers are more involved and effective when their share in the profit is assured;
- Repeat business is possible only if the farmer's return on investment is high ($3-$5 for each $1 spent);
- Strict quality assurance is indispensable for success;
- Capital intensive projects are often neither necessary nor appropriate (so-called "white elephants") in the developing world;
- Seed production must be linked to seed demand in order to manage inventories properly;
- A long term perspective is essential for success;
- Timely availability of seed in areas of use in critical.

Creating success

While seed is a small part of total farming costs, it has greater influence on productivity than any other input. Most good farmers understand the value of high quality seed. They are willing to travel considerable distances, and are willing to buy in advance, to ensure they get quality seed.

Since most farmers in developing countries operate at a subsistence level, it has been said that they lack the resources to utilize hybrid seed. There is indeed reluctance on the part of the farmer to pay high prices for hybrid seed. Traditionally, farmers have used open-pollinated varieties, not hybrids. The former are, of course, a much cheaper input.

However, the experience of one of the leading seed companies in India (Proagro Seed Company Ltd.), suggests that there is reason to doublt this accepted wisdom about farmers in developing world. Except for 1993, Proagro's biggest constraint in the past five years has been to get enough hybrid seed produced to meet demand. Proagro's biggest constraint in the past five years has been to get enough hybrid seed produced to meet demand. Proagro's bottleneck has not been in creating demand, but rather in ensuring enough supply to meet demand for hybrid millet, sunflower, corn and sorghum seed. Approximately 1/3rd to 1/4th of the company's sales are made prior to even undertaking production. From the seed company's point of view, the importance of advance bookings is that they provide cash to make seed grower payments without getting highly indebted to banks.

If a seed company is to become successful, farmers must share in the value added (farmer's benefit). The seed grower must benefit by earning more than what he would from a commercial crop. And, the seed company must benefit by earning an acceptable return on investment. Farmers will pay for hybrid seed if it benefits them regardless of its price premium. Farmers in the developing world have centuries of crop growing experience, even if they may lack the formal education of their colleagues in the developed world. Higher input levels are no disincentive to use of hybrids.

Experience has shown industry is capable of providing quality seed to farmers as they need it. Given the prominence of agriculture in the developing world, hybrids could have the same catalytic effect on its seed industry in North America, Europe, and Japan.

As Dr. Sehgal could not attend the Workshop copies of the paper were distributed to all the participants well in advance. Dr. Hallauer coordinated the deliberations on this paper. He informed the group about the IPR laws as present in the U.S.A. Dr. Hess informed the group about the CGIAR's stand on the IPR. Dr. Hess also informed that CIMMYT would opt for patenting its material to prevent others from patenting it.

BREEDING CORN HYBRIDS FOR VIETNAM

P. Padmakar Reddy [1]

Abstract

Corn is grown in Vietnam in approximately 500,000 ha. The country presents 7 different ecological zones and corn is grown in most of these zones. However, there are three broad distinct areas comprising of North, South and the Central highlands. In the North, maize is grown in approximately 300,000 ha. The area comprising both South the Central highlands accounts for the remaining 200,000 ha.

Vietnam's corn growing area is between 8-23^{o} N lat. Based on latitude and altitude it appears to be a tropical and subtropical environment. However, close observation of corn growing conditions in the North makes it clear that subtropical germplasm from other parts of the globe may not adapt directly. High wind velocity, typhoons, viruses, maydis and turcicum leaf blights, waterlogging, low sunshine and continuous rainfall make the northern corn growing area "harsh subtropical" climate for corn. Central and South Vietnam have some similarities with other tropical - subtropical corn growing areas of the world.

Bioseed in Vietnam has screened 600 inbred lines, 268 single crosses, 300 double crosses, 60 populations and 10,000 segregating materials. We have introduced three hybrids which are adapted to the local conditions. Hybrids in the pipeline, are based on lines developed in Vietnam and are expected to perform better than current hybrids being marketed.

Vietnam is predominantly an agricultural country, and most of the nation's economy depends on the agricultural sector. Maize is the second most important cereal crop after rice and it is mainly used as a livestock feed, especially in piggeries and poultry industries. It is also used as a human food in the North mountainous regions and Central highlands.

Vietnam's entire area lies between 8^{o} to 23^{o} N lat. and corn is grown in all parts of the country. The corn growing environments in this country are both tropical and subtropical. However, the country's corn growing areas have been identified in 7 agroclimatic zones (**Fig. 1**). Among these, Zone 3 (Red river delta), Zone 5 (Central highlands) and Zone 7 (South eastern Nambo and Mekong delta) have the most potential for intensive corn cultivation and productivity.

Maize area in 1992 was approximately 457,000 ha (**Table 1**) with national average yield at 1.7 t/ha. The corn productivity of Vietnam is one of the lowest in the world, mostly because large areas are still planted with unimproved local varieties and due to the knowledge of hybrids among the farmers. Corn hybrids were introduced in this country only in 1989-90. It is presumed that by the end of 1993, hybrids will be planted in <10% of the total corn area.

Corn is mostly grown under rainfed conditions, mostly during in the rainy and post-rainy seasons. In a few limited areas of the country, corn is grown in irrigated conditions. The details of the planting seasons of the various maize growing zones is given in **Table 2**.

From the corn breeding point of view, Vietnam represents a challenging and interesting area. Northern Vietnam represents a harsh subtropical climatic zone and subtropical (ized) germplasm may not adapt directly well because of high adverse conditions like high velocity winds, typhoons, waterlogging conditions, acid soils, short day length in the winter season, continuous rainfall, virus diseases, maydis and turcicum leaf blights, etc. The Central and southern part of the country have some similarities with other tropical-subtropical corn growing areas of the world.

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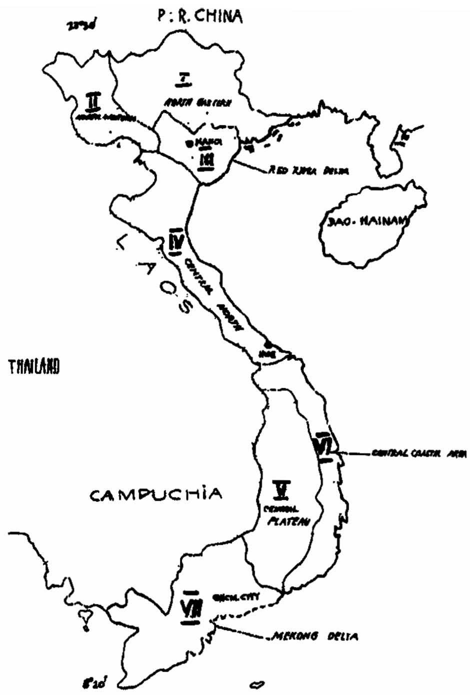

Fig. 1. Seven maize growing areas identified in Vietnam.

Table 1. Area under corn production.

