PN-ABM 422

Joint Assessment and Planning of Vegetable Research and Development

Proceedings of an ROC/AVRDC workshop, Shanhua, Taiwan, *20-22 March 1990*

Asian Vegetable Research and Development Center

PN-ABM-422

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Welcome Remarks

Emil Q. Javier
Director General
Asian Vegetable Research and Development Center

Allow me to begin by extending a warm welcome to all our colleagues from the Council of Agriculture (COA), Provincial Department of Agriculture and Forestry (PDAF), National Science Council (NSC), the Biotechnology Center and the Committee of International Technical Cooperation (CITC). Realizing how busy you all are, your presence today is a very encouraging manifestation of the deep reservoir of goodwill that you hold for AVRDC. For this, we are very grateful indeed.

Relationships among individuals, among institutions, are like seeds. They can grow spontaneously in the most inhospitable environments. However, they always grow healthier, they produce more flowers and yield bigger and sweeter fruits when they are carefully nurtured, cultivated, fertilized, watered and safeguarded.

Nevertheless, it is always a good idea not to take our relationship for granted. That is the first objective of our workshop today - to review and assess the cooperation between ROC institutions and AVRDC - to recall the achievements, the successes as well as the omissions and shortcomings. By doing so, we can recognize those we do very well and continue them and also identify where we fall short and learn how to avoid them.

In addition, we want our relationships to grow. Therefore, we are introducing a second dimension to that liaison. We want to explore if there is common ground between the international orientation of AVRDC and the increasing global outlook of the government of the Republic of China and its people. ROC has much relevant experiences, trained people and resources it can share with less developed societies and countries. AVRDC shares a similar vision and mandate and we are optimistic that there is much potential for synergy for our separate efforts. The second objective of our workshop therefore is to find out where that synergy and complementation lie.

This search for a second dimension to our relationship runs parallel with the strategic planning AVRDC is conducting at present. During the remainder of the 20th century, we believe it is opportune for AVRDC to set its sight beyond our immediate environment in Southeast Asia and move to South Asia, to Africa, to Latin America, and beyond. Our experiences in the humid to subhumid tropics have direct relevance to these other regions of the world and we believe we have something substantial to contribute to the amelioration of hunger and poverty through improvement in the production, distribution and consumption of vegetables.

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Moreover, not only do we plan to expand our geographical coverage, we also intend to widen our commodity scope and discipline orientation. In other words, we aim to make it a truly global comprehensive center for research on vegetables in the tropics.

This new agenda would require resources far beyond what we have available at present. However, we are emboldened and fortified by the fact that demand for vegetables is rising rapidly in all countries. The governments in the developing countries and the international donor community fully recognize this emerging trend, and there have been repeated calls for an international initiative on vegetable research. But among the set of possible institutional arrangements, the expansion of AVRDC, we strongly believe, is the most scientifically and fiscally responsible alternative. And we have many friends in the international community who share this view.

We have three busy days ahead, so let me repeat our most cordial welcome and our most sincere wishes for a fruitful workshop.

Opening Remarks

Paul M.H. Sun
Commissioner
Provincial Department of Agriculture and Forestry

I am very pleased to be here today to open this workshop. As you are probably aware, there has long been a very fruitful and successful cooperation between the Provincial Department of Agriculture and Forestry and AVRDC. And I am very proud to point out that this cooperation has resulted in significant contributions to the improvement of the welfare of the farmers in the country in the last two decades.

This cooperation is characterized mostly by the number of AVRDC breeding lines released by various PDAF research institutions after testing to local farmers. Vegetable soybean and tomato are good examples. In the 1970s, vegetable soybean was an insignificant crop in Taiwan. Today, it constitutes nearly 60 % of the total exports of fruits and vegetables processed in Taiwan. At present, tomato also accounts for a large portion of the total vegetable production value.

Due to the surge of economic development experienced in Taiwan in recent years, agriculture has reached a transition stage. Although we are considered a newly industrialized country, agriculture is still the backbone of the economy. New technologies are required to be used to further increase productivity. However, concerns on environmental protection and conservation need to be also addressed.

Thus, a better focused joint effort in the application of socially acceptable, economically viable and ecologically sound technologies is needed at this time to address gaps in agricultural production and marketing. I hope that through this workshop, we can explore and identify new approaches and collaborative activities that will strengthen not only the working relationship between PDAF and AVRDC, but also contribute to the further development of agriculture in Taiwan. I sincerely hope that the successful cooperation between PDAF and AVRDC could be extended to other partners of the Center in the future.

I hope that the interaction between AVRDC and its local partners in the next few days will be both fruitful and interesting.

Implementation and Achievements in Leguminous Crops

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Abstract

Legumes are an important part of the Chinese diet. Among the legumes, soybean, vegetable soybean and mungbean are the most widely used. They are also principal crops of the Asian Vegetable Research and Development Center (AVRDC). Total soybean area and total amount of production has steadily increased in Taiwan since 1960, reaching the current level of about 8,000 ha planted to soybean and about 15,000 t of produce. Soybean import jumped from 164,000 t in 1966 to more than 2 million t in 1988. However, the average yield per hectare increased from less than 1 t/ha to more than 2 t/ha. Higher labor costs increased the cost of production to such an extent that soybean lost its competitive edge over other profitable agricultural products such as vegetable soybean. Furthermore, the price of imported soybean was considerably cheaper than domestic soybean. Vegetable soybean area increased from an insignificant level in 1975 to reach 10,000 ha in 1988. Mungbean is a minor crop and its acreage and production also decreased over the years. The cost of labor for harvesting inhibits mungbean production. The biotic, abiotic and economic aspects need to be considered in prioritizing soybean and mungbean research areas.

In Taiwan the Council of Agriculture and the Provincial Department of Agriculture and Forestry plan and determine the objectives and priorities for soybean research and allocate funds for the attendant research activities. Various institutions like District Agricultural Improvement Stations (DAIS), Taichung Agricultural Research Institute (TARI), National Chung Hsing University (NCHU) and National Taiwan University (NTU) conduct research activities. Since 1956 more than 20 soybean varieties have been released by national institutions. Among these varieties eight were popular among farmers.

The national programs of host countries were linked with AVRDC in research and development activities, focusing on germplasm exchange, collaborative research, demonstration and extension of varieties to local farmers, training of local scientists and foreign scholars, and communications.

Collaborative research activities resulted in the release of three soybean varieties (KS # 9, 10; Tainan # 1) one vegetable soybean (KS # 1) and two mungbean varieties, Tainan Selection No. 3 and 5. About 50% of the grain soybean area and about 70% of vegetable soybean area are planted to these newly developed varieties. The total net value of both grain soybean and vegetable soybean from AVRDC in 1988 is about US$40 million.

AVRDC has trained 78 junior scientists and summer students in various disciplines. National program scientists benefited from participating in conferences and workshops organized by AVRDC.

The host Government hopes that the relationship with AVRDC could be further strengthened by exchanging germplasm and technology, developing innovative areas for collaborative research and by jointly sponsoring symposia and workshops. Research will focus on vegetable quality as well as quantity. Taiwan is expected to benefit from AVRDC accomplishments as strong linkage between the national programs and AVRDC programs is expected to sustain progress, maintain comparative advantage and make further advances in legume production.

Introduction

Legumes are used directly as food and are an important part of the Chinese diet. Oil extracted from legumes is an important industrial product. Legumes are also used as a source of poultry and livestock feed. The following are the major legumes of the Republic of China: groundnut (*Arachis hypogaea*); soybean (*Glycine max*); mungbean (*Vigna radiata*); red bean or "Adzuki" bean (*Vigna angularis*); rice bean (*Vigna calcaratus*); broad bean (*Vicia faba*); kidney bean (*Phaseolus vulgaris*); lima bean (*Phaseolus lunatus*); asparagus bean or cowpea (*Vigna sinensis*), hyacinth bean (*Dolichos lablab*) and pigeon pea (*Cajanus cajan*).

The favorite legume among the Chinese is soybean which is a major source of protein. It is a principal crop of AVRDC. Soybeans are used in a variety of ways, as food for humans and as a feed for animals. Vegetable soybean is an important export crop for the frozen food industry.

Mungbean is another important crop. It is utilized as mungbean sprouts, mungbean noodle, and as an ingredient in various confectionaries, cakes, and sweet porridge (Chao 1982). Mungbean, like soybean, is another principal crop of AVRDC.

Trends in Soybean and Mungbean Production and Trade

Soybean

The area planted to soybean increased steadily from 194' '20,362 ha) to 1960 (59,665 ha) in reponse to the increasing demand for it as food for human consumption and as feed to sustain the livestock and poultry industries. However, the area planted to soybean progressively declined to the current lowest level of about 8,000 ha (Table 1). The major soybean production areas are Pingtung and Kaohsiung counties (Table 2) . Soybeans are also grown to a certain extent in Chia-Nan and Hualien counties. Soybean is planted in autumn, spring. and summer in all of the counties mentioned.

The distribution of soybean acreage in different years and seasons is given in Table 3. Although the areas planted to soybean decreased, the total production did not decrease significantly until after 1978. This was attributed to the genetic improvement introduced by researchers. From the low yield of less than 1 t/ha, the average yield/ha increased to 2 t/ha (Table 1) . The introduction of high-yielding, disease-resistant varieties primarily brought about the increase in yield. There are two major reasons for the decline in the area planted to soybean: Firstly, in November 1966 the Government lifted the import control for soybean. As a result, import of soybean jumped from 164,500 t in 1966 to 1,110,000 t in 1979 until it reached an all time high of 2,099,456 t in 1988 (Table 4). Secondly, increased industrialization and shortage of farm labor raised the labor cost so high that soybean was no longer a competitive crop. Its cultivation was not as profitable as that of other competing crops such as adzuki bean or vegetable soybean.

Table 1. Soybean area, production and yield in Taiwan from 1948 to 1988.

Year	Area (ha)	Production (t)	Yield (kg/ha)	Year	Area (ha)	Production (t)	Yield (kg/ha)
1948	20,362	12,439	611	1969	45,227	67,111	1,482
1949	20,284	12,052	594	1970	42,749	65,174	1,525
1950	20,299	12,542	618	1971	40,151	60,990	1,519
1951	23,251	13,411	577	1972	36,123	60,221	1,670
1952	24,315	14,627	602	1973	36,491	60,596	1,662
1953	28,228	17,426	617	1974	44,454	66,918	1,505
1954	30,048	20,309	676	1975	41,448	61,920	1,495
1955	34,509	24,150	700	1976	35,548	52,998	1,491
1956	33,505	28,442	705	1977	30,117	51,718	1,717
1957	41,029	33,053	806	1978	24,472	40,824	1,668
1958	47,893	41,881	870	1979	19,333	31,782	1,644
1959	53,785	44,461	828	1980	15,328	25,934	1,892
1960	59,565	52,653	882	1981	10,293	15,883	1,543
1961	59,581	53,899	905	1982	7,782	12,043	1,549
1962	55,008	53,010	974	1983	5,592	8,592	1,536
1963	55,223	52,645	976	1984	5,535	9,546	1,725
1964	50,970	57,616	1,132	1985	7,111	12,211	1,717
1965	53,176	85,709	1,236	1986	9,449	14,890	1,576
1966	51,326	63,271	1,233	1987	9,012	18,043	2,002
1967	52,302	75,226	1,439	1988	7,699	14,641	1,902
1968	49,461	72,995	1,476				

Source: Taiwan Agricultural Annual Report.

Table 2. Soybean production in different years by region in Taiwan.

Location	Year	Area (ha)	Location	Year	Area (ha)	Location	Year	Area (ha)
Taipei	1960	213	Changhua	1960	2,831	Pingtung	1960	21,866
	1974	9		1974	484		1974	28,878
	1977	5		1977	293		1977	20,503
	1988	0		1988	33		1988	1,504
Yilan	1960	688	Nantou	1960	678	Taitung	1960	1,371
	1974	563		1974	184		1974	205
	1977	468		1977	99		1977	149
	1988	11		1988	28		1988	113
Taoyuan	1960	556	Yunlin	1960	3,360	Hualien	1960	2,584
	1974	1		1974	4,910		1974	1,581
	1977	0		1977	1,201		1977	2,118
	1988	0		1988	1,402		1988	767
Hsinchu	1960	1,622	Chiayi	1960	4,760	Taichung	1960	83
	1974	22		1974	1,313	(city)	1974	5
	1977	44		1977	756		1977	4
	1988	0		1988	1,666		1988	0
Miauli	1960	2,110	Tainan	1960	4,275	Kaohsiung	1960	820
	1974	52		1974	958	(city)	1974	344
	1977	9		1977	395		1977	272
	1988	0		1988	1,689		1988	38
Taichung	1960	803	Kaohsiung	1960	10,945	Total	1960	59,665
(county)	1974	377	(county)	1974	4,571		1974	44,454
	1977	266		1977	3,475		1977	30,117
	1988	24		1988	651		1988	7,923

Table 3. Soybean area and yield during different seasons in different years.

Year	Area (ha)			Yield (kg/ha)		
	Autumn	Spring	Summer	Autumn	Spring	Summer
1963	32,208	11,887	11,127	1,023	855	974
1964	31,255	10,594	9,121	1,167	1,034	1,124
1965	37,096	9,264	6,816	1,330	1,073	1,113
1966	37,034	7,728	6,564	1,275	1,119	1,184
1967	38,157	8,004	6,149	1,532	1,203	1,163
1968	37,387	6,611	5,463	1,573	1,145	1,213
1969	34,608	5,885	4,784	1,568	1,214	1,197
1970	32,743	5,331	4,675	1,599	1,280	1,283
1971	30,996	4,755	4,400	1,584	1,298	1,297
1972	27,751	4,286	4,086	1,786	1,302	1,265
1973	26,033	5,305	5,153	1,849	1,239	1,151
1974	31,083	8,414	4,957	1,639	1,226	1,143
1975	31,497	8,318	3,831	1,575	1,282	1,168
1976	28,956	3,759	2,833	1,571	1,282	1,224
1977	22,807	4,241	3,269	1,825	1,447	1,324
1978	15,816	5,337	3,320	1,847	1,326	1,320
1979	13,310	3,616	2,398	1,794	1,324	1,290
1980	10,446	2,700	2,183	1,827	1,462	1,332
1981	6,012	2,826	1,474	1,669	1,452	1,199
1982	4,033	2,243	1,506	1,674	1,437	1,372
1983	3,150	1,240	1,202	1,677	1,209	1,507
1984	3,018	1,367	1,150	1,821	1,694	1,507
1985	3,165	1,862	2,084	1,823	1,778	1,502
1986	4,194	2,099	3,156	1,769	1,966	1,060
1987	3,317	2,988	2,097	1,895	2,293	1,703
1988	2,041	2,812	2,846	1,799	2,185	1,695

Table 4. Comparison of domestic production and import of soybean in Taiwan.

Year	Production (1000 t)	Import (1000 t)	Total (1000 t)
1963	52.6	124.9	177.5
1964	57.6	181.8	239.4
1965	65.7	161.4	227.1
1966	63.2	164.5	227.7
1967	75.2	346.9	422.1
1968	72.9	384.9	457.8
1969	67.1	472.2	539.3
1970	65.1	617.5	682.6
1971	60.9	524.8	585.7
1972	80.2	711.0	771.8
1973	60.5	626.0	686.5
1974	66.9	528.6	595.5
1975	61.9	827.4	889.3
1976	52.9	799.5	852.4
1977	51.7	662.7	714.4
1978	40.8	959.4	1,000.2
1979	31.7	1110.5	1,142.2
1980	25.9	938.9	964.8
1981	15.8	1113.3	1,129.1
1982	12.0	1150.4	1,162.4
1983	8.5	1413.8	1,422.3
1984	9.5	1344.6	1,354.1
1985	12.2	1469.3	1,481.5
1986	14.8	1739.3	1,754.1
1987	18.0	1950.3	1,968.3
1988	14.6	2099.2	2,113.8

In contrast to the area alloted to grain soybean, the area for vegetable soybean increased from an insignificant level in 1975 to the current level of about 10,715 ha (Fig. 1). Appropriate soybean varieties and production technology, assured market and attractive prices, and assistance from frozen food factories contributed to the expansion of the vegetable soybean area and production. The yield of vegetable soybean and soybean steadily increased since 1983 as a result of the improved varieties released to the farmers (Fig. 2).