('000 ha)

Area	Year 1980	1985	1990	1991	1992
Northern part	139.2	153.3	155.5	157.8	167.6
Midland	17.9	15.9	28.3	28.9	33.5
Red river delta	35.4	33.7	69.3	67.5	81.5
Zone 4	49.7	38.3	44.9	46.9	52.6
Central highland	37.9	53.5	45.9	43.3	29.2
Central coastal line	38.7	34.1	28.2	28.5	31.4
Eastern Nambo	49.1	57.0	48.5	48.8	48.8
Mekong delta	11.1	11.5	11.2	11.1	12.4
TOTAL	379.0	397.3	431.8	432.8	457.0

Source : Dept. of Internatl. Cooperation, MAFI.

A corn breeding program in this country should have the following objectives:

1. Breeding for high yield with yellow semiflint kernels.
2. Breeding for disease resistance, i.e., maydis and turcicum leaf blights, banded leaf sheath blight, rust and viruses.
3. Breeding for tolerance to strong winds (typhoons) in the North.
4. Breeding for different maturity requirements suitable to the various cropping patterns.
5. Breeding for tolerance to water stress (both drought and waterlogged conditions).

Bioseed in Vietnam has the above five objectives in mind. We believe in location specific breeding and hence have initiated a full-fledged corn breeding program for this country. We are testing different maturity hybrids to fit the different agroclimatic zones and suitable for different cropping patterns.

We have screened around 600 inbred lines, 268 single crosses, 300 double crosses, 60 populations and synthetics and 10,000 segregating materials (10,000 rows). During the initial screening and evaluation of different germplasm in Vietnam, the following observations have been noted:

1. Lancaster group materials show better adaptation and tolerance to *maydis* leaf blight than Stiff Stalk-derived materials (**Table** 3).
2. By visual screening, the race of *H. maydis* present in the country appears to be O type, but this needs further testing and pathological confirmation.
3. Majority of exotic subtropical materials do not adapt directly, due to harsh subtro pical climate.
4. Some of the inbred lines tolerant to foliar diseases otherwise fertile in other tropical and subtropical environments, show either partial or complete sterility in North Vietnam.

Table 2. Corn planting seasons in Vietnam.

Area	Rainfed/ Irrigated	Season	Planting Time
Zone 1	Rainfed	Spring	February
(North eastern)	Rainfed	Summer/Autumn	May-June
Zone 2	Rainfed	Spring	February-March
North western)	Rainfed	Summer/Autumn	June-July
Zone 3	Irrigated	Spring	January-February
(Red river delta)	Irrigated	Summer/Autumn	May-June
	Irrigated	Winter	August-September
Zone 4	Irrigated	Spring	February
(Central north)	Irrigated	Summer/Autumn	May-June
Zone 5	Rainfed	1st crop	April
(Central Plateau)	Rainfed	2ns crop	July
Zone 6	Rainfed	1st crop	December
(Central coastal)	Rainfed	2nd crop	May-June
	Rainfed	3rd crop	July-August
Zone 7	Irrigated	1st crop	April
(Eastern Nambo)	Irrigated	2nd crop	July-August
(Mekong delta)	Irrigated	1st crop	December-January
	Irrigated	2nd crop	March-April
		3rd crop	July-August

Some of CIMMYT's populations and pools have been screened for *maydis* leaf blight under natural conditions. Among these, the late maturity Pop. 28 and advanced lines of Pop. 345 are performing better and are useful in our breeding program. The details of *maydis* leaf blight scores are in **Table 4**.

Achievements:

I. The hybrid Bioseed 9670 has already been released. The main features of this hybrid are:
   * Medium maturity, good for winter, spring and summer/autumn seasons.
   * Widely adaptable and suited to local cropping patterns.
   * Well adapted throughout Vietnam.
   * Showing good performance in lowlands and rainfed conditions.
   * Good root and stalk strength.
   * Has field tolerance to *maydis* and turcicum leaf blights.

* Yield potential of 8.0 t/ha.

II. Hybrid Bioseed 9754 has shown good performance in the South as well as in the Central part of the country. The salient features of this hybrid are:

* Medium-late maturity tropical hybrid.
* Yellow shiny orange flint kernels.
* Tolerant to foliar diseases.
* Uniform and long cobs.
* Yield potential of 10.0 t/ha.

Bioseed is in the process of promoting new hybrids to replace the present 9670 and 9754 hybrids. The new hybrids are expected to perform much better and would be tolerant to foliar diseases. The yields are also expected to be higher than the presently commercial hybrids.

Table 3. *H. maydis* tolerance of Lancaster and Stiff Stalk group lines.

Lancaster Group	*H. maydis* score	Stiff Stalk group	*H. maydis* score 1/
NS1	6	SS1	4
NS2	5	SS2	2
NS3	6	SS3	4
NS4	6	SS4	4
NS5	6	SS5	4

1/ 1 = highly susceptible and 9 = resistant.

Table 4. Reaction to *H. maydis* - CIMMYT corn materials received from Thailand.

Pedigree	*H. maydis* score 1/
Viemyt 49 (HS)	6
Bramyt 22 (HS)	6
SW 3 C4	7
NS 1	6
Advanced lines - Pop. 31	5
Advanced lines - Pop. 145	6
Advanced lines - Pop. 345	7
Pop. 28 (HS)-Bulk	7
Pop. 32 (HS)-Bulk	6
Pop. 145 (HS)-Bulk	6
Pop. 345 (HS)-Bulk	7
EEY x RPP-F1 -Bulk	6
Stalk Rot resistant-Bulk	4
Pop. 26-Bulk	7
Pop. 45-Bulk	6
Pop. 33-Bulk	5
Pop. 48-Bulk	3
Pool 39-Bulk	3
Pool 41-Bulk	3

1/ 1 = highly susceptible and 9 = resistant.

In line with Bioseed's philosophy, we stand for performance difference. We are committed to Vietnam's agriculture in general, and to the farmers growing maize in particular, by introducing and making available to them better quality hybrids tolerant to diseases, adapted to different ecological zones and cropping patters in the country and giving maximum importance to yield and maturity.

CARGILL MAIZE RESEARCH ACTIVITIES IN ASIA

Tunya Kunta 1/

Abstract

Cargill Seeds Co., Ltd. is a subsidiary of Cargill Co., Ltd, the world's largest grain trading firm. Corn breeding research of Cargil Seeds Co., Ltd. in Asia has been carried out in Thailand and Philippines since 1979. Cargill also has testing sites in India, Pakistan, Indonesia, and Japan. the primary objective of Cargill maize research in Asia is to develop high yielding corn hybrids mostly suitable to environmental conditions and farmer practices for the whole Asian region. The existing inbreds have been developed by introgressing the elite germplasm from around the world into the locally adapted germplasm. The resulting hybrids have been tested over several years and environments before being released to the farmers. At present, Cargill commercial hybrids released in Asian countries are C-501 (Thailand, Pakistan, and Indonesia), C-520 (Thailand, Bangladesh, and Philippines), C-633 (India), C-333 (Thailand and Malaysia), C-777 (Thailand, and Pakistan), CPX-3905 (Philippines), C-744 (Thailand) and C-922 (Thailand).

Cargill Inc., USA's biggest private company (Fortune, July 13, 1992), was founded by William W. Cargill in 1865 as a single grain-storage facility in rural Iowa. During the past 128 years the company has evolved into a world leader in the commodity marketing, transportation, and processing industries. In 1993, the company employed 69,000 people in 47 business in over 55 countries.

Breeding research of Cargill Seeds, Ltd. in Asia has been carried out since 1979 in Thailand and Philippines. Cargill Seeds Ltd. is a subsidiary of Cargill Inc. At present, Cargill has two main research stations: Pitsanulok, Thailand and Koronadal, South Cotabato, Philippines. Cargill also has testing sites in India, Pakistan, Indonesia and Japan. The primary objective of the two main research stations is to develop corn hybrids that are suitable to environmental conditions and farmer practices not only for Thailand and Philippines, but also for the whole Asian region. Elite germplasm from around the world including tropical, subtropical, and temperate zones has been introgressed into the locally adapted germplasm in Thailand and Philippines. The products of the introgression are the adapted inbreds giving genetic constituents of the elite germplasm around the world especially the subtropical germplasm. The adapted inbreds with high combining ability are crossed with other promising inbreds to make new hybrids. The resulting experimental hybrids are primarily tested over different environments in Thailand and Philippines. The promising and precommercial hybrids are then tested over several locations in Thailand, Philippines, India, Pakistan, Indonesia, and Japan. These tests are conducted at Cargill satellite stations and testing sites by Cargill researchers. The precommercial hybrids have also been tested in Vietnam, China, and Malaysia via CIMMYT. Specific hybrids that have been tested over locations and years and that have proved to be suitable to each country are then registered and released to farmers. Cargill hybrids that have been released in Asian countries and still in the market for 1993 are described below.

Cargill 777 main characteristics are: High yield potential (mean yield of 8.0 t/ha with maximum of 10.6 t/ha), wide adaptation, long ear, excellent tip filling, good standability, high shelling percentage, and easy to harvest. Cargill 744 and 922 are our latest releases for Asian countries. Cargill 744 has high yield potential (similar to C-777), high level of disease

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1/ Crop Res. Manager, Cargill Seeds Ltd., 6-7th Floor Chokchai International Bldg., 690 Sukumvit Rd., Bangkok 10110, Thailand.

resistance, especially to sorghum downy mildew, common rust, and leaf blights, fast dry down of the mature ear, and is easy to harvest. Cargill 922, a single cross, has a high yield potential (mean yield of 9.0 t/ha with a maximum of 11.5 t/ha), good uniformity for plant height and ear size, similar level of disease resistance as C-744, long ear, good tip filling, and is easy to harvest.

Hybrids	Days to mature	Countries and year released
C-2525	105-110	Indonesia (1983), Thailand (1982). Removed from the market in 1985.
C-501	95-100	Thailand (1989), Pakistan (1992) Indonesia (as C3, 1993)
C-520	100-105	Thailand (1992).
C-633	105-110	Thailand (1992). Removed from the Thai market in 1993. India (1993)
C-333	105-110	Thailand (1989)
C-777	105-110	Thailand (1991), Pakistan (1992)
C-733	110-115	Thailand (1992)
C-757	95-100	Indonesia (1992)
CPX-3905	95-100	Philippines (1993)
C-744	100-105	Thailand (1993)
C-922	105-110	Thailand (1993)

Our annual research budget in Asia exceeds US$ 1 m dollar. We employ more than 10 breeders and 50 agronomists in the region to carry out our research programs. Our corn hybrids are well known throughout the Asian countries where we are gaining a seed market share, especially in Thailand.

We will continue to grow and hopefully in the near future our hybrid corn will be a prominent hybrid also for Vietnam.

Questions to the author:

FROM : F. Kasim
Q : What is the policy of private sector for hybrid development targeted to marginal environment such as acid soils?
A : Develop germplasm tolerant to Al. toxicity (Brazil), backcrossing to local lines, putting them in hybrid combinations in Thailand, and sending hybrids to test at acid areas.

FROM : A. Hallauer
Q : Two parts: 1) What is the "half-life" or length of time a hybrid is marketed?
2) Is it different from hybrids marketed in North and South America.
A : In Thailand a hybrid only lasts 2 to three years, where as in North and South America good hybrids last 5 to 6 years. The rest of Asia is like North/South America in product life cycle.

RESEARCH AND POTENTIAL OF HYBRID CORN IN ASIA

Poomsan Silpisornkosol [1/]

Abstract

Charoen Seeds Co. is part of the Charoen Pokhan Group and DeKalb Plant Genetics. In 14 years of activity and research, a total of six corn hybrids have been released. This paper describes the installations the institution possesses in Thailand and where research is being done throughout Asian countries.

Corn is one of the important cereal crops in this region in addition to rice and wheat. However, in recent years there has been a surplus of rice production along with a trend of less consumption of corn as human food especially as living standards improve. Corn is used as a major feed ingredient for poultry and swine, and in certain areas it has potential use for feed of dairy and beef cattle. These animal products could be further processed as value added products either for domestic consumption or export markets. In Thailand, corn production has been successfully used to replace irrigated rice during the dry season due to limitation on available irrigation water.

Corn hybrids have been introduced to major corn growing areas in Asia as an important tool to increase corn production, and have been well accepted in many countries such as China, Japan, Korea, Taiwan, Thailand, Philippines, India, and Indonesia.

Corn hybrids which are suitable for these regions should posses the following characteristics:

1. High yield potential
2. Pest resistance
3. Drought stress tolerance
4. Good standability
5. Good grain quality suitable for animal feed (free of aflatoxin)
6. Early maturity to allow an additional crop.

Charoen Seeds Co., Ltd. was established in 1979 as a joint venture between the CP Group of Thailand and Dekalb Plant Genetics from the USA. The purpose of this joint venture research company is to develop corn and sorghum hybrids adapted to Thailand and other areas in Asia and Indochina. The CP Group, which has long experience in agricultural business in this region, will produce, process, and market seeds while Dekalb Plant Genetics will provide technology and germplasm for research. Besides the seed business, the CP Group also provides and markets other related agricultural inputs such as fertilizers, pesticides, and agricultural equipment. During 14 years of this successful joint research, the company has continuously released improved hybrids as presented in Table 1. Dekalb Plant Genetics, with a long history of corn research, allows access to germplasm which is available through Dekalb's corn breeding programs around the world. This germplasm is very useful in developing hybrids with special features and reduces the time to develop hybrids. Useful germplasm comes from the USA, Argentina, Brazil, Mexico, and other countries. Some of this germplasm can be used directly, while some others require adaptation. Germplasm from the USA has shown excellent potential for earliness, lower ear placement, root and stalk quality, and desirable plant type.