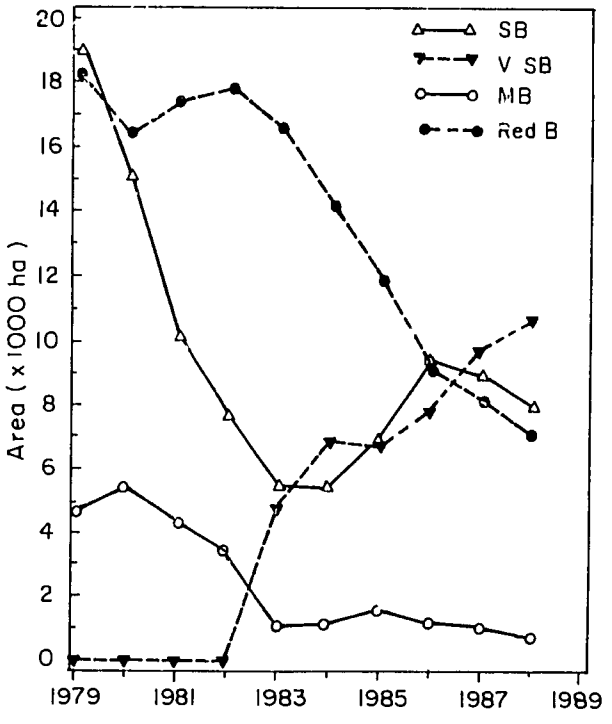

Fig 1. Area planted to soybean, vegetable soybean, mungbean and adzuki bean in Taiwan.

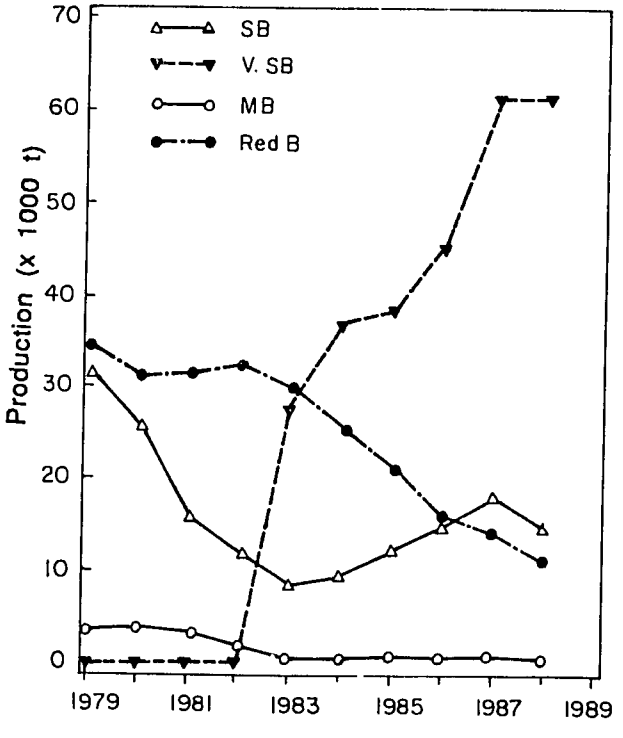

Fig. 2. Production of soybean, vegetable soybean, mungbean and adzuki bean in Taiwan.

Mungbean

Mungbean is traditionally a minor crop in Taiwan. The major mungbean production is concentrated in the Chia-Nan area of Southern Taiwan, where 95% of the mungbean is grown during spring as a rotation crop. The Chia-Nan area covers the Chiayi and Tainan counties and lies between 22.5° and 23.38° N. The environmental and edaphic conditions are described by Cheng (1988).

The area and production of mungbean in Taiwan declined over the years (Table 5). The primary reason for the decrease in area and production of mungbean is the increase in labor cost, especially for harvest. Mungbean has many flushes of flowering and the pods mature at different times requiring multiple harvests and repeated expenses. The average yield of mungbean is also in general low and ranges between 400 and 800 kg/ha.

The total volume of mungbean imported from abroad during 1979-89 is given in Table 6. Mungbean is imported from Thailand, Myanmar, Indonesia, Philippines, Japan, Malaysia and Singapore. But import from Thailand accounts for almost 80% or more of the total importation.

Table 5. Mungbean area, production, and yield in Taiwan.

Year	Area planted (ha)	Total production (t)	Average yield (kg/ha)
1977	3816	2305	604
1978	4381	2827	645
1979	4691	3583	764
1980	5547	3816	688
1981	4421	3287	744
1982	3426	1832	535
1983	1092	471	431
1984	1155	476	412
1985	1704	667	392
1986	1218	616	506
1987	1082	779	720
1988	807	559	692

Source: PDAF 1978-87.

Table 6. Mungbean imported from abroad between 1979 and 1989.

Year	Total (t)	Import from Thailand (t)	Export Price (US$/kg)[a]	Export Total (t)
1977	25,645	24,420 (95.2%)[b]	0.34	1
1978	32,142	31,748 (98.8%)	0.32	46
1979	19,695	19,513 (99.1%)	0.33	19
1980	20,523	20,445 (99.6%)	0.38	80
1981	24,594	23,947 (97.4%)	0.50	7
1982	26,216	20,434 (77.9%)	0.49	2
1983	22,488	15,972 (71.0%)	0.44	25
1984	22,060	16,460 (74.6%)	0.45	4
1985	21,661	19,246 (88.9%)	0.40	2
1986	25,362	19,889 (78.4%)	0.38	1

Source: Anon. 1978-87.
[a]Exchange rates: US$1.00 = NT$36.00, March 1990.
[b]Numbers in parentheses represent import from Thailand as percent.

Problems in Soybean and Mungbean Production

Soybeans in Taiwan can be grown year-round. Normally, three crops are raised in a year: spring crop is planted from February to March; summer crop, from June through July and fall crop, from September to mid October. The fall crop has a major share of the area in Southern Taiwan while the spring and summer soybeans are planted in other parts of Taiwan due to differences in the cropping system requirements.

Vegetable soybeans are planted primarily in Pingtung-Kaohsiung area in southern Taiwan in fall. In recent years spring crop has been gaining importance both in Pingtung-Kaohsiung and Chia-Nan area.

Constraints to soybean production can be classified into biotic and abiotic. The biotic problems vary with seasons. For example, soybean rust and downy mildew are serious problems in spring and fall. But bacterial pustule is severe during summer. Beanfly is a serious problem in spring and fall. Scarabeid beetle is a problem in spring. Stink bugs and pod borers are important pests in fall. Defoliators can occur in all three seasons. Spider mites occur in fall. Although a number of other diseases and insect problems were observed, research focused on the following constraints: soybean rust, downy mildew, bacterial pustule, beanflies, stink bugs, and pod borers.

Priority areas for research and their corresponding objectives include photoperiod and temperature response (to incorporate insensitivity), higher cost of production (to reduce cost of production by mechanized methods), flooding (to provide proper drainage during typhoons), seed weathering (to develop resistance to weathering and to develop quality seeds).

Imported soybean is much cheaper (US$ 0.26/kg) than the domestically produced soybean (US$ 0.77/kg). But the guaranteed official purchase price of soybean is US$ 0.96/kg. The increase in cost

of production is mainly due to labor costs incurred for planting, other management operations and harvesting.

Mungbean is primarily a spring crop grown in the first crop rotation. The two cropping patterns involving mungbean are described by Cheng (1988). Mungbean is also intercropped with sugarcane, corn or watermelon. A summer crop of mungbean is also currently being promoted as part of a rice field diversification program.

Among the constraints, Cercospora leaf spot (CLS) and powdery mildew (PM)are the major diseases of mungbean. Beanflies, green leaf hoppers, aphids, defoliating caterpillars, pod borers and storage weevils are the key pests of mungbean. Photoperiod sensitivity, nonsynchronous maturity and susceptibility to weathering are some of the abiotic constraints. Low temperature at the initial growth stages inhibits growth; and continuous rain during harvest time hampers harvest and limits productivity. Flooding and frequent typhoons often threaten mungbean production in summer.

Research Policy, Institutions and Resources

Soybean and mungbean are important food legumes both in terms of being a source of vegetable protein and of being a component in the cropping system in Taiwan. Therefore, the national research program of the Council of Agriculture (COA) during its annual research planning determines the goals, objectives and appropriate research activities.

The major objectives of soybean research include the development of improved soybean cultivars which are especially suitable for preparing traditional soybean foods, disease and pest resistance and suitability for mechanical harvest in the different seasons. Development of vegetable soybeans aims to meet the exportation needs of the frozen food industry.

For mungbean, the important objectives are to develop improved varieties with higher yield potential, synchronous maturity, disease and pest resistance, dull seed coat and adaptation to mechanical harvest.

The ultimate research goal for both crops is to reduce the cost of production through mechanized production techniques and increase the profit through increased productivity. Control of diseases and insects should preferably be made through genetic rather than through chemical means.

Kaohsiung District Agricultural Improvement Station (DAIS) and Taiwan Agricultural Research Institute (TARI) are the major institutions responsible for soybean varietal improvement. In addition, DAISs in Tainan, Hualien, Taoyuan, Taitung, National Chung Hsing University (NCHU) and National Taiwan University (NTU) conduct selected research activities. The Pingtung and Chiayi Institutes of Agriculture also conduct research on soybean.

The key institution conducting mungbean varietal improvement research is Tainan DAIS. NTU and NCHU conduct some basic research on mungbean.

The Council of Agriculture along with the Provincial Department of Agriculture and Forestry (PDAF) annually review the research projects and national requirements. All the key researchers from various institutions come together for the review and discussion of their results, constraints and research needs. COA maps out the overall plan for soybean production and makes funds available for various research institutions.

Soybean and Mungbean Varieties Developed and Released to Farmers in 1956-80

From 1956 to 1980 a total of 21 soybean varieties were developed and released to farmers (Table 7). Among them Shih Shih, Palmetto, NTU-KS 5, Kaohsiung No. 3, Kaohsiung No. 8, Tainung 4 and 15 and Hualien 1 were adapted and widely grown by the farmers.

Kaohsiung DAIS, NTU, TARI and Hualien DAIS were very active and successful in developing and promoting the above varieties. A small breeding program for mungbean was active for more than 20 years at Tainan DAIS. It developed Tainan Selection No. 1 and No. 2 from local varieties which were later released to farmers in 1966 (Cheng 1988). Although the yield of new varieties was high, their poor adaptation to low temperature caused the farmers to prefer the local varieties such as Dull Green or Oily Green, etc. Taiwan farmers and consumers prefer dull seed coat over the shiny seed coat.

Table 7. Soybean varieties released during 1956-80.

Variety name	Year released	Institution
San-Kuo	1956	Hsinchu DAIS
Shih Shih	1957	Taichung and Kaohsiung DAIS
Palmetto	1957	Kaohsiung DAIS
Wakashima	1960	Kaohsiung DAIS
Taliento	1949	Kaohsiung DAIS
Acadian	1960	Kaohsiung DAIS
Nungyuan 1	1958	Kaohsiung DAIS
Chung Hsing 1	1964	National Chung Hsing University
Chung Hsing 2	1964	National Chung Hsing University
Chung Hsing 3	1967	National Chung Hsing University
NTU-KS 5	1963	National Taiwan University and Kaohsiung DAIS
Kaohsiung No. 1	1959	Kaohsiung DAIS
Kaohsiung No. 2	1959	Kaohsiung DAIS
Kaohsiung No. 3	1961	Kaohsiung DAIS
Kaohsiung No. 8	1980	Kaohsiung DAIS
Kaohsiung No. 9	1982	Kaohsiung DAIS and AVRDC
Kaohsiung No. 10	1984	Kaohsiung DAIS and AVRDC
Tainan No. 1	1986	Tainan DAIS and AVRDC
Tainung 1 (R)	1963	Taiwan Agricultural Research Institute
Tainung 2 (R)	1963	Taiwan Agricultural Research Institute
Tainung 3	1967	Taiwan Agricultural Research Institute
Tainung 4	1973	Taiwan Agricultural Research Institute
Tainung 15	1980	Taiwan Agricultural Research Institute
Hualien 1	1980	Hualien DAIS

Research Interaction with AVRDC and Impact

The establishment of AVRDC in Taiwan in 1971 served to strengthen vegetable and legume research and support the research effort of development agencies. Mungbean has always been a principal crop of the Center. Soybean became a principal crop in March 1973. Taiwan's research institutions and government agencies linked with AVRDC's research and development program, particularly in crop improvement and training activities. Taiwan's researchers had free access to AVRDC germplasm, improved technologies and training.

The major interaction in research and development activities could be broadly described under the following categories: (1) germplasm exchange, (2) collaborative research, and multilocational trials, (3) demonstration and extension of improved varieties to local farmers, (4) training of local scientists and foreign scholars, (5) communication and joint planning.

Operational Logistics

The Government of the Republic of China was extremely cooperative in the exchange of germplasm within the country and between foreign countries and AVRDC following regulations of the country through their plant quarantine office.

AVRDC provides germplasm and breeding materials free for all trials.

The local research institutions and universities can establish collaborative research with AVRDC for which Council of Agriculture (COA) and/or Provincial Department of Agriculture and Forestry (PDAF) or National Science Council (NSC) provide operating expenses.

For specific experiments the national institutions provide or identify free access to facilities and experimental plots. Occasionally AVRDC is required to provide part or all of the operating expenses.

AVRDC participates with the local institutions in the regional and district trial networks.

AVRDC trains junior researchers, extension workers and summer students at the Center in various subjects.

Germplasm Exchange

Soybean. In 1973 and 1974 AVRDC received a significant number of soybean accessions from TARI, NCHU and Kaohsiung DAIS. In subsequent years the number of accessions received from local institutions was negligible (Fig. 3 a,b and c). The total number of accessions donated to AVRDC was 2257.

In return, AVRDC provided a total of 757 accessions and 2920 breeding lines from 1976 to 1988 (Table 8).

Mungbean. A total of 60 mungbean accessions were received from five research institutions in Taiwan (Fig. 4). AVRDC distributed 51 accessions and 115 breeding lines (populations) (Table 8) to the local researchers.

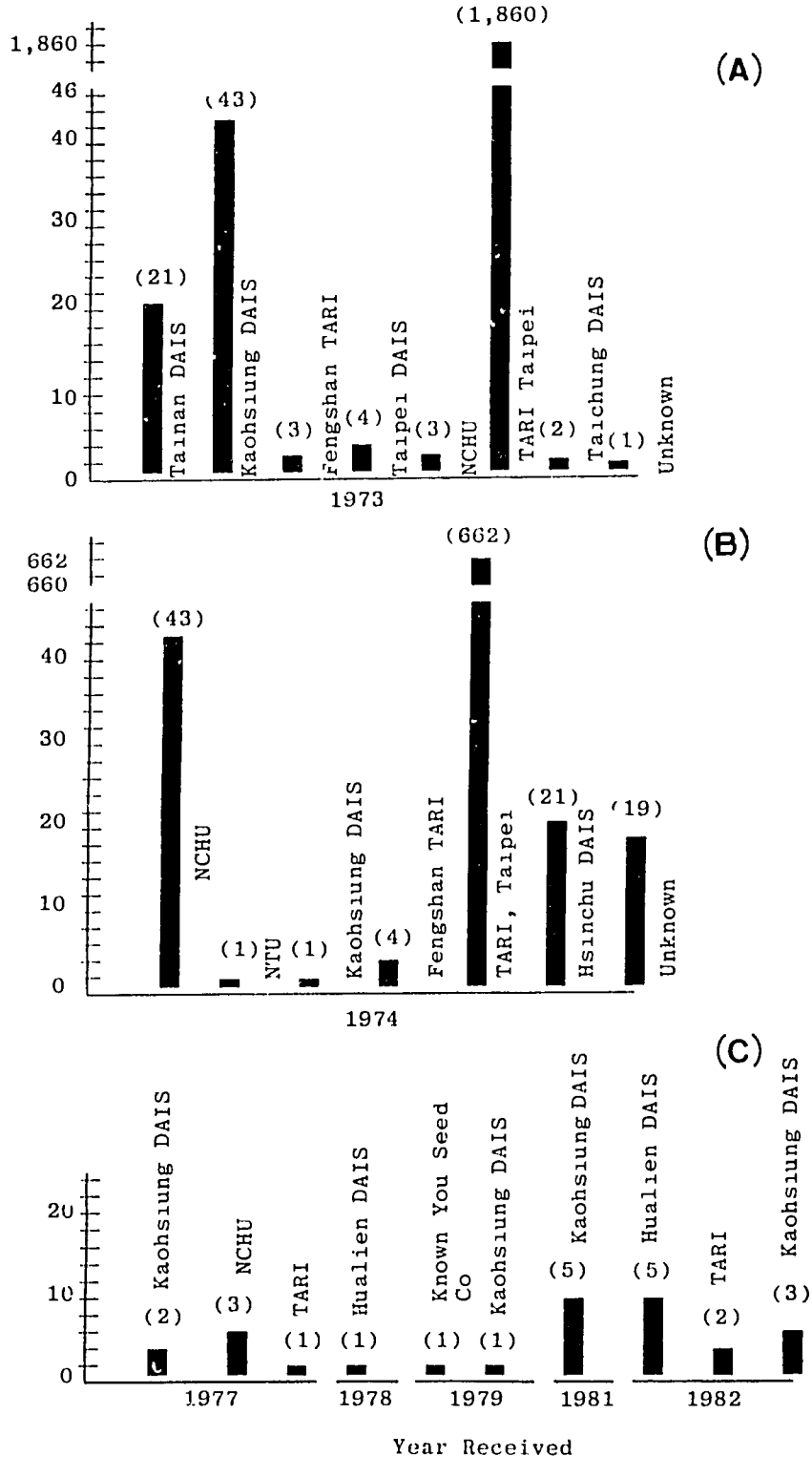

Fig. 3a, b, and c. The number of soybean germplasm received from local institutions in Taiwan in 1973 and 1974 and from 1977 to 1982.