Our research farm is located at Muak-Lek district, Saraburi province in the upper central region of Thailand with more than 200 rai (32 ha) of research land and a fully equipped irriga-

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[1/] Research Manager, Charoen Seeds Co., Ltd., 36 Soi Yenchit, Chand Road, Yannawa Bangkok 10120, Thailand.

tion system which allows research to be carried out throughout the year. Testing of new hybrids is done throughout various growing areas in Thailand. The CP Group has three major seed production farms located in Saraburi, Kampangphet, and Chiang Rai respectively, with a seed processing plant located at Pattananikom, Lopburi.

Germplasm from other institutes such as CIMMYT, Kasetsart University, and the Department of Agriculture have proved to be useful for inbred development.

Table 1. List of corn hybrids commercially released in Thailand by Charoen Seeds Co., Ltd.

Year	Hybrid	Description
1981	CP 1	Good yield potential
1985	CP 707	Good yield potential
1989	DK 811	Good yield potential, uniform
1990	DK 211	Short and early, good yield potential
1991	DK 222	Short and early, good yield potential, good rust resistance
1991	DK 888	Very uniform, excellent yield and grain quality and free of grain mold.

In addition to Thailand, we also extensively test our hybrids in Indonesia. At present we have two corn hybrids available in Indonesia, CPI-1 and CPI-2. CPI-1 has been in the Indonesian market for more than six years, and it is full season in maturity. CPI-2 was released for the Indonesian market in 1992 and is expected to be well accepted because of its earlier maturity, suitable for many corn producing areas in Indonesia.

We are also conducting preliminary yield evaluations of our hybrids in Vietnam, Laos, Kampuchea, and Myanmar. When important issues have been settled, we hope to launch our corn hybrids in these countries.

Questions to the author:

FROM : R. S.Paroda
Q : What is the percentage of single cross in Thailand?
A : 80% in single cross, 20% in three way cross.

FROM : Firdaus Kasim
Q : What is the policy of private sector for hybrid development targeted to marginal environments such as acid soils?
A : We do not have the program aim for that environment yet but if there is a potential and the area is necessary for production we would certainly consider it seriously.

CIBA SEEDS IN SOUTHEAST ASIA.

Jose Valmayor [1]

Abstract

Ciba Seeds is part of Ciba Geigy Co. with headquarters in Switzerland. Ciba Seeds entered the seed market in the 1970's and is now one of the three top corn seed selling companies in Thailand. The paper describes the facilities it possesses in Thailand and its testing activities throughout Asian countries.

It is my pleasure and a great honor to address this illustrious audience today on "Ciba Seeds in Southeast Asia". Firstly, I would like to thank the organizers, CIMMYT, and the Ministry of Agriculture and Food Industry of the Soc. Rep. of Vietnam, for giving my company this opportunity. CIMMYT regional conferences on maize have for many years played an important role in disseminating information and forging connections between key persons in the maize field throughout the Asian region. It comes at a very opportune time that this 5th Asian Regional Maize Workshop should be held in the Soc. Rep. of Vietnam where vast changes are occurring in the economy, and where agriculture for crops such as rice is already competing successfully on an international scale.

Ciba Seeds worldwide

I would like to start by telling you a little about our company worldwide. Ciba-Geigy is a Swiss based multinational chemical company with headquarters in the city of Basel. Ciba is strong in the fields of textile dyes and chemicals, plastic additives, polymers, pharmaceuticals, agrochemicals, and seeds. Our total turnover in 1992 was about 22,000 m Swiss Francs. This revenue places Ciba among the top 100 highest private companies in the world. At Ciba, we try to provide useful solutions to our customers through technology. So, in a way we are like a "hybrid" between businessman and scientists.

The agrochemical division of Ciba was number one in sales in the world in 1992. Ciba believes that the future of plant protection lies in safer, more convenient, and more environmentally friendly technologies and products in the future. Biotechnology and genetic engineering will help make these new plant protection requirements a reality. And the avenue for introducing these new products will be seeds. This is why Ciba entered the seed business in the early 1970's ment stations all over the world using conventional breeding techniques to develop corn hybrids that suit farmers needs. Ciba also has 2 biotechnology research centers using new genetic engineering techniques to make corn hybrids with resistance to diseases, insect pests, and herbicides. Aside from maize, we also carry out research on hybrid wheat in the United Kingdom, and do research on and sell sunflower, soybean, and sorghum seed in various countries. Ciba Seeds is one of the top five maize seed companies in the world.

Now let us look a little closer to home. Southeast Asia yearly plants almost 9 m ha of maize. This region is home to 450 m people and has some of the most dynamic and fastest growing economies in the world. Furthermore, most maize farmers in Southeast Asia do not use hybrids yet and this presents a tremendous opportunity for farmers to improve their incomes and for seed companies to meet their needs profitably. Southeast Asia is therefore an interesting maize seed market for several seed companies including Ciba.

Ciba Seeds entered the seed business in Southeast Asia with the concept of setting up a large breeding center in one optimal location, and conducting extensive off-station trials to

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[1] Seeds Business Manager, Ciba-Geigy (MPL) Ltd., 159/30 Vibhavadi Rangsit Road, Don Muang, Bangkok 10210, Thailand.

develop maize hybrids that meet the real needs of farmers in the region. Our philosophy is that we must offer something that is good for the farmer as well as good for ourselves, or create a "win-win" situation.

Thailand is the home of our maize breeding center where hybrid development work began in 1981. We have a 36 ha irrigated farm in Nakhon Sawan province where we use local and international germplasm to develop maize hybrids that are high yielding, lodging and disease resistant, drought tolerant, and possess other traits that maize farmers need. We also have our own seed processing plant in Lopburi province. When seed companies began selling hybrids in Thailand in the early 1980's, many people doubted that Thai farmers could afford hybrid seed, or whether hybrids would be worthwhile for the farmer. However, after planting hybrid maize seed with adequate inputs, farmers discovered that their yields and incomes can reach almost twice as much as when they use improved open pollinated seed or Suwan seed. As a result, maize hybrid seed now accounts for 30 to 40% of total maize seed used in Thailand and continues to grow. So far, Ciba hybrids have been well accepted by Thai farmers. From our first commercial sales in 1987, we now are among the top 3 suppliers of hybrid grain maize seed in Thailand. Ciba Seeds has also been very successful at developing hybrids for baby corn, the immature corn cob that is eaten as a vegetable. Now we are the top supplier of hybrid baby corn seed in Thailand. We are very happy with the role that Ciba has been able to play in helping Thai farmers.

Economic development in Southeast Asia has also brought changes to the grain maize industry. Increasing populations with higher incomes are consuming more and more meat and dairy products, meaning higher demand for maize for animal feed. On the other hand, as countries develop, their labor rates increase and traditional maize exporters now find they must serve local markets first, while new countries are becoming maize exporters. All this means maize farmers have to become more productive. And since the amount of land planted to maize in most countries most probably cannot be increased, maize farmers in this region will have to turn to hybrids to increase their yields and incomes. In this changing market place, Ciba Seeds is seeking to service the growing needs of maize farmers in the neighboring Asian countries. Our principle for these new markets is the same: 1) that hybrids from our breeding program should be well tested in the countries where the product will be grown to make sure they meet farmers needs and 2) we must offer maize farmers a proposition that is good for them and as well good for us, or create a "win-win" situation.

Ciba Seeds is now testing its maize hybrids in the Philippines and Vietnam, and we hope to start soon in Indonesia. Although we may not be as far ahead commercially in the region as other seed companies, we know there is always an opportunity for companies with good products and a fair approach. And we look forward to the day when we can play a significant role in helping maize farmers in these countries as we already do in Thailand.

ACTIVITY OF MAHYCO IN INDIA

Rajendra R. Deshpande [1]

In 1963 farmers tilled and toiled. The land was dry and dusty, bare and barren, the farming techniques were ancient and seeds indifferent. It was at that time that Mr. B. R. Barwale transformed their world after successfully launching the hybrid maize seeds with the assistance of Dr. W. H. Freeman, an expert in this area.

It was on November 24, 1964, that Maharashtra Hybrid Seed Co. (MAHYCO) was established in India as the first private organization in the field of commercial seed production.

The Green Revolution in India has indeed been ushered in by the seed improvement program. Introduction of high yielding varieties and hybrids has achieved a successful breakthrough. The hybrid seed miracle has demonstrated the possibilities of exploiting plant vigor to increase yield. For the last three decades, development of products suitable for Indian markets and Indian agricultural conditions has been made possible by the research and demonstrations carried out by Mahyco, the torch bearer of the Indian Seed Industry.

Mahyco, a breeding research company, was established in symbiosis with the Green Revolution and it has developed a special niche in the seed industry by strengthening its commitment to science and technology.

Mahyco's first research center was set up in 1966. At present six genetic research centers staffed with professional scientists have pioneered many remarkable innovations in producing advanced hybrid seeds in 35 different crops. Shortly we will be adding products in wheat, sesame, castor bean, and most important, in paddy. Mahyco has given the Indian farmer his first ever hybrid cotton seed based on a well-known technique that utilized both genetic and cytoplasmic male sterilities. This has proved to be economical and practical.

India was the first country in the world to produce cotton hybrids exploiting both genetic and cytoplasmic male sterile systems.

Mahyco's research activity has in fact been encouraged by the Government of India, scientific institutions, and commercial firms.

In the past two years, Mahyco has been honored with many prestigious awards, of which the most prominent are:

- A National Award in recognition of Mahyco's contribution on R & D efforts to India's agricultural sector.
- Award of the Federation of Indian Chambers of Commerce and Industry (FICCI) in recognition of Mahyco's corporate initiative in research involving science and technology.
- An international Seeds and Sciences Technology Award in appreciation of Mahyco's effort to promote agricultural progress.
- During the Silver Jubilee celebration of the Indian Society of Genetics and Plant Breeding, a special award was delivered by the Society to Mr. B. R. Barwale for his valuable contribution through Mahyco's research in the field of Plant Breeding.

Mahyco conducts research on 35 field crops and has released 127 hybrids in different crops cultivated throughout India.

Mahyco offers the following range of high yielding maize hybrids to the farming community of India:

a. Very early maize hybrids which mature in 80-85 days in kharif season. These are MEH-114 and MEH-115 which yield 5-6 t/ha.

b. In intermediate maturity group with 100 days to maturity, we have developed high yielding, disease tolerant hybrids with yield potential of up to 6-7 t/ha. These are MMH-65, MMH-66 and MWM-107.

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[1] Maize breeder. Maharashtra Hybrid Seeds Co., Ltd. 19 Rajamahal, 84 Veer Nariman Road, Bombay 40020, India.

c. In full season maturity group, with 120 days to maturity, we have developed to hybrids with a yield potential of 7.5 t/ha. These are MMH-25 and MMH-69.

Every year we distribute our hybrid maize seed to be planted in 40,000 ha, out of which 1,500 ha were planted with sweet corn hybrid seeds. We are marketing a total of 30-35 t of such sweet corn hybrids. Additionally, Mahyco has a good hybrid popcorn for Indian farmers. We are screening approximately 900 new hybrids per year to select the ones with highest yields and multiple disease resistance. Screening for disease resistance is done at hot spots wherever they are located in India.

Mahyco has approximately 750 high quality, devoted staff. They feel "a belongingness to the organization" that has helped the organization to reach the status it occupies now.

Mahyco today is the largest seed company of Indian origin with a strong marketing organization assisting farmers throughout India. A total of 13 marketing centers in various states coordinate sales/distribution of seeds over 5000 dealers who provide technical after sales service.

On behalf of Mahyco I am thankful to CIMMYT scientists for their help in continuous supply of maize populations, inbreds, and technical guidance. I am also thankful to IARI scientists, particularly Dr. N.N. Singh, for his support in the evaluation of commercial hybrids through the national program and his own support to institutions in the private sector.

Finally I am also thankful to Dr. Carlos De Leon for giving me the opportunity to talk about Mahyco in this Fifth Asian Regional Maize Workshop.

PACIFIC SEEDS - PLANT BREEDERS FOR ASIA

Peter Thompson [1/]

Pacific Seeds has been operating in Asia and the Pacific for more than 30 years.

Our main crops are hybrid maize, hybrid sunflower, hybrid grain sorghum, and hybrid forages for animal feeding. We have active breeding programs in these crops, and also in hybrid canola, soybean, pulse crops, and winter cereals. It has been our honor to introduce many of these crops to Asian countries, and to successfully develop domestic and export usage of the resultant crop produce.

In a number of instances, we have directly linked the supply of seed against export of resultant produce.

As part of the Zeneca group (ICI's biotechnology company), Pacific Seeds uses "hi-tech" breeding methods involving RFLPs (genetic fingerprinting). This has led our group to be the first to sell commercially herbicide tolerant hybrid corn. (This was the 1991/92 release in USA of imizadoline-tolerant maize).

As part of our scientific approach, Pacific Seeds has been able to gain good understanding of the farmer's field level. This has developed in our company a practical outlook, so you will often find us bringing new solutions and new crops to the frontier of development in Asia.

In this paper, we would like to explain some of the philosophies and policies of the company, and to tell you something of our corn program.

Development philosophies and policies in Asia.

Pacific Seeds is foremost a service company, using high-technology breeding systems to release, produce, and market hybrid seeds for the Asian farmer.

A. **Market focus.**

While we are a company which spends an excess on biotechnology in Zeneca, we know that the first question the farmer asks about new varieties is "where are the markets?" For this reason, we strive to ensure that our hybrid seeds meet high domestic and international standards, and that buyers are waiting for the crop produced by the farmer.

Besides, we realize that modern crop hybrids often need exacting growing conditions, and require correct application of fertilizers and other agricultural chemicals. Thus, you will find that we employ experienced technical advisors, and team with specialists from other companies to ensure that the farmers get the best advice for the complete growing "package".