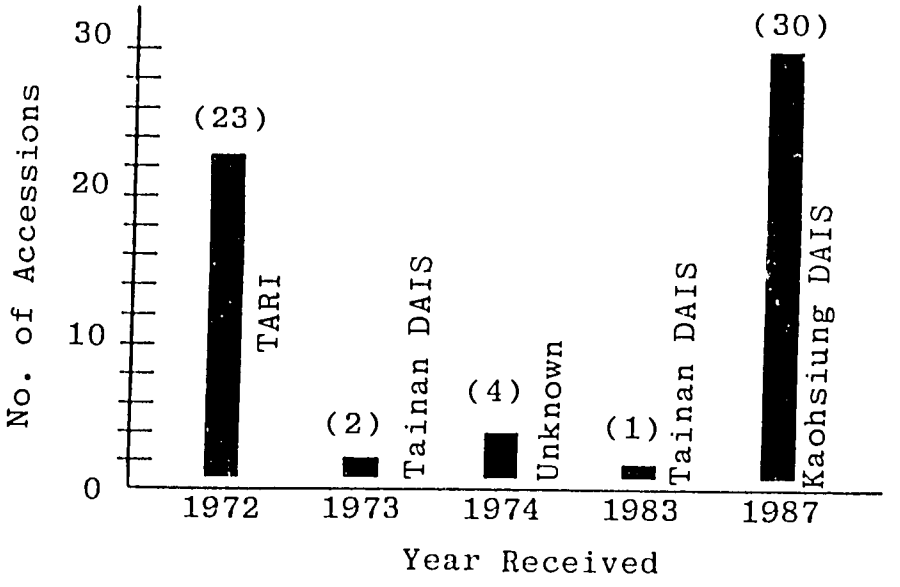

Fig. 4. Mungbean accessions received from institutes in Taiwan from 1974 to 1987.

Table 8. Accessions and advanced lines provided to Taiwan.

Year	Soybean	Mungbean
1976	-	5
1977	114	18
1978	1550	77
1979	82	63
1980	153	70
1981	133	80
1982	118	15
1983	93	29
1984	336	-
1985	114	-
1986	397	25
1987	518	-
1988	956	23
1989	434	21

Collaborative Research and Multilocation Trials

The Center has collaborated with TARI and Hualien DAIS in screening for soybean rust resistance. Similarly, epidemiological studies on soybean rust were conducted in cooperation with Kaohsiung, Taitung and Hualien DAIS and TARI. Screening for beanfly resistance was undertaken in cooperation with Hualien, Taitung, Kaohsiung, Tainan and Taichung DAIS. Germplasm observation trials (GOT), preliminary yield trials (PYT), regional yield trials (RYT) and adaptation trials (AT) were undertaken collaboratively during spring, summer and autumn 1974 (Table 9).

Since 1983, Kaohsiung DAIS has conducted vegetable soybean RYT collaboratively with AVRDC. Collaborative research on vegetable soybean breeding is in progress with Kaohsiung DAIS.

Likewise, Tainan DAIS collaborated with AVRDC in organizing and conducting mungbean RYT and AT in addition to other cooperative research (Table 9).

Demonstration and Extension of Improved Varieties

Soybean. After 2 years of regional trials followed by district yield trials AGS 12 was found to be the best yielder and was released as a new variety. Kaohsiung DAIS named it Kaohsiung No. 9 in June 1982. Two other AVRDC lines, AGS 129 (a narrow leaflet entry) and AGS 66 (an early maturing entry), were later found to be better than Kaohsiung No. 9. The yields of AGS 129 and AGS 66 in different years and different seasons are given in Table 9.

Table 9. Number of collaborative research experiments, various yield trials, regional, district and adaptation trials conducted by AVRDC in different institutions in Taiwan during different years.

Year	Soybean	Vegetable soybean	Mungbean
1973	1	-	
1974	2	-	
1976	1	-	
1977	12	-	
1978	7	-	5
1979	17	-	6
1980	29	-	8
1981	31	-	22
1982	31	-	13
1983	33	14	17
1984	37	13	8
1985	39	12	8
1986	38	8	10
1987	40	1	9
1988	40	2	7
1989	40	9	5
Total	398	59	118

The yields of two improved grain soybeans were fairly stable during spring and summer in Chia-Nan area to which they were well adapted (Table 10).

AVRDC provided the breeders' seed and in some cases assisted in the production of foundation seed for DAIS and farmers' associations. The volume of seeds of different varieties supplied to local institutions is given in Table 11.

Table 10. Yield of AGS 129 and AGS 66 in different years and in different seasons in RYT and DT.

Year	Yield (t/ha)					
	AGS 129			AGS 66		
	Spring	Summer	Autumn	Spring	Summer	Autumn
1982	3.5	3.0	2.3	3.2	2.9	2.2
1983	2.5	3.1	2.4	1.9	2.8	2.5
1984	2.7	3.4	2.7			
1985	2.4	2.7	2.6			
1986	(2.8)	(2.0)	(2.3)	(2.7)	2.6	(2.5)
1987	(2.8)	(2.6)	(2.5)			
1988	1.9	2.4	2.0			
1989	(3.1)	(1.2)	(2.3)			(1.9)

Note: Figures in parentheses from trials at AVRDC.

Table 11. Amount of improved soybean seeds (Breeder and Foundation Seed) provided to farmers association for demonstration through DAIS.

Year	Entry	Amount of seeds (kg)
1982	AGS 66	2,248
1983	AGS 66	1,271
1984	AGS 66	1,200[a]
1986	Tainan Selection No. 1	376
	Kaohsiung No. 10	147
	AGS 292[b]	25
1988	Tainan Selection No. 1	164
	Kaohsiung No. 10	81
	OCB	90
1989	Tainan Selection No. 1	46
	Kaohsiung No. 10	32
	G 2120	25
	KS # 1	12

[a]In Tungshih and Yichu 20 ha was planted during summer and the average yield was 3.4 t/ha which was 1 t/ha higher than local variety H 15.
[b]Vegetable soybean.

Based on their best performances AGS 129 and AGS 66 in the RYT and DT Kaohsiung DAIS and Tainan DAIS were released respectively as Kaohsiung No. 10 on 4 October 1985 and Tainan Selection No. 1 on 20 November 1986.

On 2 May 1983 AVRDC organized a field day for 42 participants from COA, PDAF, TARI, farmers' associations, DAIS and frozen food industry establishments. All of them expressed a desire to replace the existing vegetable soybean variety 205 (Tzurunoko) whose graded pod yield was poor. Again on 26 September 1984 AVRDC organized a meeting for more than 30 participants from 24 frozen food industry establishments to introduce the new vegetable soybean lines at AVRDC. Four promising lines were introduced to the participants in the meeting. Promising entries were compared in the RYT and DT. The frozen food industry assisted in the evaluation of the entries for quality and acceptability in the Japanese market.

As a result of the above interaction, a pureline selection from an introduction, "Taisho Shiroge", was found to have better graded pod yield and acceptable pod quality for Japanese vegetable soybean market and therefore, the variety release committee approved the request by Kaohsiung DAIS. It was the first improved vegetable soybean released in Taiwan. It was named Kaohsiung No. 1 on 23 April 1987. Taiwan Seed Service planted 40 ha for seed production. It was estimated to produce 100 t of seed for planting about 1000 ha in spring 1988.

The graded pod yield of Kaohsiung No. 1 was consistently superior to the previously grown variety 205 (Tzurunoko) in all three seasons (Table 12). The demand for seeds of this variety was so great that the price of seed shot up to US$8/kg compared to 205's cost of US$2/kg.

Table 12. Graded pod yield of AGS 292 in different years and seasons in regional yield trial and in AVRDC trials.

Year	Graded pod yield (t/ha)		
	Spring	Summer	Autumn
1985	5.6 (4.9)[a]	7.4 (6.9)	7.3 (5.6)
1986	5.7 (4.7)	3.2 (3.0)	3.5 (3.2)
1987		2.2 (1.1)	3.0 (2.1)
1988	4.1 (2.8)	3.3 (4.2)	6.9 (5.7)
1989	7.3 (6.9)		5.2 (6.7)

[a]In parentheses the graded pod yield of check variety 205 (Tzurunoko).

Similarly in 1987, the year of release of the variety in autumn, the area planted to Kaohsiung No. 1 was 800 ha. In 1988 the area increased to 3919 ha and in 1989 to 4940 ha (Table 13). Even now the cost of the seed is more than US$4/kg. The total estimated market value of Kaohsiung No. 1 produced in 1989 is worth more than US$32 million.

Table 13. Area planted to improved soybeans developed collaboratively by national program and AVRDC.

Year	Area planted to variety (ha)			
	Grain soybean		Vegetable soybean KS # 1	
	KS# 10	Tainan No. 1	Spring	Autumn
1985-86	3,690	800	-	-
1986			-	-
1987			-	800
1988			1815	2104
1989			2321	2620

Mungbean

A large number of mungbean trials were conducted since 1978 (Table 10). As a result of the promising performance of VC 1628A in RYT and DT, Tainan DAIS released it as Tainan Selection No. 3 (TN # 3). It was a cross between CES-1D-21 and PHLV-18.

TN # 3 had a yield potential of up to 2.0 t/ha, it is erect and 80% of its pods matured synchronously. Around 1235 kg of TN # 3 seeds were distributed to DAIS and farmers' associations (Table 14). TN # 3 had shiny seed coat against the preference of Taiwan farmers for dull seed coat and therefore it was not well accepted.

On 18 May 1989 Tainan DAIS released the AVRDC line, VC 3890A, as Tainan Selection No. 5 (TN # 5). It is resistant to powdery mildew and matures synchronously. The yield potential is about 2.0 t/ha, in one harvest. It is hoped that TN # 5 could be harvested by machine. The acceptability of TN # 5 by the farmers remained to be seen.

Table 14. Amount of breeders and foundation seed of mungbean produced and distributed to DAIS and farmers' associations.

Year	Variety	Amount of seeds produced and distributed (kg)
1982	VC 1628A	1,116
1986	TN # 3	34
	VC 1209C	1
	VC 2530C	1
	VC 1168B	25
1988	TN # 3	62
	VC 3890A	785
1989	TN # 3	23
	TN # 5	510

Training

AVRDC has trained a total of 78 junior scientists and summer students (19 for mungbean, 54 for soybean and 5 for soybean and mungbean) in various disciplines at the Center. Many of them were later recommended for higher training or studies abroad. Most of them continue to serve as AVRDC collaborators.

Communication and Joint Planning

During the annual review of the progress of upland crop projects, AVRDC discussed the collaborative projects with local institutions and potential collaborators. They jointly planned the future research activities in priority areas of the national program.

AVRDC has organized international conferences on soybean and mungbean. The Council of Agriculture in Taiwan has generously provided financial support and encouraged the participation of scientists from the local institutions.

AVRDC proposes a tripartite vegetable soybean consultation/workshop to review the current status and design of the future research thrusts to meet the needs of the vegetable soybean farmers and the frozen food industry.

Priorities for Future Soybean and Mungbean Research

Considerable quantities of soybean and mungbean are imported to meet the domestic demand. Due to the rising cost of labor, the domestically produced soybeans and mungbeans are more expensive than the imported soybeans. Farmers, therefore, do not find soybean and mungbean as profitable crops.

Taiwan has surplus rice production. The Government has designed a policy that encourages farmers to grow corn, sorghum, and soybean as part of the rice field diversification program. The Government provides subsidy via a guaranteed price support. To complement the Government's effort, research should focus on increasing the yield potential; reducing the disease and insect damage by genetic means; decreasing the cost of production by developing suitable varieties and management technology which will accept mechanized technology. Improved consumer quality for domestic consumption, compared to imported beans, will provide a competitive edge for domestically produced beans.

Specifically, in soybean, new improved varieties of soybean should have early maturity, multiple disease resistance (against soybean rust, bacterial pustule, downy mildew and anthracnose), good seed quality and weathering resistance, suitability for traditional soybean food processing and mechanized harvesting. Studies on resistance to insects, cost-effective technology and research management need to be stressed. Efficient disease screening techniques need to be developed. Elimination of nutritional pollutants may need to be studied.

Although mungbean is not well received by the farmers in Taiwan, research should focus on the development of dull seed coat, high yielding varieties with synchronous maturity carrying resistance to CLS and PM.

Taiwan has enjoyed a unique comparative advantage in the production, processing and export of vegetable soybeans. However, in recent years the rising cost of labor for harvest (picking pods and sorting) has threatened the industry. Thanks to AVRDC and Kaohsiung DAIS, the newly released high yielding vegetable soybean variety, Kaohsiung No. 1, has saved the industry. Further strengthening of this comparative advantage requires additional improvement in graded pod yield, better quality, and

development of mechanized harvesting. The varieties and management practices also should be developed to suit the available machinery. It is likely that domestic consumption of shelled green soybean, both fresh and processed, may increase. To meet the rising demand for vegetable soybean, both in the domestic market and in the international market, research should focus on the industrial and consumer preferences. Improvement of both quality and quantity should be emphasized.

In vegetable soybeans, new varieties should have the potential to produce better graded pod yield, longer harvest duration, better processing quality and consumer preference, adaptation to mechanized harvesting and the potential to continue to provide a competitive edge for Taiwan producers and frozen food industry, for export as well as for the domestic market. Suitable screening techniques for assessing quality have to be developed. A close liaison between the frozen food industry, trading companies and the researchers needs to be maintained and nurtured.

The Role of AVRDC

Collaboration between the national program and AVRDC on legume research in the past was excellent. National program scientists and AVRDC scientists cooperate in germplasm exchange, breeding material sharing, improved technology exchange, communication, training and information exchange.

To strengthen this linkage among scientists AVRDC should:

- Continue to facilitate exotic and improved germplasm available to local researchers.
- Recognize the host country needs and ongoing priority research areas and complement and strengthen the national program efforts to make rapid progress.
- Train additional junior researchers and provide opportunity for midlevel researchers to undertake independent research at AVRDC as a visiting scientist.
- Continue to involve national program scientists in AVRDC training program so that contact could be established between national program scientists from different countries and the local researchers.
- Encourage collaborative research activities between AVRDC scientists and local scientists.

Taiwan is fully prepared and ready to put to use AVRDC accomplishments. AVRDC has made significant contributions and impact on soybean production. More progress could be achieved through collaborative research.

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ROC/AVRDC Collaboration in Vegetable Research: Implementation and Achievements

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Fact Sheets On Vegetables in Taiwan

Trends in consumption and production. Vegetable consumption in Taiwan has tripled in the last 40 years, the annual per capita intake increasing from 38 kg in 1945, to 57 kg in 1965, and reaching up to 130 kg in 1980 (Fig. 1). The figure has levelled at 120-125 kg since then. Favorable tropical-to-subtropical climate year-round and the industry of the farmers both allow for the ample supply of vegetables.