It is our experience in Asia that small farmers with low availability of capital are usually highly risk averse. Any recommendation to increase their investment (such as the use of hybrid seed), means a perceived increase in risk. To overcome the reluctance to adopt new technology produced by this risk aversion, we need to look carefully at the farming systems to understand:

1. What are the sources of risk (e.g. drought in rainfed conditions, agricultural slumps, falling market prices, etc.)?
2. How to overcome risk aversion (e.g. by showing high benefit: cost ratios, by introductory pricing system, etc.)?

B. **Exacting standard.**

As Asian farmers move into market economics, both we and they are pressured to meet higher standards. The present day commerce says that farmers must be competitive across international borders, and for a seed company like Pacific, we also must be competitive in all the countries where we operate.

[1/] Technical Services Manager. ICI Pacific Seeds (Thai) Ltd., P.O. Box 15, Phraphuttabat, Saraburi 18120, Thailand.

Farmers must constantly strive to meet higher standards for production, to maximize yields, and to minimize their cost of production.

A company like Pacific must ensure the high quality of the seed it sells, and of the sales and "after-sales" service.

Functions of Pacific Seeds.

Our main functions in Asia are:

1. Breeding : We are active from Turkey in the West, to Japan in the East.
2. Production: We produce directly or with partners at more than 7 strong production bases in Asia and the Pacific.
3. Processing: We designed the VIAPAC long-life seed packaging to ensure that farmers get fresh, vigourous seeds.
4. Marketing: We have strong farmer-centered marketing throughout Asian countries for the principal field crops. Our marketing staff are highly trained in technology of crop production.
5. Industry-building: It is a key point of Pacific policy to build strong crop indus tries, in which we can then play our role.

C. Pacific corn in Asia.

Pacific Seeds are actively involved in corn improvement throughout Asia, from Turkey to Japan. We are fortunate in being able to use our Zeneca (ICI) Seeds global network for consultation, advanced genetic biotechnology, and to speed up plant breeding and seed increases.

Pacific Seeds places strong emphasis on breeding for high yield under stress conditions. Stresses which are common are:

a. Moisture stress: In Asia, a lot of corn is produced in the semi-arid tropics, where rainfall distribution is erratic.
b. Heat stress: Some countries in the region experience temperatures in excess of 40 C.
c. Light stress: In the humid tropics, cloudy skies represent less than optimum solar radiation.
d. Flooding: High intensity storms and tropical depressions often lead to temporary flooding of upland maize crops.
e. Nutrient stress: In the past, Asian farmers have often applied low levels of nutri ents to maize, and natural fertility has decreased.

D. Diseases and pests.

Resistances are also central to our program. In fact, we are fortunate that good genetic resistance is available to nearly all serious pests and diseases of maize in Asia. Often, incorporation of resistance can be complemented with use of integrated pest management programs, and prophylactic fungicide treatments.

Selected planting patterns and agronomic practices are also being used to ensure that farmers obtain best results from the levels of disease and pest resistances in their maize hybrids.

Export quality grain is a very important consideration in the Pacific Seeds programs. Because of our strong involvement with corn produced in Asia for nearly 20 years, we know that todays corn importer may be tomorrows exporter, and that export markets will pay a premium for Asian flint corns. This is why you will find all Pacific Seeds corn (and sorghum) hybrids have export quality grain.

In summary, Pacific Seeds is an Asian seed service company, approaching the final customer, the farmer, with a market orientation. In the past 30 years we have developed technology which works well at the small farmer level, and yet comes from some of the worlds most advanced biotechnology research. Because of this, we can invite your to join with us in "growing for a better future".

Questions to the author:

FROM : R. S. Paroda

Q : Could you indicate the volume of your efforts on corn hybrids in this region and any rough idea about percent area coverage under your hybrids in these countries?

A : Pacific Seeds works from Turkey through to Japan in Asia and works in a lab at low value developing markets. We have significant market share in India, Pakistan, Bangladesh, Thailand, and Vietnam.

PIONEER AND THE SEED BUSINESS IN THAILAND

Weerasak Doungjan [1/]

Abstract

Corn area in Thailand is approximately 1.5 m ha and seed requirement about 28,000 t annually. Maize production is largely concentrated in the Thai Corn Belt located 150-250 km North and 200 km East of Bangkok.

Pioneer Hi-Bred International, Inc. (PHI) established Pioneer Hi-Bred (Siam) Co., Ltd. (PHS) on January 4, 1980. PHS is a research company with responsibilities for sorghum breeding and testing of corn hybrids. P.6181 was the first Pioneer corn hybrid in Thailand. It was produced and distributed by Siam Seeds Co., Ltd. in 1981. Super Seeds Co., Ltd. became producer and distributor in 1982.

Pioneer started breeding corn in Thailand in 1983 and also maintained a sorghum breeding program. PHS changed its name to be Pioneer Overseas Corp. (Thailand) Ltd. (POCT) and in 1985 transferred the sorghum breeding program to Pioneer Overseas Corp. (Philippines) Co., Ltd. POCT concentrated on breeding corn and became a testing site for sorghum.

The marketing company for Pioneer in Thailand is Pioneer Hi-Bred (Thailand) Co., Ltd. (PHT) and was established in 1985. PHT has sales activities in the Thai Corn Belt and the production team includes a processing plant and seed production fields in Lampoon and Chiang Mai provinces, respectively. The headquarters of the company are located at:

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Introduction

Thailand is an exporter of food and other agricultural products. Thailand has been exporting grain corn for the last 10 years except in 1992 when corn had to be imported for the feed mill industry. The corn area has decreased due to an increase in sugarcane acreage and drought effect on corn yield as well. At the present, the corn area in Thailand has decreased from nearly 2 m ha to 1.5 m ha and the seed requirement has been reduced from 40,000 t to 28,000 t.

Seed center

There are several international seed business companies in Thailand such as CP-DeKalb, Cargill, ICI-Pacific, Ciba Geigy, and Pioneer. In the early 1980's several local companies produced and distributed Suwan 1, the recommended variety from Kasetsart University. But this is not a good business any more because Suwan 1 is too common and can not compare to the hybrids even under drought stress. Presently several local companies like Thai Seeds Industry and Original Marketing have stopped their activities on seed production. One outstanding local company today is UniSeeds.

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Just start

In 1980 the demonstrations of Pioneer hybrids were conducted by Siam Seeds, which was the producer and distributor in Thailand. It was very hard to convince farmers to grow hybrids instead of Suwan 1 at that time, even if these were free of charge!

The first commercial hybrid of Pioneer in Thailand was P.6181, but its volume of sales was very limited. This hybrid was developed by Pioneer in the Philippines. Siam Seeds marketed P.6181 in 1981 (**Table 1**).

Table 1. The Pioneer corn hybrids in the Thai market.