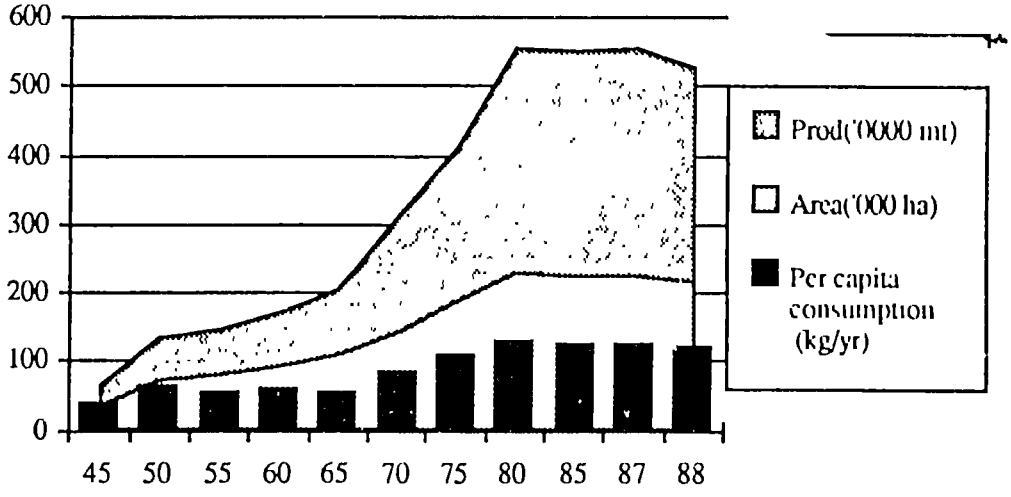

Fig. 1. Trends in vegetable production, acreage and per capita consumption in Taiwan, 1945-88.

At present, more than 70 kinds of vegetables are produced in a total area of about 220,000 ha. The farm value of vegetables is about 21-22% of the total crop production, a little less than that of fruits.

Leading vegetables in 1988 in terms of total acreage devoted to production include cucurbits (watermelon, melon and cucumber), crucifers (cabbage, Chinese cabbage, radish, cauliflower, and leaf mustard), bamboo shoots, vegetable soybean and tomato (Fig. 2). Altogether, they account for about 55% of the total acreage.

Crucifers have the largest volume of production, followed by cucurbits, bamboo shoots, tomato, and vegetable soybean in that order (Fig. 3). Altogether, these vegetables account for about 60% of the total volume of vegetables produced in Taiwan in 1988.

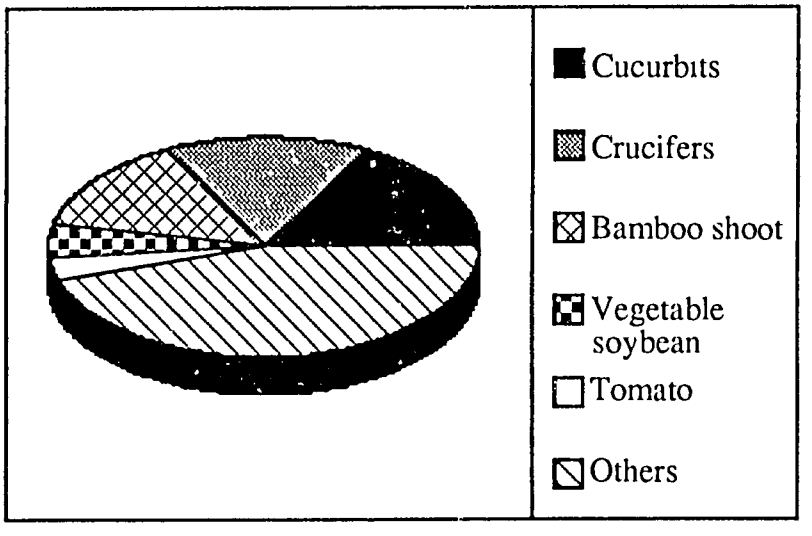

Fig. 2. Proportion of total production area devoted to vegetables and/or groups of vegetables in 1988.

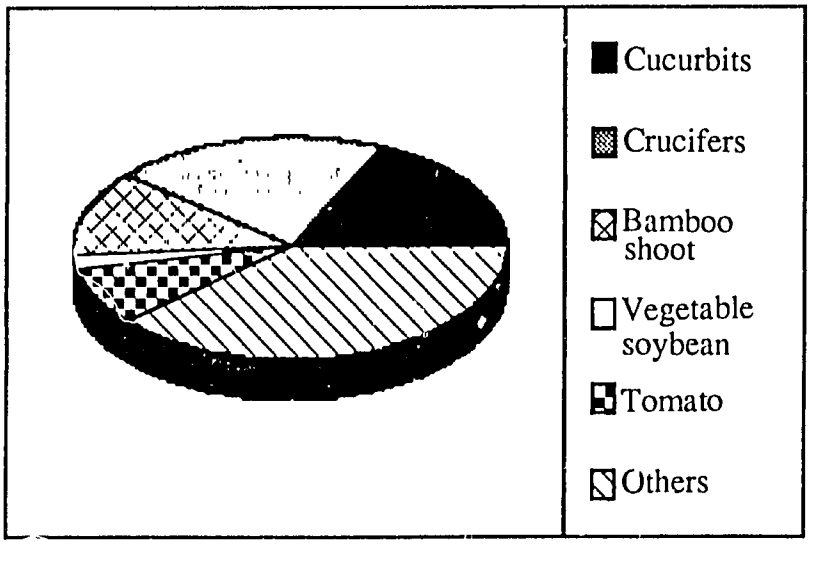

Fig. 3. Proportion of total production volume for vegetables and/or groups of vegetables in 1988.

Other popular vegetables include cucurbitaceous species such as bitter gourd, wax gourd; solanaceous species such as pepper, potato, eggplant; cruciferous species such as pak-choi; legumes such as peas and snap beans; stem crops such as coba and ginger; and water convolvulus.

Although vegetables are grown islandwide, the most important production localities are Yuanlin, Pingtung, Tainan and Changhua, both in terms of acreage and volume of production. Altogether, these areas account for about 53.6% of the total acreage and 55.7% of total production (Fig. 4 and 5).

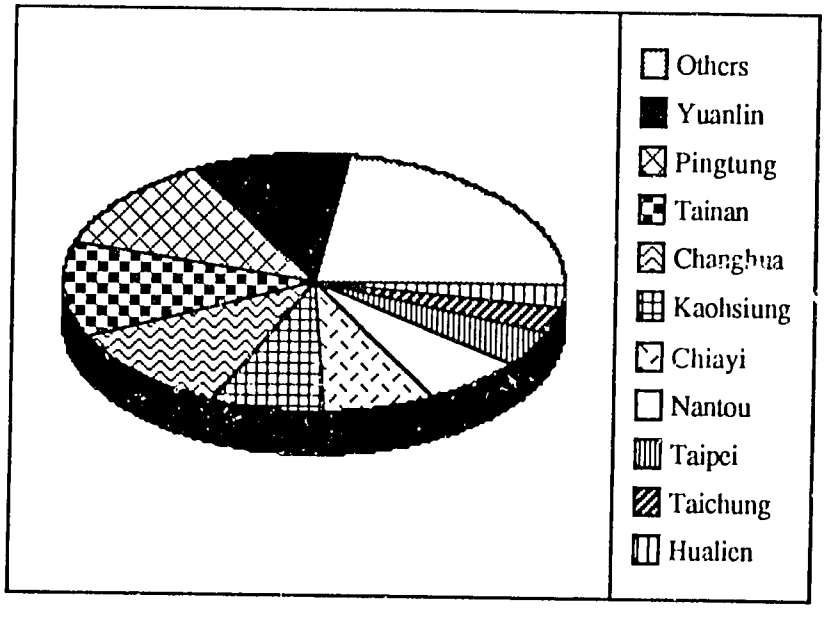

Fig. 4. Major vegetable production areas in Taiwan in 1988 based on total acreage (by county).

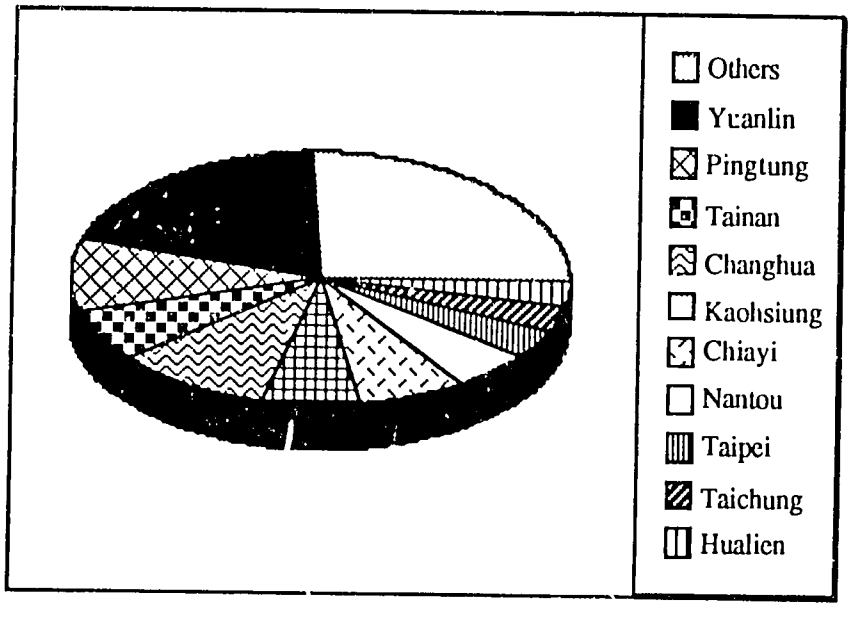

Fig. 5. Major vegetable production areas in Taiwan in 1988 based on total production volume (by country).

The next important areas are located in Kaohsiung, Chiayi, Nantou and Taipei, with cumulative values of 25.7% and 22.4% of total area and production, respectively.

Two of the common cropping patterns applied in vegetable production are vegetables produced between two rice crops and rice or another crop rotated in on land planted year-round to vegetables. Rice is rotated in for most of the vegetable production patterns.

Vegetable research and development. During the early postwar years, most researchers in local research institutes and stations were largely engaged in rice research. Very little research, if any, was done on vegetables. Following the vegetable survey of 1952, a series of projects for vegetable research was initiated by the then Sino-American Joint Commission on Rural Reconstruction (JCRR), now known as the Council of Agriculture (COA), in cooperation with various research and improvement stations of the Provincial Department of Agriculture and Forestry (PDAF).

Research programs in the 1950s emphasized the introduction of new vegetable species and cultivars. In the 1960s, research centered on the improvement of cultivation techniques for different crops. Breeding programs were not initiated until the 1970s. In the same period, the specialized vegetable production areas were established under the technical and financial assistance of the government. In the 1980s, more sophisticated cultivation techniques were implemented. For example, plastic house and plastic mulching techniques were used to produce high-quality, off-season vegetables. The low-cost hydroponic production system was established for the subtropical areas through research in the last few years.

From then on, the vegetable industry grew vigorously and steadily.

The significant achievements attributed to local vegetable research and development include the following:

- Successful development and extension of new varieties of asparagus, onion, mushrooms, seedless watermelon, muskmelon, broccoli, processing tomato and strawberry.

- Replacement of late-maturing, low-yielding, old varieties with early, uniform, higher-yielding, more heat-resistant types in several species of crucifers, cucurbits and solanaceous crops. The official releases of new varieties listed in Table 1. Through the encouragement of private seed companies, open-pollinated varieties were significantly replaced by F_1 hybrids in the late 1970s for watermelon, cucumber, cabbage, Chinese cabbage, cauliflower, broccoli, tomato, bell pepper and spinach. This trend is expected to continue for oriental melon, bitter gourd, pumpkin, radish, pak-choi, chili pepper, kohlrabi and others.

- Releases resulting from collaboration between ROC and AVRDC scientists.

- Application of improved practices such as tissue-culture method to produce virus-free potato stock seeds, garlic bulb and strawberry plants for propagation; the use of row cover and floating mulches to get better thermal and moisture environment and less light energy for plants.

- Protected cultivation of fruits and leafy vegetables to alleviate pest problems and damage from torrential rain, increasing crop number while decreasing pesticide spray and using hydroponic cultures such as noncirculating system, floating dynamic root system and nutrient film techniques. Establishment of seedling-raising centers for vegetables like cabbage, strawberry, etc, also contributed to the progress of the industry.

Table 1. Official cultivar releases of vegetable crops in Taiwan since 1976.

Crop	Variety name	Release date
Onion	Tainan No. 1	03/19/1976
	Tainan S. No. 2	03/19/1976
	Tainan S. No. 3	03/20/1985
Pea	Taichung No. 11	12/10/1980
	Taichung No. 12	02/03/1988
	Taichung No. 13	01/17/1989
Tomato	TSS No. 1	12/10/1980
	Tainan S. No. 2[a]	12/21/1982
	Tainan S. No. 3[a]	12/08/1986
	Taichung-ASVEG No. 4[a]	07/14/1989
Melon	Tainan No. 8	04/24/1982
Strawberry	Tsunhsiang	04/24/1982
	Taoyuan No. 1	02/17/1990
Seedless watermelon	TSS No. 2	06/19/1982
Chinese cabbage	ASVEG No. 1[a]	09/15/1982
	Taoyuan-ASVEG No. 2[a]	07/21/1989
Asparagus	Tainan S. No. 1, No. 2 & No. 3	10/02/1984
Pak choi	Tainung No. 1	11/15/1985
Vegetable soybean	Kaohsiung S. No. 1[a]	04/23/1987
Snap bean	Taichung No. 1	11/23/1988
Taro	Kaohsiung No. 1	05/05/1989

[a]Releases resulting from collaboration between ROC and AVRDC scientists.

- Development of highland areas for summer production of vegetables such as cabbages, tomato, bell pepper, and peas (both for tender shoot and snap type). This led to an increase in vegetable supply during the summer months when adverse stresses such as high temperatures, high rainfall and high humidity drastically limit vegetable production in the lowland production areas.

- Development of more marketing channels for frozen broccoli, podded pea and vegetable soybean, etc., for export under contracted production, and improved packing for sale directly to supermarkets and for improved shelf-life. Standard grading systems have been developed and implemented for 25 vegetables, namely—asparagus, coba, carrot, pak choi, radish, potato, welsh onion, cabbage, Chinese cabbage, water convolvulus, lettuce, leaf mustard, cauliflower, cucumber, bitter gourd, bottle gourd, eggplant, tomato, green bean, sweet pepper, broccoli, bamboo shoot, pea, drumhead savoy, and nonheading Chinese cabbage.

- Improvement through vigorous dissemination of agricultural information. Booklets on cultivation methods or seed production for different vegetable crops were published as materials for training or technical team meetings. Video tapes, slide sets and television or radio broadcasting programs were also produced.

- Improvement through sustained support to vegetable research. The ROC government now allocates more funds for research programs, human resource development and facilities. For example, research funding was only NT$20,000 in 1967, but it increased to more than NT$ 1 million for three vegetable projects in COA at Fengshan Tropical Horticultural Experiment Station (Fengshan THES) in fiscal 1990. Another case showing government support for vegetable research was the budget allocation from COA of NT$15,379,000 in 1990 for studies on the improvement of vegetable varieties and cultivation techniques. There were other projects concerned with the improvement and production of specified commodities such as asparagus, watermelon, potato, etc. Current research projects could be grouped into breeding, cultural physiology, seed (seedling) production and postharvest handling. PDAF also gives support. In 1990, NT$17,774,000 was allocated by PDAF to Taiwan Agricultural Research Institute, Fengshan THES and 6 DAIS for 62 projects, including 33 for variety improvement, 18 for cultural improvement, 6 for seed and seedling production, and 5 for protected cultivation (Table 2). Varietal improvement continues to receive a large proportion of project support.

Table 2. Research projects on vegetables funded by PDAF in 1990.

	Number	(%)	Amount (NT$)	(%)
Varietal Improvement	33	53	9,036,000	50.8
Crucifers	6		1,345,000	
Solanaceous crops	5		1,234,000	
Cucurbits	7		2,089,000	
Leguminous crops	3		1,192,000	
Others	12		3,175,000	
Cultural Improvement	18	29	4,035,000	22.7
Solanaceae	1		60,000	
Cucurbits	3		680,000	
Others	14		3,295,000	
Seed and seedling production	6	10	2,108,000	11.9
Protected cultivation	5	8	2,595,000	14.6
Total	62	100	17,774,000	100

AVRDC: A Service to Tropical Vegetable Research

The Asian Vegetable Research and Development Center (AVRDC), located in Taiwan, was officially designated in 1973 to collaborate with the national program entities to improve vegetable production and marketing in the lowland tropics. In this developing tropical zone, fruits and vegetables represent some 16% of the diet and provide a vital supplement of minerals, vitamins, plant proteins and edible fibers to diets traditionally high in carbohydrates (rice, cassava and other starchy foods).

Taiwan was selected as the site for this specialized research center based on: the suitability of its humid tropical climate; its history as an outstanding vegetable-producing area; its excellent institutional infrastructures for farmer's associations, local and city markets linked by good transportation and

communication; the presence of outstanding academic institutions; the availability of highly trained personnel; and proximity to research institutions and supporting agricultural industries.

In pursuit of its mandate, the Center performs four general functions: as a germplasm center, it is the focal point for the collection, conservation and utilization of vegetable germplasm; as a technology center, it generates and distributes improved genetic materials and develops effective production methodologies for use and/or for further development by the national agricultural research systems (NARS); as an information center, it generates, collects and disseminates information about vegetables; and, as a training center, it conducts training programs to help develop the human resources needed by the NARS to solve the problems of vegetable production and utilization in the tropics.

AVRDC chose six priority crops for genetic and production improvement under tropical conditions, based on their economic importance in Asia and in developing countries as a whole; income generation potential, nutritional attributes, amenability to research, and the Center's perceived comparative advantage. These crops are: Chinese cabbage, mungbean, potato, soybean, sweet potato, and tomato. Potato research was concluded in 1979; pepper (both hot and sweet) was officially added to the list in 1986. The productivity and quality of these vegetables in the tropics are limited by biotic stresses, such as debilitating diseases and insect pests, and abiotic stresses, including high temperature, high humidity, excessive rainfall, drought and poor soil. Thus, research at AVRDC specifically aims to meet the most important requirements for tropical adaptation of its priority crops.

The Center's vegetable research is comprised of two major programs. Altering the genetic makeup of the priority crops to make them more adapted to the tropics is one of the major activities carried out by the Crop Improvement Program. Reducing the abiotic stress levels through appropriate management constitutes the complementary half of the Center's two-pronged approach to resolving the problems of tropical adaptation. This type of research is undertaken by the Production Systems Program.

Interfacing the Vegetable Research Programs of ROC and AVRDC

The vegetable research programs of ROC and AVRDC deal with areas of common interests to both organizations. In view of this, a strategic interfacing of their programs is necessary. Collaboration between ROC and AVRDC scientists in several key areas has existed since the beginning of the Center's full-scale operation in 1973. These major areas of collaboration and the achievements that have been attained are discussed below.

Germplasm exchange. One of the most important research components of AVRDC is a germplasm center. Starting from its inception, the Center has built up sizeable collections of vegetable germplasm to serve as the foundation for its crop improvement research. The germplasm collection of the Center's priority crops (excluding legumes) now totals 13,147 accessions (a total of 15,242 was recorded in 1991). In addition, there are about 700 accessions of other nonpriority species, e.g. amaranth, etc. (1991 recorded only 675 accessions excluding eggplant and allium, now included among the priority crops).

The above genetic materials have been shared with ROC's vegetable researchers over the years. The AVRDC vegetable collections include germplasm contributed by ROC research stations and scientists (Tables 3a and 3b).

In addition to the sharing of genetic resources, duplicate collections of vegetable germplasm maintained at both AVRDC and ROC research organizations serve to ensure the safety as well as the integrity of these precious genetic materials. A good example of this is the duplicate collection of sweet potato germplasm at AVRDC and at Chiayi Agricultural Experiment Station.

Germplasm enhancement, evaluation and development. There is a constant need for better cultivars and advanced technology to sustain the growth and development of the vegetable industry. Thus, past collaboration between the ROC and AVRDC research programs has focused on joint germplasm development and evaluation.

Table 3a. Amount of germplasm of the Center's priority vegetables (accessions only) which have been shared by ROC research organizations and individuals with AVRDC.

Crop	Year	Number	Remarks
Tomato	1973-85	60	about even public and private contributions
Chinese cabbage	1972-89	72	64% from private sources
Sweet potato	1974-89	321	69% from Chiayi Station
Peppers	1981-86	31	94% from private sources

Table 3b. Amount of germplasm of the Center's priority vegetables (accessions only) which have been shared by AVRDC with ROC research organizations and individuals.

Crop	Year	Number	Remarks
Tomato	1977-89	670	Almost even distribution of private and public sectors
Chinese cabbage	1976-89	444	77% to public sector
Sweet potato	1976-89	147	69% from Chiayi Station
Peppers	1987-89	216	94% from private sources

The number of breeding-related experiments that have been jointly carried out through the years on priority vegetables by ROC and AVRDC scientists is shown in Table 4. Most of these experiments were evaluation trials; however, a few have been in the area of joint screening and selection from breeding populations. As a result of this collaboration, a total of five improved cultivars (two Chinese cabbage cultivars; two processing tomato cultivars; one fresh market tomato cultivar) have been officially released to Taiwan vegetable farmers by the ROC national program (see Table 5; also Table 1).

Integrated pest management. One of the most important areas of past collaboration between AVRDC and ROC scientists is on the integrated management of major vegetable pests (IPM). In particular, the efforts of the Center's scientists have been directed at control of insect pests. Best control through genetic resistance was not feasible. Increasing concern over the abusive use of pesticides by vegetable farmers and the harmful effects of these chemicals on human health and on the long-term sustainability of the environment compelled scientists to look for alternatives or environmentally safe solutions. In the past, the emphasis on collaborative IPM research has been placed on two very important pests—diamondback moth of crucifers and sweetpotato weevil.

Diamondback moth. Diamondback moth is the most destructive pest of cruciferous vegetables in Taiwan. Pesticide use to control this pest is rampant and the insect has developed resistance to most chemicals available in the market. AVRDC imported one parasite, *Diadegma semiclausum*, from Indonesia for the control of diamondback moth in Taiwan. For the past 4 years, AVRDC, in

collaboration with PDAF and with financial support from the ROC government, has been conducting IPM trials in Luchu (Kaohsiung county), Shrlin (Taipei county), Wuling (Taichung county), and Nanshan (Ilan county). The imported parasite is now established in the highland areas of central Taiwan and has reduced the status of diamondback moth to a minor pest, resulting in considerable savings on pesticide cost. Efforts are now being intensified to control this pest in the lowlands. A nationwide working group on diamondback moth has been formed in Taiwan. An AVRDC entomologist is a member of this group.

Table 4. Breeding-related experiments jointly carried out in the past by ROC and AVRDC scientists.

Crop	Year	Yield trials[a]	Other experiments[b]	Total entries
Chinese cabbage	1980-89	192	-	1,088
Processing tomato	1975-89	52	5	1,900
Fresh market tomato	1979-89	9	2	211
Tropical tomato	1975-83	27	2	250
Cherry tomato	1983-89	7	2	109
Sweet potato	1973-89	92	30	>5,566

[a] Evaluation trials of breeding lines developed by ROC and AVRDC crop improvement scientists.
[b] Involves joint screening and/or selection of segregating populations and accessions, especially for pest resistance.

Table 5. Specific cultivar releases by ROC's cooperating research stations of AVRDC's priority vegetables.

Crop	Local Name	AVRDC Code	Cooperating Station
Chinese cabbage	ASVEG No. 1	Hybrid No. 62	Fengshan Trop. Hort. Expt. Station
Chinese cabbage	Taoyuan-ASVEG 2	Hybrid 82-156	Taoyuan DAIS
Tomato (PT)	Tainan Sel No. 2	CL 1561-6-0-5-1-3	Tainan DAIS
Tomato (PT)	Tainan No. 3	PT 3027	Tainan DAIS
Tomato (FM)	Taichung-ASVEG 4	FMTT	Taichung DAIS

For the past 3 years, ICP has been collaborating with the Development Center for Biotechnology (DCB) and testing the *Bacillus thuringiensis* strains and formulations that DCB has been producing to control diamondback moth.

Sweetpotato weevil. Sweetpotato weevil is the most destructive pest of sweet potato in Penghu Island. A collaborative research project between AVRDC and Penghu branch station of Kaohsiung DAIS started in 1975. In the past, the Center's sweet potato germplasm collection was evaluated for resistance to the weevil. Failing to find any usable level of genetic resistance, research on the management of the weevil through IPM has been emphasized. After successful trials at the station, IPM trials were extended to the farmers' fields. The Penghu branch station now plans to further extend IPM to over 100 ha of production area in Penghu in 1990. AVRDC is backing up this program with technical advice and with a supply of weevil sex pheromone.

Other collaborative research activities. In addition to the primary research areas of collaboration, a number of small, short- to medium-term experiments have been jointly conducted by ROC and

AVRDC scientists. Moreover, sharing of materials, information and technology may be enumerated for other AVRDC disciplines as follows:

In plant physiology, the following studies have been jointly carried out: Source-sink relationship and photosynthesis in sweet potato (collaboration with National Chung Hsing University and Chiayi Agricultural Experiment Station; Growth regulators in general; Flowering in Brassicas (collaboration with Fengshan Tropical Horticultural Experiment Station).

In virology, the following cooperative activities can be cited: Project on virus elimination in sweet potato, indexing, and virus characterization (COA/OICD funding); provision of CMV isolates for biotechnological studies; screening of germplasm of private seed companies for virus resistance; provision of antisera and virus indicator plants to local institutes; and others.

Miscellaneous cooperative linkages. While not directly dealing with research, ROC research organizations and AVRDC have been collaborating on other areas that serve to advance the interests of research itself. Such collaboration includes the following: joint coordination and sponsorship of scientific meetings; training of research staff; and mutual professional services as resource persons or advisers to training and/or graduate study programs.

Seven international meetings have been held in Taiwan by AVRDC. Several of these meetings have received financial and technical support from ROC organizations; some have been jointly sponsored by ROC research institutions and AVRDC.

In 1990, two international gatherings will again be coordinated by AVRDC in Taiwan. One meeting is entitled "Second International Workshop on the Management of Diamondback Moth and Other Crucifer Pests" which will be held in Tainan, on 10-14 December 1990. The meeting is jointly sponsored by COA, FFTC and AVRDC. An organizing committee consisting of scientists from COA, TARI, NCHU, TACTRI, FFTC and AVRDC is handling the details of this meeting. The other is "Regional Consultation and Training Workshop on Vegetable Viruses" which will be held at AVRDC 1-28 October 1990.

Excluding the undergraduate university students who come to AVRDC for a 2-month research training period and the vocational school teachers who came as special-purpose trainees at one time, the Center has graduated a total of 49 members of technical staff of both public and private research entities of ROC. This number excludes the training scholars who specialize in legumes.

Challenges to ROC/AVRDC Collaboration

The future agricultural development of Taiwan will undoubtedly exhibit the following characteristics: it will be increasingly internationalized; agricultural production will be more quality-conscious; more enterprise-directed; and will be increasingly mechanized. As income increases, consumers will demand more variety and higher quality in the food they eat. Agricultural researchers will, therefore, have to face problems of growing complexity and sophistication; some problems will be biological in nature whereas others will be social, economical, educational and even political in nature.

The most important challenges that confront the ROC and AVRDC vegetable researchers are:

Prevailing seasonality of vegetable supply. In general, the price of vegetables rises gradually in April and May, due to the scarcity of vegetables in the hot and humid season, and then drops after November, when products flood the market during the relatively cooler period.

Labor shortage. Labor available for vegetable production will continue to decrease as general wages in the other sectors of the economy continue to increase. It seems that mechanized production has become an essential solution, in which case the required technology and the thorny social issues that mechanized production bring about will have to be addressed.

Chemical and fertilizer pollution. Two major reasons for this are the high incidence of diseases and insects and the abusive use of pesticides. The intensive cropping system on Taiwan's limited production areas necessitates the use of inorganic fertilizers and other chemicals.

Marketing: bottleneck to profit. Vegetable growers market their produce through intermediaries because the latter have the collection, shipping and marketing channels. Even when there is a short supply of vegetables and the price fluctuates several fold, vegetable growers receive a disproportionately lower share, if any, of the additional profit.

Prospects for Sustaining the Vegetable Industry

- Plant breeding for resistance to pest and disease and plant pathology research need to be strengthened. Modern biotechnology will eventually be harnessed in the continuing race between crop improvement scientists and the disease-causing organisms and the pests. Studies on developmental physiology related to quality and yield will be increasingly important.

- A sound seed/seedling multiplication and certification system should be established to ensure a good and consistent supply of pure, quality or uniform seeds/seedlings. Related research in nursery management such as the plug system with automation will have to be implemented.

- Development and adoption of improved cultural techniques should be encouraged to further increase productivity of quality vegetables.

- Mechanized vegetable cultivation will have to be stepped up to reduce production cost. Critical labor shortages in the future will put further pressure on the agricultural sector, making mechanized production a needed solution.

- An efficient system of storage, marketing and transportation for vegetables is required in major vegetable production areas.

- More funds will be needed to support basic research activities.

Implementation and Achievements in Cropping Systems

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Introduction

Annual production from a given land area can be increased by improving the yield of a crop, or by growing extra crops during the year. In most tropical regions with long growing seasons, small land holdings, high labor-land ratios, and multiple cropping systems could be the most effective means of increasing farm productivity.

Vegetables are versatile and can be easily incorporated into different cropping systems, and they can produce even at short intervals between staple crops. They can also be potential contributors to sustainable agriculture due to the great variation in their genetic resources, their unique suitability in multiple cropping systems, and the opportunity for high returns they offer while improving soil properties. Vegetables, therefore, form an important resource for farm production systems in the tropics. But to date, vegetables remain underexploited. Therefore, cropping systems research at AVRDC aims to develop principles and methodologies to pursue optional cropping systems with improved and stable productivity. These improved cropping systems would be fine-tuned with the environment so that benefits from natural resources such as space, moisture, and radiation could be harnessed to sustain production in the tropics.

Small-scale agricultural production under intensive farming systems has been very successful in Taiwan during the last three decades, especially the rice-based multiple cropping system that plays an important role in sustaining crop productivity in Taiwan. Many new varieties and production techniques developed in Taiwan are suitable for the tropical areas in the world, proved by the success of ROC agricultural missions in several developing countries. The need to document these important production experiences has grown out of many years of successful production.

Tremendous economic development has brought change in the dietary habits of the people in Taiwan. Rice consumption has declined since 1977 resulting in a remarkable surplus in rice supply. This overproduction of rice has become a critical problem. A series of plans to convert the cropping pattern in the paddy field have been carried out by the government to reduce the production of rice. The results of the "Six-year Program on Rice Production and Rice Field Diversion" starting in 1984 were significant. Although these results are attributed mainly to some effective administrative measures and production strategies (e.g. subsidies such as rice grain on converted paddy field, guaranteed purchasing prices on some domestically produced upland food crops, i.e. corn, sorghum, and soybean, and effective organization and regulations), there were several research projects that actually contributed to the development of the new cropping patterns with high productivity. To sustain this productivity,

AVRDC embarked on projects such as the compilation of the Taiwan experience as well as the generation of principles in the designing of new cropping systems. AVRDC also aims to establish an effective working model for cropping systems research. This paper summarizes this cooperation on the development of new cropping patterns in converted paddy field and on cropping systems studies in Taiwan.

Rice-Based Cropping Systems and Recent Rice Field Division in Taiwan

The extent of arable land in Taiwan was 894,974 ha in 1988. Some 483,514 ha or 54.0 % of this area were paddy fields. Based on the available amount of water for rice growth, the paddy field is classified into double rice cropping area (344,084 ha): first crop, single rice cropping area (9,722 ha), and second crop, single rice cropping area (129,708 ha).

The leading rice-based cropping patterns for each category have been described by Cheng (1975) and Su (1981) as follows:

- Double rice cropping: First crop of rice - (summer catch crops) - Second crop of rice (winter catch crop).
- First-crop-single-rice-cropping: First crop of rice - Second crop of upland crops.
- Second-crop-single-rice-cropping (This is done mainly in the central-southern region.)

First crop of upland crops - Second crop of rice (including three main patterns: one, two and three rice crops in 3 years, respectively).

The first crop of rice has a more stable and higher yield than that of the second crop of rice due to the favorable summer conditions (Chang and Wu 1986). The second crop of rice is more suitable than the upland crops for summer planting as it is affected by heavy rain and typhoons.