Hybrid	Year market	Origin	Merit traits	Remarks
6181	1981	Phil	Tol. to stress	Removed from the market.
3228	1986	Phil	DMR, late planting	Maintain as baby corn
3272	1986	Thai	Yield, specific adapt.	Removed from the market.
3298	1988	Thai	Early maturity, wide adapt.	Removed from the market.
3276	1989	Thai	Yield, seedling vigor	Replaced 3272
3294	1990	Thai	Yield, uniformity	Removed from the market.
3250	1990	Thai	Early maturity, yield	Replaced 3298
3266	1990	Thai	Baby corn	Removed from the market.
3252	1991	Thai	DMR, yield, wide adapt.	
3264	1991	Thai	Yield, drought tol.	First single cross
3248	1993	Thai	Yield, wide adapt.	Tol. to rust
3256	1993	Thai	Yield, wide adapt.	Replaced 3276

In 1982 the producer/distributor changed from Siam Seeds to Super Seeds. Super Seeds marketed P 6181 throughout the Thai Corn Belt but it was not successful, and only a small volume of seed was sold.

Pioneer decided to establish a corn breeding program in Thailand in 1983, a little later than our strong competitors. We had to work three seasons a year to develop inbreds and hybrids. We had breeding programs in corn and sorghum in the 8 ha of our research station. In 1985 the sorghum program was transferred to POC-Philippines and Thailand became a testing site for this crop.

In October 1984 Pioneer Hi-Bred (Siam) changed the name to be Pioneer Overseas Corporation (Thailand) or POCT.

Our business

In early 1985 Pioneer developed a joint venture company to operate a seed business in Thailand. Pioneer Hi-Bred (Thailand) or PHT was established and endevored to develop a business profitable to farmers and to Pioneer.

The headquarters of Pioneer in Thailand are located in Bangkok. The production team including seed production fields and processing plant are located in Chiang Mai and Lampoon provinces respectively. We divided the Thai Corn Belt into 8 sales regions for the efficiency of marketing management and convenience for Pioneer customers. We have various products, including grain corn, baby corn, sorghum, and sorghum Sudangrass seed (**Table 2**).

Table 2. Pioneer varieties and products in Thailand (Marketed by PHT).

Products	Year								
	1985	1986	1987	1988	1989	1990	1991	1992	1993
Grain	P 6181								
Corn		P 72	P 72	P 72	P 72				
		P 28	P 28	P 28	P 28	P 28	P 28	P 28	P 28
			P 98	P 98	P 98	P 98			
					P 76	P 76	P 76	P 76	P 76
					P 94	P 94			
						P 50	P 50	P 50	P 50
							P 52	P 52	P 52
							P 64	P 64	P 64
									P 48
									P 56
Baby Corn			P 28	P 28	P 28	P 28	P 28	P 28	P 28
Sorghum	P 8199	P 8244	P 8244	P 8244					
		W 8310							
					S 81	S 81	S 81	S 81	S 81
Sorghum Sudan grass					P 988	P 988	P 988	P 988	P 988

Our philosophy to handle seed business is to provide superior products (leader products) to the farmers. **Table 2** shows that PHT has marketed various hybrids to Thai farmers since 1985. We dropped P 6181 from the market and replaced it with P 3272, the first hybrid from POCT. Pioneer has a very good name from this hybrid in terms of yield and tolerance to drought.

The adoption of hybrid corn by the Thai farmers was very slow in the early 1980's but has increased since 1987 (**Fig. 1**). Not only has the response of the farmers to hybrid corn been very positive, but also the competitiveness among seed companies has warmed up. Pioneer has been conservative in terms of increasing sales volume and investment. It takes time to let the products talk. However, we do believe that we will achieve our ultimate target very soon.

Conclusion

Thailand has much space for expansion of hybrid corn. We have an additional 10,000 t of hybrid corn seed waiting to replace Suwan 1. The key for success will depend on how we compete with the strong companies like CP, which has developed well sustained enterprises.

Today, Thai farmers are ready to adopt new technologies for increasing yield (**Table 3**). They need single cross hybrids with high yield potential and are willing to pay more for these. At present Pioneer has enough germplasm suitable to the development of excellent hybrids. Moreover, we have the strong support of Pioneer Worldwide plus the aggressive Pioneer team in Thailand. Well, we are ready to go with the leader! Thank you.

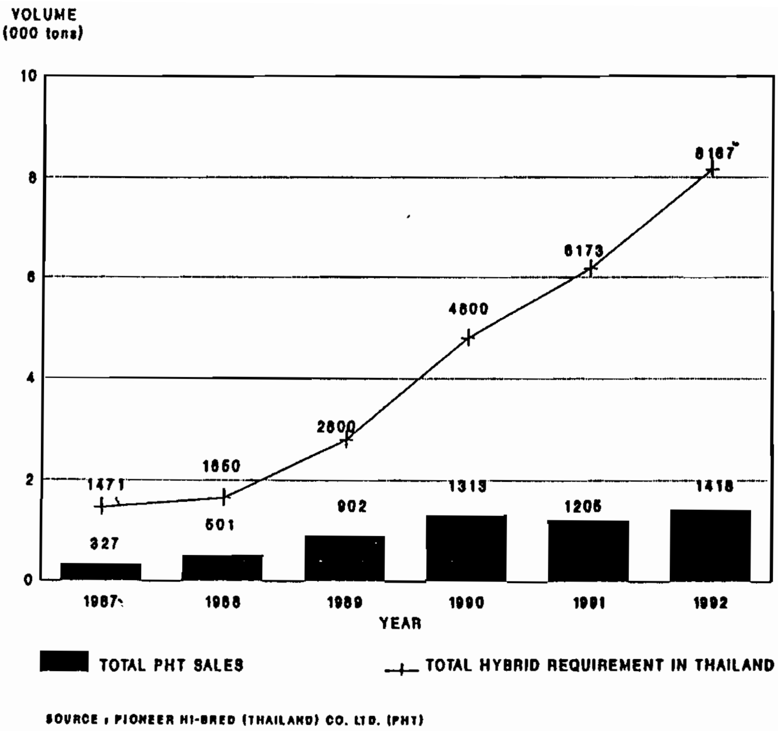

Fig. 1. Total PHT sales and total hybrid requirement in Thailand.

Table 3. Present situation of hybrid corn in Thailand.

1. Highly competitive in product development.
2. Good knowledge among hybrid corn farmers:
   - demand specific hybrid
   - want better hybrid and are willing to pay more.
3. Some mechanized:
   - planting
   - spraying
4. High population density:
   - 62,500 plant/ha
5. Fast adoption of hybrid seed:

Year	Est. tons
1988	1,700
1989	3,000
1990	5,000
1991	6,000
1992	8,000
1993	10,000 (30% of total seed requirement).

6. Adoption of fertilizer:
   - basal application
   - top dressing application.

Questions to the author:

FROM : F. Kasim

Q : What is the policy of private sector for hybrid developtargeted to marginal environments such as acid soils?

A : We need to clarify what we mean by marginal. If marginal means a small area then it will be addressed accordingly, if it is a large area then we will allocate resources needed. Environments are evaluated based on market opportunity and not on the degree of challenge to providing product for that market.

FROM : M. Morris

Q : Does Pioneer have "rules of thumb" for defining potential markets (in terms of minimum area, number of farmers,or volume of seed sales)?