In intensive vegetable production in Taiwan it has been the practice of farmers to rotate with a rice crop some of the vegetable crops to maintain continuous and efficient use of pest control, weed control and soil resources. One of the main purposes of the rice field conversion program is to shift the double rice cropping systems to similar rotational systems of single rice crop in association with various combinations of upland crops. Although there are no statistical data on the classification of converted rice fields, the changes in acreage of rice production in different parts of Taiwan show that the central-southern region with the lowest percentage of double rice cropping area had the largest reduction from 1983 to 1985 (PDAF 1986). This seems to indicate that the rice field conversion during this period was mainly carried out in single-rice-cropping area. It is known that poor drainage and heavy texture of paddy fields are the main factors affecting growth of converted upland crops, especially in the rainy season (Iida 1986, Ishii 1986, Su 1981). The conversion in single rice cropping area may help to avoid these problems, but on the other hand, it may have adverse effects on productivity in the long run.

AVRDC - ROC Cooperation in Component Technology Improvement for New Cropping Systems

Several research projects have been carried out by Taiwan Agricultural Research Institute (TARI) and six District Agricultural Improvement Stations (DAIS) across this island in cooperation with AVRDC to enhance the adoption of crops substitution, and to develop suitable conversion cropping systems.

Changes in Agricultural Environments in Taiwan

Technological development has been causing the following changes in agricultural environments in Taiwan.

- Emphasis on agricultural productivity shifted from per unit land to per labor due to a shortage in the agricultural labor resource. The average cultivated area per agricultural worker was between 0.53 and 0.60 in 1952-74. It then increased steadily each year to 0.90 in 1988 (COA 1989).
- The major market for many agricultural products such as asparagus and mushroom shifted from international market to domestic market. The export quantity of vegetables, canned asparagus and mushrooms decreased from 185,788, 31,297 and 44,500 t in 1984 to 102,278, 7,743 and 15,143 t in 1988, respectively (COA 1989). This was mainly attributed to the sharp increase in production cost in recent years, hence the industry could not compete with other countries.
- There is an increasing demand for off-season products. For example, the monthly amount of tomato transacted at Taipei was more evenly distributed in 1988 than in 1983 (Fig. 1). This is related to the requirement for better quality products, because of the economic development and hence a higher wage.

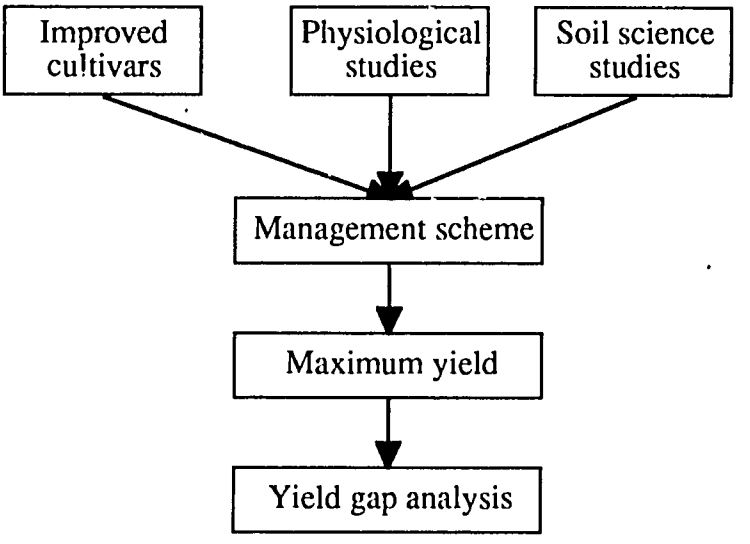

Fig. 1. Approaches of maximum yield trials for soybean.

- The government's policy does not only aim to secure the supply of staple food crops but also to encourage farmers to grow quality crops that can compete in the international market.

Technology for Improving Labor Productivity

Two approaches to improved labor productivity are: Firstly, improvement of crop variety to save labor and the cooperation of AVRDC and Tainan DAIS in the release of a uniformly maturing mungbean variety - Tainan Selection No. 5, is a good example of this variety. In the cultivation of this

variety, the number of harvestings is reduced from the traditional 5-7 to 1-2. This makes mechanized harvesting of mungbean possible.

Secondly, adoption of mechanized harvesting - In cooperation with Taiwan Provincial Department of Agriculture and Forestry (PDAF) and Tainan DAIS, AVRDC has identified and introduced a tomato processing harvester from Italy. Tests showed that this is a promising machine under Taiwan's conditions. Trials on mechanized harvesting of mungbean in the farmers' fields indicated that more than 1.5 t/ha of mungbean could be obtained in once-over mechanized harvesting.

Agricultural Production Technology for Domestic Market

To offset a shrinking export market, the industry adapted the diversification of agricultural products as a main apprroach. In other words, more new crops are being evaluated for their physical, biological and socioeconomic suitability. This led to intensive studies on relationships of species and environment. Three programs directly related to these efforts include the following:

Development of 'regional agriculture' - location - specific agricultural products. Results of this program improved not only the production of more crops, but also the quality, transportation, and marketing of products.

Mapping suitable production areas. For selected major crops, mapping of suitable production areas was adopted as a systematic approach to help farmers in selecting location-specific crops. To support this activity surveys and experiments have been conducted throughout the island by the ROC national agricultural institutes since 1984 for maize, sorghum, peanut, processing tomato, grape, and asparagus. Maps of suitable production areas to guide farmers in selecting suitable crops have been produced.

Establishment of data base for vegetable performances under tropical conditions. As mentioned, vegetables are versatile and can be easily incorporated into different cropping systems. However, the information on vegetable performance under tropical conditions is not readily accessible. A well organized data base on this area will be useful for farmers in selecting crops. A computerized data base for performance of vegetables under tropical conditions is being prepared at AVRDC. Data on the characteristics, which might be used in designing a cropping system such as yield level, growth duration, and suitable growth temperature of 100 varieties of 34 vegetables have been collected so far. These data are compiled in an applicable form in choosing a crop for a particular cropping pattern, locality or purpose. The methods of vegetable grouping based on their attributes for the hot humid conditions are being studied. The first attempt aimed mainly to rate the heat tolerance of vegetable varieties tested. They are grouped into three suitable temperature regimes based on their performances under three different temperature seasons. There were substantial variations in yields of vegetables under similar temperature conditions, including high temperatures. These data can be used to examine the relationships between yields of a particular variety or a crop and temperature conditions, and to select heat-tolerant vegetable varieties.

Technology for Improving off-Season Products

Vegetable production in Taiwan is low and the supply is limited during the hot humid summer. The improvement of vegetable supply in summer has been identified as a priority for agricultural research in Taiwan. One of the most effective and popular means is the development of heat- and flood-tolerant varieties. The cooperation between AVRDC and ROC in the implementation of their national programs has been impressive. There were two heat-tolerant Chinese cabbage F_1 hybrids, 'ASVEG No. 1' and

'Taoyuan-ASVEG No. 2'; one processing tomato F_1 hybrid, 'Tainan Selection No. 3'; and two fresh-market tomato F_1 hybrids, 'Taichung-ASVEG No. 4' and 'Hualien-ASVEG No. 5' released for off-season production. 'Tainan Selection No. 3' has extended the tomato processing season in Taiwan by at least 2 months, i.e. from October to May. 'Taichung-ASVEG No. 4' is getting popular since its release in June 1989 due to its resistance to TMV, bacterial wilt and cracking. The newly released 'Hualien-ASVEG No. 5' is an F_1 hybrid similar to 'Taichung-ASVEG No. 4', but with larger fruits. The Chinese cabbage, Taoyuan-ASVEG No. 2, was a good example of a new variety developed on the basis of crop interaction, climatic environment, and socioeconomic conditions. It is a heat-tolerant and high-yielding variety, and is originally recommended for summer planting. However, it sometimes has the serious problem of tip-burning during summer. On the other hand, it is close to Chan-puh type, a type of Chinese cabbage preferred by consumers in Taiwan. It is not as easy to bolt as the Chan-puh varieties in the autumn planting and thus it was recommended for autumn planting. It is well accepted by both farmers and consumers.

Technology for Sustainable Agriculture

Land fertility in Taiwan is generally low due to overexploitation of soil nutrients and inappropriate soil management. Loss of nutrients from the soil through intensive agriculture has been getting more serious attention recently. Leguminous crops with the ability to fix nitrogen in the soil have been eyed for improving soil fertility in multiple cropping systems.

The release of AVRDC promising soybean lines AGS 129 and AGS 66, as Kaohsiung Selection 10 and Tainan Selection 1, respectively, was part of these efforts. AGS 129 is a narrow-leaf type and does not lodge easily. It has a high yield potential under high temperature and high humidity and is suitable for spring and summer plantings and for machine harvesting. AGS 66 matures about 7-10 days earlier than AGS 129 in summer planting and is more suitable for the rice-soybean-maize cropping pattern in the central-southern region.

The maximum yield trial of soybean under continuous cropping at AVRDC not only shows the yield potential of soybean in different planting seasons but also provides a chance for establishing integrated management technology. The approaches of maximum yield trials are shown in Fig. 1. More than 4 t/ha of seeds have been consistently obtained in spring with a steady yearly increase in 1984-87. The improved integrated management technology made it possible for AVRDC to achieve higher soybean yield than that in other locations in the regional yield trials, except in the autumn planting in Kaohsiung areas where Kaohsiung's warmer environment contributed to higher yield (Table 1).

Table 1. Mean yields of soybean entries at each location in regional yield trial.

	1985			1986
Location	Spring	Summer	Autumn	Spring
Kaohsiung	2.84	2.18	2.77	1.73
Tainan	3.00			1.65
Taitung	2.65			1.98
Hualien	2.42			1.85
Taichung	2.82	2.08		2.93
Taoyuan	2.48	2.52		2.41
AVRDC	3.47	3.18	2.65	3.38

Traditionally, soybean is planted mainly in autumn after the second crop of rice in the Kaohsiung-Pingtung areas in Taiwan. Production of soybean during summer in Taiwan is risky due to the ravages wrought by typhoons and heavy rain. However, the failed soybean crop will benefit the next maize planting in the above-mentioned rice-soybean-maize cropping pattern in the central-southern parts of Taiwan (Chiayi-Tainan areas). This can happen because soybean plants can be plowed into the soil as green manure and the maize can be planted earlier. The increase in return in maize covers the loss in soybean. With the release of improved soybean cultivars and the demonstration of their yield potential, the farmer has accepted the concept that soybean can help the next maize planting. The main soybean production areas and season have shifted in Taiwan (Table 2).

Table 2. Changes in hectarage and percentage of soybean production in Taiwan between 1983 and 1988.

Year	Total area (ha)	Cropping (%)		Region (%)	
		Winter	Summer	Kaohsiung	Tainan
1983	5,592	56.3	21.5	19.3	56.5
1988	7,699	26.5	37.0	61.0	28.0

AVRDC-ROC Cooperation in the Development of the Principles and Methodologies in Cropping Systems Research

The productive base of a cropping system is plant growth, which is influenced by management and environment. Management for the cropping systems research includes the arrangement of crops in time and space, choice of variety, and cultural techniques. Environment is composed of biotic (e.g. pests and weeds), abiotic (e.g. land and climate-related variables), and socioeconomic (e.g. labor, cash, cost of inputs, and market) factors. There are many factors involved in a cropping system and the relationships among these factors are complicated. The objective of cropping systems research is to predict the best management from the information about the environment. Therefore, the cropping systems research needs a holistic approach, and emphasizes the environmental impact on crop production.

Cropping Systems Research Network in Taiwan

To develop a technique for converting a cropping system to reduce rice production, a series of experiments was initiated in 1986 by the six District Agricultural Improvement Stations in cooperation with AVRDC. Cropping systems of upland crops substituting either first or second crop of rice are being compared with the traditional system of double crops of rice. This network also aimed to study the long-term effects of new rotation patterns in productivity. In addition to the results of crop yields and profits, the cost of unit product, the labor requirement and water consumption for each crop, the crop-to-crop interactions, and the effects of different rotations on chemical (e.g. organic matter, pH, and nutrients) and physical (e.g. bulk density) characteristics of soil, and biological environments (e.g. weeds and pests) are also being recorded. These activities provide the opportunity to develop the principles and methodologies essential in pursuing the objectives of the cropping systems research. Thus, AVRDC is mainly involved in data storage, system analysis and application and using these results to identify key factors for designing improved cropping systems.

Preliminary analysis of results from field trials in the first 3 years (from 1986 to 1988) showed that there was great variation in crop yields caused by yearly climatic changes. Thus, there was substantial variation in returns; some patterns had a coefficient of variation higher than 50%. It appeared that the

approach of comparing the economic return in 1 year only is not a reliable way to evaluate cropping patterns. An accurate prediction of crop performances such as growth duration and yield performances is important for cropping systems research. To compile the data obtained from this network, a form that can be applied in designing cropping patterns, the growth duration and yield of each commodity in different season plantings and locations were calculated and their standard deviations were also included for risk analysis (Table 3 and 4). This information provided an easy way to compare the growth duration and yield level in a particular season and locality. For example, the performances of soybean, maize, and peanut in specific locations and seasons can be compared with those in a rice conversion project. It appeared that this information should be collected from all possible sources (publications, reports, and yield trials) to support efficient estimation and consequently, the designing of new cropping systems. The data including location, soil type, previous crop, name of crop and variety, planting and harvesting dates, and crop performance should also be recorded in all kinds of yield trials to be used in cropping systems design. The new technology of modelling for crop growth and yield will be a very useful means for this kind of analysis and prediction.

Table 3. Growth duration (days) of crops in different locations and seasons, 1986-88.

Crop	Season	Taoyuan	Taichung	Tainan	Kaohsiung	Hualien	Taitung
Rice	Spring	131.7±5.8	124.7±10.7	146.2±15.9	115.2±1.3	159.0± 2.9	124.3± 5.4
Rice	Summer	118.0±5.1	127.1± 3.8	107.5± 3.1	93.8±1.3	123.3±13.3	94.0±11.6
Soybean	Spring			106.2± 2.7	100.5±7.1		109.7±[illegible].8
Soybean	Summer			101.6± 8.8		101.5± 1.2	
Soybean	Autumn				99.8±0.8		
Peanut	Spring					137.7± 6.6	
Peanut	Summer	117.3±8.0	133.3±14.6				
Maize	Spring	133.7±9.7	109.6± 3.2		125.0±2.9	126.0± 8.0	108.0±12.8
Maize	Summer						98.5± 0.5
Maize	Autumn			133.7± 6.0	134.[illegible]		136.8± 0.7

Table 4. Crop yields (t/ha) of crops in different locations and seasons,

Crop	Season	Taoyuan	Taichung	Tainan	[illegible]	Hualien	Taitung
Rice	Spring	5.5±0.3	5.8±0.2	6.2±0.3	5.5±0.1	3.7±0.9	5.6±1.0
Rice	Summer	4.5±0.8	4.2±0.7	4.5±1.1	4.3±0.3	3.2±0.6	4.7±0.6
Soybean	Spring			2.9±0.6	2.9±0.2		3.2±0.7
Soybean	Summer			2.3±0.3		2.0±0.4	
Soybean	Autumn				2.6±0.2		
Peanut	Spring					2.3±0.2	
Peanut	Summer	2.0±0.3	2.7±0.5				
Maize	Spring	4.7±0.1	2.4±1.2		5.4±0.3	4.3±0.8	3.9±2.3
Maize	Summer						4.6±0.5
Maize	Autumn			6.1±2.1	5.6±0.3		5.8±0.4

Results also pointed out that in addition to crop yield level (which affects economic return) and total growth duration), water and labor requirements are important in cropping pattern evaluation in Taiwan. No conclusive results have been recorded on the changes of soil fertility and pest population in different cropping patterns.

Development of Knowledge Base in Crops Production

The improvement of cropping systems should be intensively information-based. Accurate information must back up efficient cropping system designs. The following projects were established to build up the knowledge base in crop production.

Mapping the suitable production areas for substituting crops. For selected major crops, this procedure is an important systematic approach to help farmers in selecting suitable crops for specific environments. A well organized data base on the results of these studies will be useful to farmers in other regions for their crop selection.

A series of surveys and experiments have been conducted by soil scientists in District Agricultural Improvement Stations (DAIS) throughout the island since 1984 to investigate the suitable production areas, in terms of climatic conditions and soil characteristics for maize, sorghum, peanut, processing tomato, grape, and asparagus. Maps of suitable production areas are being made and used as a guide to farmers in selecting suitable substitute crops.

Data base of vegetable performances under tropical conditions. A computerized data base on vegetable performances under tropical conditions is being prepared. Data on characteristics such as yield level, growth duration, and suitable growth temperature of 100 varieties of 34 vegetables have been collected and compiled in a form applicable in selecting suitable cropping pattern, locality or condition. The methods of vegetable grouping based on their attributes for the hot humid conditions are being studied. The first attempt aimed mainly to rate the heat tolerance of vegetable varieties tested. They are grouped into suitable temperature regimes in Taiwan. Substantial variations in yield of vegetables and varieties under similar temperatures including high temperature have been recorded. These data can be utilized to examine the relationships between yields of a particular variety or crop and temperature conditions, and to select heat-tolerant vegetable varieties.

Development of System Analysis Methodology

Testing, validating and applying the soybean growth and yield model (SOYGRO). A crop growth model is developed based on the fundamental understanding of the interactions between crops and environment. This model can assist in transferring agricultural production technology from its site of origin to new locations with similar or different environments, in agronomic decision making, in predicting the suitability of a crop and in identifying its genetic improvement direction in a given environment. However, the crop growth models have limitations because they do not include all factors that occur in reality. They require calibration and testing for site-specific application.

A network including AVRDC and Taiwan Agricultural Research Institute and six district agricultural improvement stations was organized to study the system analysis on relationships of soybean yield and environmental factors. Initial significant effects of environments on the growth and yield of soybean were found. Significant interactions of genotypes and environment were also found. These data were used for testing, validating and applying the soybean growth and yield model, SOYGRO. It was found that this model could accurately predict physiological stages of soybean in different locations and seasons. It is also feasible to apply this soybean growth model in the tropics for yield estimation,

provided with some modifications on the relationships of assimilate and environments, and nitrogen and yield.

Expert Systems

Expert systems are designed to simulate a human expert's approach, knowledge and experience in making a diagnosis or recommendation. These systems contain knowledge base and simulation models.

An expert system for crop selection is being developed at AVRDC, using the data base of vegetables mentioned earlier. This expert system aims to select suitable crops to be incorporated into staple food crop-based cropping systems. The selection is based on the following flow:

- Identifying production period of staple food crop.
- Estimating possible growing duration before or after staple food crops, based on water availability.
- Providing information on temperature range of above-mentioned growth duration.
- Sorting the data base based on growth duration and temperature range.

Conclusion

Agricultural production in Taiwan is suffering from a relatively higher production cost than that in other countries. Hence, it is facing the pressure of competition under free trade in the international market. Furthermore, the productivity of most arable lands in Taiwan is declining due to intensive production systems that have no appropriate management. It is an urgent task for the production of crops in Taiwan not only to improve yield and quality, and reduce production cost, but also to contribute to sustainability. These tasks need a holistic systems approach and cropping systems research. Research in the following areas is needed:

- A centralized and computerized information center to collect and analyze all available data on crop performances under different environments and their responses to management.
- Development and/or application of model and expert systems for important crops and for designing of improved cropping systems.
- Studies on nutrient recycling and efficient utilization of natural resources.

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Agricultural Science and Technology Development in Taiwan: A Review

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Introduction

In spite of shortage of land and other natural resources, Taiwan has successfully developed its agriculture and built up a strong economy. Its economy has continued to grow vigorously during the past three decades. Per capita GNP in real terms increased 10 times, averaging 6.4 % per year from 1952 to 1989; and per capita income increased from less than US$200 to US$6890 during the same period. The high economic growth with very low inflation average of 6.4% annually has been called an economic miracle. As a result of economic development, living standards and social welfare have greatly improved. Per capita daily nutrient availability increased from 2078 cal to 3017 cal and the supply of protein rose from 49.04 g to 89.5 g during the period from 1952 to 1988.

Many factors have contributed to Taiwan's agricultural development. Among them, technical innovation and extension have played an especially important part. Between 1952 and 1989 agricultural production increased at an annual rate of 4.0%. The output gains were achieved mainly through technological improvements that raised the productivity of both labor and land. However, since the mid 1960s with industry becoming the predominant sector in the country's economy, agriculture has moved from a major supporting role to a sustaining one. The traditional labor-intensive farm operation has increasingly given way to capital-intensive production. Agricultural production has increased in value by over 40 times since 1952. The total value of agricultural products amounted to NT$313.50 billion in 1988. Farm exports in the same period increased by 30 times; they were worth US$3.7 billion in 1988, but they compared poorly with the farm imports of more than US$ 5.8 billion in the same years.

Although agriculture has contributed to the national economy, its place in the economic system has changed drastically. After World War II, agriculture was the mainstay of the economy. Its successful development laid the base for industrial and overall economic development by providing low-cost labor, food, raw materials and capital. But the importance of agriculture has declined in recent years. In 1952, agriculture provided more than 32% of the gross domestic product (GDP), but it decreased to 4.9% in 1989. During the same period, the proportion of agricultural employment to total employment decreased from 56% to 13%, and the share of agricultural exports dropped from 96% to 6%.

The reasons for the decline are: competition from other sectors in the use of natural resources and labor, changing food consumption patterns, and especially, the trade liberalization policy in recent years. In addition, the desire to improve the quality of life and rising environmentalist sentiments have also exerted strong impact on the agricultural sector, forcing the government to adopt new measures.

The emphasis of the current policy is on boosting farm income and improving the agricultural structure. Over the years, therefore, COA has stressed the need for: (1) increasing agricultural productivity through technical innovations; (2) adjusting the production structure in accordance with market trends; (3) improving product marketing and processing; (4) strengthening the role of the farmers' associations and agricultural extension; and (5) improving agricultural production and rural development.

These rapid changes presented agriculture with new problems similar to those that other industrial countries met at a similar stage of development. With continued increase in services and industrial employment, the farmer is faced with rising labor costs. This and increased expenses for other inputs required new technologies that adversely affected the farmer's net income. There has been a noticeable migration to cities, especially among the younger people. More and more farm families have turned to part-time farming and depended on off-farm earnings to supplement their income. Growth in agricultural production has slowed down. To sustain this growth, a series of development programs has been carried out since the 1970s. The first one, known as the Accelerated Rural Development Program, was introduced in 1973. In 1979, a 6-year Program for Strengthening Rural Development and Increasing Farmers' Income was put into practice, and a similar program followed in 1985 to continue the increasing growth momentum. Currently, the Council of Agriculture (COA) is in the process of formulating an integrated agricultural adjustment program for 1991.

Limited by natural resources, our agriculture relies much more on research and technological innovations. A basic goal of agricultural research is to foster a high agricultural productivity that conserves rather than dissipates natural resources.

Major Achievements

The overall effect of advancing agricultural research and technology has given farmers more control over nature, and has increased production, reduced production risks, and increased marketing efficiency. The main accomplishments are as follows:

- Generally improved livestock and cultured fish with higher reproduction rates.
- Genetically improved high-quality, high-yield and pest-resistant crop varieties.
- Improved methods of soil conservation, drainage and irrigation.
- Control of livestock and fish disease and prevention of exotic diseases.
- Efficient control of pests and diseases affecting crops and stored products.
- Better crop, livestock and fish nutrition.
- Improved farm equipment and mechanization practices.
- More efficient processing and food marketing.
- Improved fishing efficiency and artificial propagation of fish for cultural purposes.
- A higher standard of living in rural areas.
- Improved forest management and remote-sensing technology.

Problems

In pursuing development in agriculture, Taiwan is now faced with a number of problems. The major ones are market fluctuations and competition from farm imports, small-scale farming, shortage of labor, low rate of return on agricultural investment, income disparity between farm and nonfarm families, ever increasing demand for quality farm products, greater consumption of meat, vegetables and fruits,

pollution from overuse of pesticides and fertilizers, and waste disposal resulting from an expanded animal industry in addition to the ever-increasing seriousness of environmental pollution.

Current R & D Priorities

Current agricultural research priorities are designed to increase food production both in quantity and quality to meet the needs of a growing population. These priority areas are as follows:

- Adjustment of agricultural production structure and improvement of farmland use;
- improvement of forest productivity and management, conservation of slopeland, water and soil, and improvement of watershed management;
- ensuring proper use of coastal areas;
- development of seawater aquaculture and sea-farming technology for better utilization of coastal water for fish production;
- increasing animal production efficiency;
- minimizing food loss by improving postharvest treatment, handling and storage technology;
- development of new pest control technology and preventing livestock and poultry losses from diseases;
- improvement of marketing systems including grading, packaging and transportation techniques;
- use and preservation of plant and animal germplasm; and
- biotechnology research and development.

Outlook

In the years ahead, the relative importance of agriculture in the overall economy will be decreasing, but it will continue to perform important functions. These functions are:

- Provision of an ample, stable supply of foodstuffs aimed at achieving economic and social stability; and
- Preservation of green resources and expansive, rustic scenery, thus keeping the rural communities in peace and comfort.

Technical innovation will remain a prime mover in sustaining continuity and expansion of our agricultural development. Since our agricultural resources are limited, further development will depend heavily upon increasing land productivity and assuring the security of renewable resources through intensive and well-managed technological research. Although advanced technology has enhanced production capacity and resulted in the current surplus of rice and some other products, destructive climatic conditions could rapidly eliminate food reserves and cause food shortages.

To ensure food security, sophisticated and efficient production systems with better control over weeds, diseases and pests and less dependence on weather must be developed. Transportation systems and distribution patterns will be further developed to move efficient primary and processed products to consumers more efficiently. New technologies for processing and packaging will ensure the continued availability of sufficient but low-cost food. Storage technology will allow storing new varieties of commodities, controlling insects and harmful microorganisms that have become increasingly resistant to current control methods.

Through hundreds of agricultural research projects now underway, scientists are discovering new and better ways to grow crops, to produce superior livestock, poultry, fish, more effective ways of distribution of farm products and better management of agricultural information. Major objectives of agricultural science and technology programs are as follows:

- Promotion of mission-oriented, long-term national research projects, to improve agricultural production marketing to increase the farmers' income.
- Coordination of structural and functional improvement, and reorganization of agri-research institutions, including the readjustment of organization, research goals, division of labor and closer cooperation.
- Strengthening of support for extension organizations to facilitate the transfer of technology and information to end-users.
- Strengthening of research and development of food processing technologies and new products and expansion of both domestic and foreign markets.
- Promotion of cooperation with international/foreign agri-research institutions.

Appendices

Appendix A. Studies actually disbursed under fiscal 1974, 1988 and 1989 special budgets for agricultural development.

	No. of projects			Subsidies disbursed			% of the total		
Items	1974	1988	1989	1974	1988	1989	1974	1988	1989
				(Unit: NT$1000)					
Farm production	105	103	113	824,955	1,300,496	1,541,268	39.96	35.25	41.09
Infrastructural improvement	90	102	96	912,231	864,439	673,939	45.68	23.43	17.97
Research development	83	173	172	179,603	880,990	882,029	8.99	23.88	23.52
Marketing and extension	12	43	46	59,522	531,963	531,963	2.98	14.42	14.18
Others	20	13	16	47,660	111,072	121,681	2.39	3.01	3.24
Total	320	434	443	1,996,973	3,688,960	3,750,880	100.00	100.00	100.00

Appendix B. Budget allocated for R&D projects.

Items	1989	1990
	(Unit:NT$1000)	
Agriculture	341,504	343,700
Forestry	103,431	96,800
Fisheries	68,000	61,500
Husbandry and Veterinary	196,015	170,000
Food Technology	195,425	233,875
Marketing and Information	55,590	88,300
Agricultural Economics and Planning	22,500	27,500
Human Resource Advancement	30,000	45,000
International Cooperation	158,581	167,581
Others	27,760	-
Total	1,198,806	1,234,256

Appendix C. Budgets allocated for national agricultural research projects.

Item	1989	1990
	(Unit:NT$1000)	
Biotechnology	63,500	63,000
Agriculture Pollution	25,000	27,000
Biological Control	5,000	17,000
Protected Cultivation	35,000	33,000
Food Technology	7,000	-
Locally Made Agricultural Machinery	35,000	35,000
Agriculture Germplasm	55,000	90,000
Cultivated Fishery	15,000	15,000
Biological Products	65,000	34,000
Total	315,500	314,000

Appendix D. Budget for COA subsidized crop improvement under FY 1989 and FY 1990.

Item	1989	1990
	(Unit:NT$1000)	
Agronomy	74,260	73,175
Horticulture	138,829	132,000
Plant Protection	59,600	65,650
Soil and Fertilizer	19,200	23,200
Agricultural Machinery	46,000	48,000
Total	337,889	342,025

Appendix E. Expenditure for agricultural R&D in 1989.

Agency	Basic	Applied	Development	Total
		(Unit:NT$1000)		
Central Government Institutions	73,616	4,275	-	77,521 (2.95%)
Universities and Colleges	92,616	264,470	56,370	413,456 (15.76%)
Provincial Institutions	106,290	1,072,735	377,442	1,556,467 (59.32%)
Institutions supported by enterprises or foundations	73,384	399,594	90,900	563,878 (21.49%)
Others	5,213	7,480	-	12,693 (0.48%)
Total	350,749 (13.37%)	1,748,554 (66.63%)	524,712 (20.00%)	2,624,015 (100.00%)

Appendix F. Human resources for Agricultural R&D in 1989.

Agency	PhD	MS	BS	Others	Total
Central Government Institutions	35	16	31	2	84 (3.3%)
Universities and Colleges	367	301	312	76	1056 (41.6%)
Provincial Institutions	120	307	241	365	1033 (40.6%)
Institutions supported by enterprises or foundations	39	114	100	90	343 (135%)
Others	1 (1.0%)	6	15	3	25
Total	562 (22.1%)	744 (29.3%)	699 (27.5%)	536 (21.1%)	2541 (100%)

Appendix G. Number of R&D projects.

Items	1989	1990
Agriculture	714	713
Forestry	208	170
Fisheries	100	111
Husbandry and Veterinary	144	135
Food Technology	203	192
Marketing and Information	26	25
Agricultural Economics and Planning	20	27
Human Resource Advancement	40	57
International Cooperation	23	31
Others	5	14
Total	1,483	1,475

Progress in Research and Application of Biotechnology on Vegetable Production in Taiwan

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Abstract

Research on biotechnology in vegetable production has been active over the past 4 years in Taiwan, although a direct application of the research results is still at the initial stage. Current developments in biological control agents, transgenic plant technology, artificial seed technology, and pesticide and plant disease diagnosis are encouraging. These technologies can have significant impact on future vegetable production in terms of both quantity and quality. In this report, research results and the work in progress at the Development Center for Biotechnology are described and presented as main examples for biotechnology application in vegetable production. Part of the efforts and the progress other institutions have achieved in this field will also be discussed.

Introduction

What scientists have come to learn about crop production has been impressive. Over the past two decades, agricultural productivity in Taiwan has had an overall increase of 300% (Council of Agriculture 1986). This increase has helped feed the growing population of Taiwan. The annual agricultural production has been reduced from about 5% in the 1960s down to 1.5% in the year of this report (Council of Agriculture 1986). Such a reduction has indicated certain barriers that were present in the production system. Barriers such as high rural labor cost, relatively low farm income and the reduction of farm land may not be within the capability of agricultural sciences to deal with, but generally technical innovations are the prime movers in agricultural development of Taiwan, especially since Taiwan's resources are limited. Intensive and well managed research is essential in boosting land productivity.

Vegetable production has been improved significantly through conventional plant breeding, hybrid seed production, application of agrochemicals including fertilizers and pesticides, and farm mechanization. However, the conventional approach has reached its limitation in breeding for viral resistance, insect resistance, developing effective biological control agents, developing plant disease identifying variety and traits at themolecular level, modifying the quality of the products such as the delayed softening of tomato after harvest, etc. Therefore, it becomes an urgent need to consider biotechnology to resolve these important technical problems.

Biotechnology is a multidisciplinary technology integrated with molecular genetic techniques and other biological sciences and bioengineering technology. Over the past 4 years, research and application of biotechnology in vegetable production have been actively progressive in various institutions in Taiwan. In this report, the progress of the work made at the Development Center for Biotechnology (DCB) in areas of 1) developing biological insecticides, 2) developing fungicides of biological origins, 3) artificial seed technology, and 4) transgenic plant technology will be described as examples. Part of the results and progress made in other institutions will also be reviewed.

Development of Biological Insecticides

Chemical insecticides have been applied in agriculture for nearly 50 years. However, using chemical insecticides such as those with high efficacy, broad spectrum and long residual effect has its own disadvantages. The rapid development of pest resistance to chemicals, introduction of secondary insects, elimination of natural beneficial insects, residual contamination of fruits and vegetables, and the damage to human and animal health are significant problems encountered in the use of chemical insecticides. The need for developing biological insecticides is quite urgent, especially in highly populated areas such as Taiwan where farm land and the living quarters are close together. In Taiwan, over 1,000 entomopathogens including viruses, bacteria, fungi, protozoa and nematodes have been identified in the past as potentially useful biological control agents (Hou 1986). These pathogens are potentially useful as biological control agents. Recently, efforts have been centered primarily on research into *Bacillus thuringiensis* and nuclear polyhedrosis virus (NPV).