A : No, Pioneer does not have "rules of thumb" for number of farmers, or volume of seed or minimum area. If we can leverage our resources and provide products profitably to farmers, then the "size" is not a determining factor.

FROM : Derek Byerlee

Q : Do you have intellectual property rights for single crosses in Thailand?

A : No, we do not. This matter is in the process of being settled. But we have informal punishment as a social punishment.

FROM : R. S. Paroda

Q : What is the policy of the government for promoting single crosses in Thailand?

A : The trend of hybrid adaptation is single cross (SX) hybrid. So Thai government has to support SX hybrid to produce higher yield, otherwise we will import corn grain very soon.

CONCLUDING REMARKS

(Notes by Dr. V.L. Chidley, Raporteur at the last session)

In the last session of the Workshop a round table discussion was held. Representatives from all participating countries were asked how CIMMYT could help in the work of corn improvement in their respective countries. Participants were also requested to indicate the problems which they want to work on as a national priority. The suggestions were:

Indonesia (Dr. F. Kasim)

1. Needs material resistant to acid soils and downy mildew.
2. Needs material tolerant to Rhizoctonia leaf and sheath blight.
3. Wishes to continue collaboration with CIMMYT and also with other countries.
4. Requests the establishment of a consortium of other countries to work in collaboration with Indonesia.

Sri Lanka (Ms. A. M. Perera)

A task fource has been created to increase the productivity of maize. However, at present only OPVs are available. To increase the productivity help from CIMMYT in hybrid and varietal programs was sought. It was also reported that early maturity varieties are required to enable farmers to harvest 2 crops per year - the traditional varieties take about 130-140 d.

Pakistan (Dr. M. Aslam)

The representative informed the group that early maturity maize is a priority for them, and wanted to know how Sri Lanka and Pakistan can benefit from the early corn program of India. He also indicated that CIMMYT material tested in Pakistan is medium-late. He suggested the establishment of a network to evaluate and select early to extra early germplasm. If established, they would like to participate in such a network. He also wanted more corn borer tolerant materials from CIMMYT.

They would also be very interested in being involved in a network to evaluate borer resistant germplasm. Dr. C. De Leon reported that 2 extra early populations - one white and the other yellow have been developed with a target of about 80 d to maturity. Dr. G. Granados indicated that for corn borer work Pakistan needs to develop more facilities to do research on this problem.

Nepal (Mr. M. M. Palikhe)

Continuous rains are a problem in Nepal and therefore, it was suggested that a project on ear rot should be added. It was also reported that Pool 9A has a good level of resistance to foliar diseases but it is too late in maturity in the areas where needed.

Bhutan (Mr. N. Wangdi)

Suwan 1 was recently released and adapts well up to 1800 m elevation, but, they need materials suitable for higher altitudes. Therefore materials suitable for highland conditions with turcicum resistance were requested.

Philippines (Messrs. E. Bautista and V. Perdido)

There is a need for training on technology for hybrid maize breeding, line development, and data interpretation to their staff. They also indicated that waterlogging, especially due to early season floods before tasseling stage of the crop, was a serious problem in northern Luzon. They want to be involved in breeding for waterlogging resistance, in addition to their participation on breeding for extra early germplasm.

Taiwan (Dr. C. T. Tseng)

Corn borer and downy mildew are the main problems in maize production. Information was requested on the correlation between these two traits.

Malaysia (Dr. L. C. Onn)

Requested high yielding (about 4 t/ha) germplasm in any maturity group as they are not concerned about the maturity. They are also interested in mechanization of the crop. He requested hybrid trials originating in Thailand. Trials from Mexico can not be accepted due to phytosanitary problems.

Thailand (Dr. C. Chutkaew)

He requested varieties suitable for paddy fields in the off-season, especially for heavy paddy soils.

A representative from the private sector wanted to know if commercial hybrids would also be tested in the region through the Tropical Asian Maize Network (TAMNET) organized by FAO. However, Dr. N. N. Singh indicated that only public materials would be tested in TAMNET.

China (South China) (Mr. C. Zehui)

It was reported that Fusarium stalk rot, turcicum leaf blight, drought, and infertile soils were the major problems in South China. The delegates expressed their desire to participate in CIMMYT programs directed to solve these problems.

Myanmar (Mr. U. S. Htun)

Requested assistance from CIMMYT in solving the main constraints for hybrid corn work in Myanmar:

1. Limitation on breeding material for inbred development, and
2. Lack of trained manpower.

Laos (Mr. B. Kanyavong)

Corn borer and downy mildew are the major problems, along with the lack of trained manpower. CIMMYT and other programs sould assist in these needs.

Vietnam (Dr. T. H. Uy)

He stressed the development and availability of improved germplasm with the following characteristics required in this country:

1. Early and medium maturity.
2. Resistance to Rhizoctonia leaf and sheath blight, and drought
3. They are also interested in participating in the hybrid program of CIMMYT.
4. They are willing to exchange inbred lines with other countries.
5. They are interested in exchanging information on OPVs.
6. It was requested CIMMYT continue offering training positions and organize courses on hybrid maize technology. Study tours of scientific staff to other countries were also suggested.

Bangladesh (Dr. K. M. Kabir)

At present only composites are being grown in Bangladesh. Although there is much land that could be planted with maize, it would require materials tolerant to saline soils. It was also stated that government policies should be developed to promote maize production in this country.

India (Dr. N. N. Singh)

The need exists to have inbred lines evaluated to develop single cross hybrids. Other interested national programs and CIMMYT should work on this.

The Coordinator of the Maize Program informed the meeting that the first priority of the program is to work on *Chilo partellus* corn borer resistance, and then they would look for resistance to other corn borers. The establishment of regional networks to solve the following problems was suggested:

1. Rhizoctonia leaf and sheath blight.
2. Corn borers in Asia.
3. Extra early maturity germplasm (80-85 days to harvest).

Dr. S. Pandey from CIMMYT invited the views of the participants representing the private sector. Their views were:

1. CIMMYT should continue to develop the database of new germplasm evaluated.
2. CIMMYT may help in developing the corn market in new areas.
3. In less developed countries where hybrid technology is not available the OPVs should continue to be developed and promoted.
4. CIMMYT protects and maintains the variability in germplasm and should continue to do so.
5. CIMMYT may help in providing trained manpower.

Dr. C. De Leon from CIMMYT informed the group that:

i. TAMNET - future participation from the private sector should be considered.
ii. Selection for extra earliness, downy mildew resistance, and other ongoing activities at CIMMYT will continue. The extra early populations are being developed as a request from various national programs in the 1990 Workshop in Pakistan.
iii. Best hybrids from Mexico and other Central American countries should be sent to TAMNET for testing.

Dr. Hess of CIMMYT emphasised the importance of TAMNET and the participation of national programs in it to make it a success. He also informed the group that training can be given to the people from various programs, and stressed the importance of inter-regional visits of maize breeders. He concluded the meeting by expressing his thanks to the Vietnamese Govt. and to Drs. Carlos De Leon and Gonzalo Granados. Dr. Carlos De Leon proposed a vote of thanks.