Bacillus thuringiensis K (B.t.k) is under active development in DCB commercialization. During the past 3 years, DCB has successfully developed a highly cost-effective and competitive process for B.t.k production. This product will be produced and sold by Taiwan Fertilizer Co., which aims to benefit farmers with quality products at reasonable prices and to reduce the pressure of chemical pollution. New production processes are not supposed to be released; however, the discovery of new strains of B.t.k can be reported. Several local isolates of B.t. have shown unique pathogenicity against diamondback moth (*Plutella xylostella*). For example, two local isolates, K2178 and K2074, are both being identified as HD-1 strain by flagella serotyping (Fig. 1) similar to the strain used in most commercial products known today. However, K2178 showed a unique pathogenicity against *Spodoptera litura* while normal HD-1 strain has little effect on this insect (Fig. 2). The other isolate, K2074, is one of the most potent strains in our collection. By specific activity (ng endotoxin protein basis), K2074 outperformed standard HD-1 strain by about 10 times (Fig. 3). After further analysis of the endotoxin crystals of these two isolates, K2178 was found to contain both P_1 and P_2 polypeptides, the same as those which have been found in a standard HD-1 strain. On the contrary, K2074 has only P_1 polypeptide in the crystal protein (Fig. 4). P_1 is the polypeptide pathogenic to lepidopterans and P_2 is against both lepidopterans and dipterans (Yamamoto and McLaughlin 1981). Therefore, P_2 polypeptide has a dilution effect on the P_1 in the crystal pathogenicity to lepidopterans. Having only P_1 in the crystal may partially explain why K2074 is more potent than a standard strain on a crystal basis.

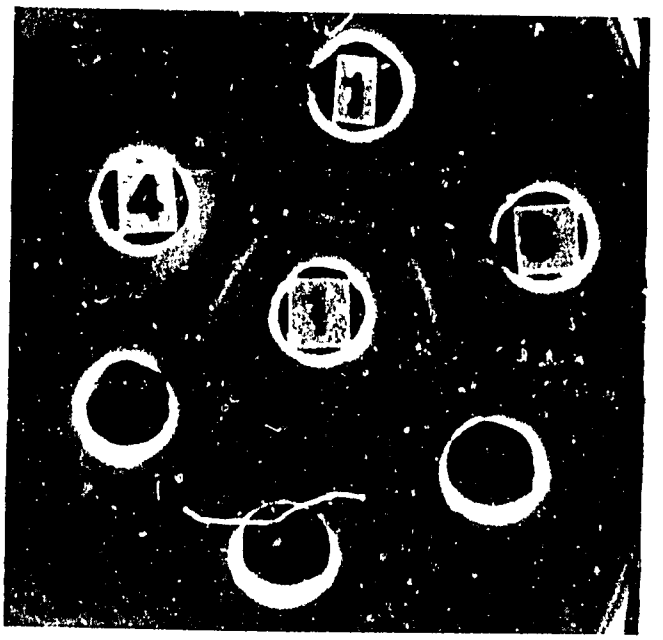

Fig. 1. The flagella serotype test of B.t. K2074 (labeled as 4) and B.t. K2178 (labeled as 8). The standard B.t.k. (HD-1) strain flagella protein antibody was placed in the well, labeled as 1 in the center. The side well of 1 is the flagella protein isolated from B.t.k. (HD-1).

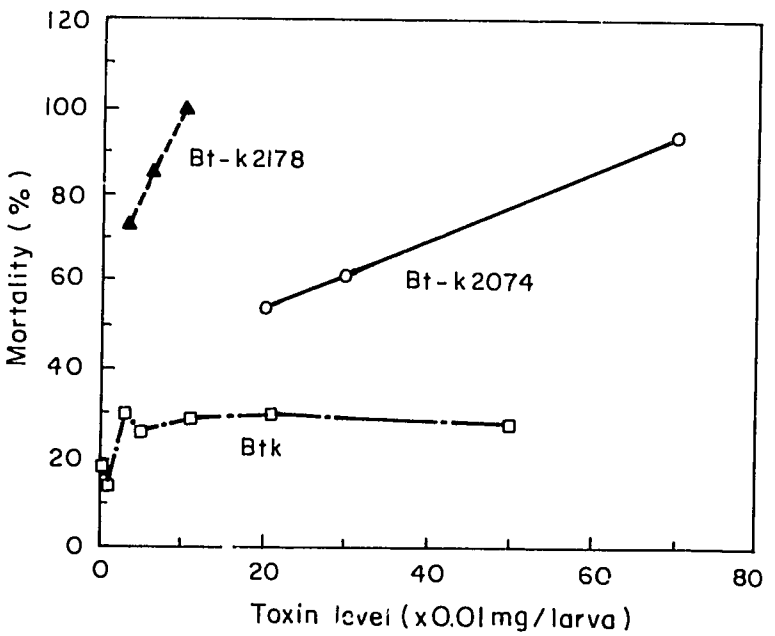

Fig. 2. Mortality of *Spodoptera litura* larvae as affected by the toxin crystals isolated from B.t. K2074, K2178 and a standard strain of B.t.k.

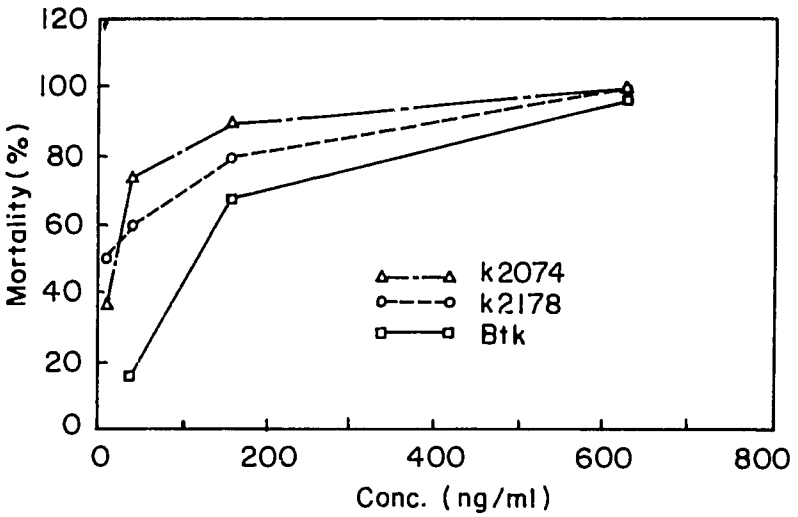

Fig. 3. Mortality of *Plutella xylostella* larvae as affected by the toxin crystals isolated from B.t. K2074, K2178 and a standard strain of B.t.k.

Fig. 4. The SDS-PAGE analysis of the polypeptides in the toxin crystals isolated from B.t. K2178 (lane 1), K2074 (lane 2) and a standard B.t.k. (lane 3).

Nuclear polyhedrosis virus (NPV) is also being investigated at DCB for its application in the field. The NPV of *Spodoptera litura* (sl-NPV) has been characterized at the molecular level, both the restriction fragment of its virion DNA and its coat protein patterns. The size of the DNA was calculated to be 123 Kb and the major molecular weight of its coat protein was found mainly to be 21 Kd, 46 Kd and 80 Kd. In the actual application, two areas of difficulties such as the following were met: a) the insects were killed 5-8 days after application, and b) the in vivo production of sl-NPV cannot guarantee that the recovered NPV is free of contamination from other microorganisms or pathogens. In the first case, the larvae of *Spodoptera litura* will still damage the vegetable leaves in 5 days and cause substantial crop loss, although the insect will eventually die. To solve this problem, we learned to use the low dosage of B.t. K2178 as a feeding retardant to mix with sl-NPV to kill insects without losing the crop (Fig. 5, 6). In the second case, it was clear that NPV produced from the infected insect will face the challenge for its purity in the market. In DCB, an insect cell culture technique has been employed to produce sl-NPV in large scale. A cell line of the ovary cells isolated from *Spodoptera litura* has been established and the scaled-up process is underway. It is potentially possible that a combination of NPV and B.t. will have a broader spectrum to cope with field conditions. In the process of developing NPV, an ELISA technique has been developed to quantitatively detect the amount of NPV that has been produced. This will be used as a tool for quality control in future production. The same technique has also been used to detect the transmission mechanism of NPV during the insect growing cycle. By an indirect ELISA test, the NPV of as low as 15 ng/ml was detectable (Table 1). NPV and granulosis virus (GV) were also developed in other institutions (Su 1989) at the research level.

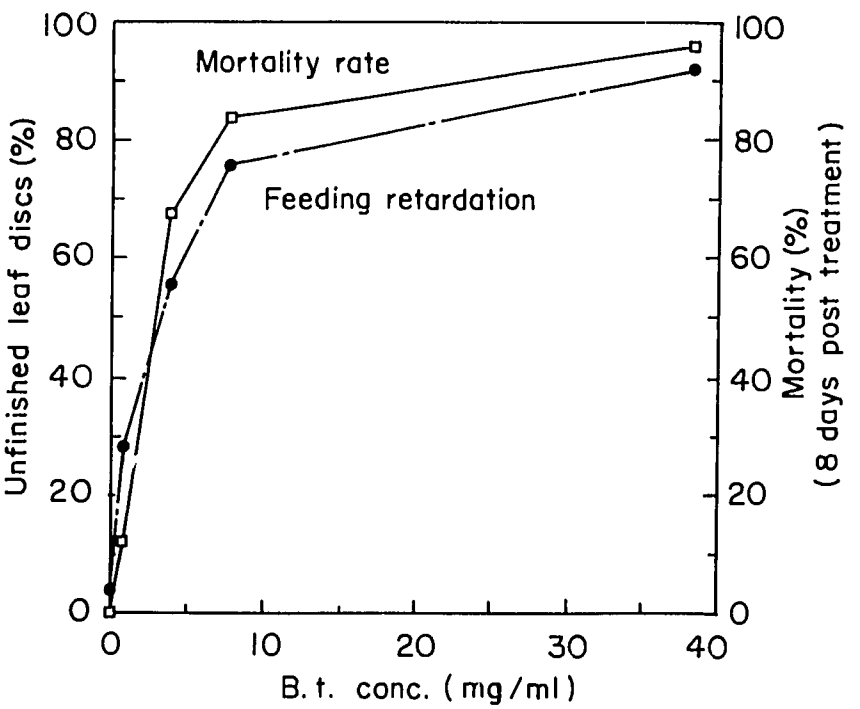

Fig. 5. Effect of B.t. K2178 on the mortality and the feeding retardation of the larvae of *Spodoptera litura*.

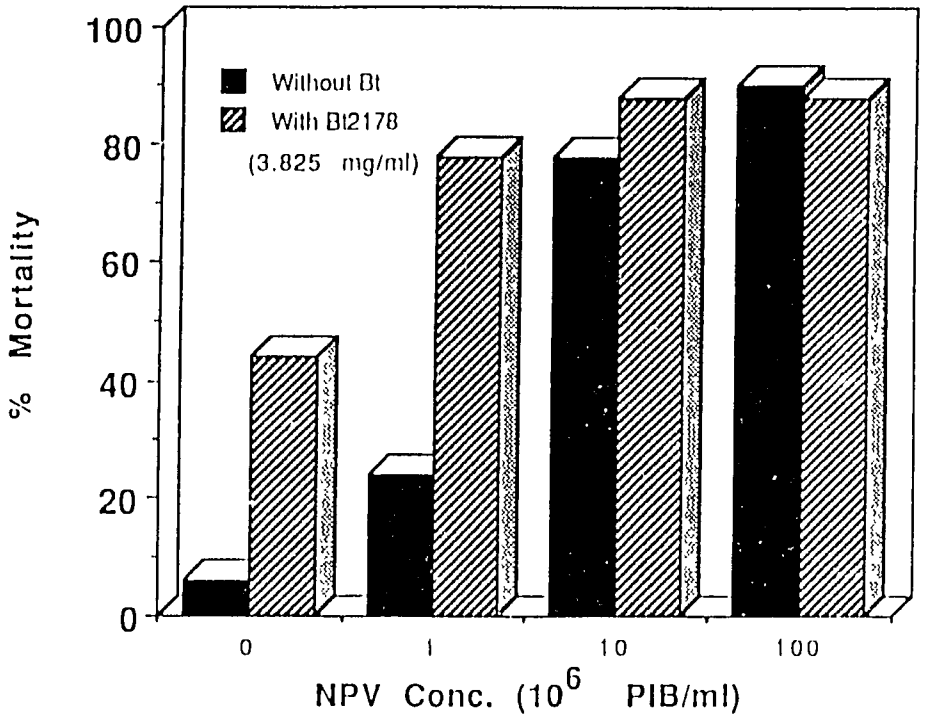

Fig. 6. The synergistic effect of B.t. K2178 and NPV on the control of the larvae of *Spodoptera litura.*

Table 1. Detectable concentration of antigen by antiserum through an indirect ELISA test.[a]

	Indirect ELISA Value (A405 nm)		
NPV (ng/ml)[b]	Intact NPV	Dissolved NPV[c] (virion)	Ck[d] (ng/ml)
2000	1.7475	2.151	0.121 (320)
1000	1.4710	1.544	0.132 (160)
480	0.9435	1.125	0.132 (80)
240	0.6920	0.816	0.134 (40)
120	0.4550	0.538	0.112 (20)
60	0.3450	0.342	0.121 (10)
30	0.2500	0.237	0.110 (5)
15	0.2220	0.178	0.120 (2.5)

[a]Antiserum was diluted to 6400-fold in the test.
[b]Purified nuclear polyhedrosis virus.
[c]NPV was dissolved by 0.05 M Na_2CO_3 for 2 hours at 4°C and then was filtered through a 0.2 Im milifore filter.
[d]Crude extract of healthy larvae of *Spodoptera litura.*

In addition to B.t. and NPV, pathogenic fungi have been used as insecticide. The conidial suspensions of *Metarhizium anisopliae* and *Beauveria bassiana* can cause 80-90% mortality of the insect larvae (beet armyworm, *Spodoptera exigua*). The results of field application were also encouraging (Kao and Tsai 1989). However, to maintain these fungi at their effective stage of sporulation requires extensive work.

Development of Fungicides

Fungicides have been extensively used in agriculture. The annual consumption of these chemicals in Taiwan alone has exceeded 3000 t. The fungicides currently used are primarily synthetic chemicals and quite a few of them are carcinogenic. The need for the development of safe fungicides is critical. Historically, pathologists of Taiwan have actively investigated the antagonistic microorganisms to control the pathogenic fungi. In Chung-Hsing University, *Bacillus subtilis* F29-3 was found to control the growth of 13 fungi and 9 bacteria (Tschen and Shen 1982). In Ping Tung College of Agriculture, *Trichoderma koningii* was effectively used to control *Rhizoctonia solani* in the field environment. Similar type of work can also be found in National Taiwan University (Chu and Wu 1980; Lee and Wu 1986) and other institutions. Research efforts in searching and identifying the counteractive microorganisms have provided leads for biofungicide development. Among these microorganisms, pseudomonades are particularly interesting since they can be colonized in the rhizosphere and some of them have been used to control soil-borne fungal diseases (Burr et al. 1978; Howell and Stipanovic 1979 and 1980; Weller 1988). The first commercially available biofungicide, Dagger G, derived from *Pseudomonas fluorescens*, has been used in cotton fields in the United States. At DCB, the fungicide development has been focused on: a) screening for potent antagonistic microorganisms, mainly bacteria and actinomyces, and strain improvement for better performance, b) identifying the active compounds produced from these microorganisms, c) developing a scaled-up process of production, d) designing a usable formulation to deliver the product and e) encouraging greenhouse and field evaluation. Currently, more than 1500 active strains have been collected from local soil. Among the strains, K413 was selected first on the list for commercial development.

Pseudomonas cepacia K413 is a broad-spectrum antifungal bacteria and the major active antifungal compound has been identified to be pyrrolnitrin as shown in a previous report (Kuo et al. 1989). The greenhouse experiments have confirmed the effectiveness of K413 on the protection of various vegetables, such as rape and cabbage from the infection of several soil-borne fungi (Fig. 7). Before entering a large-scale field evaluation, a continuous search for other potent pseudomonades has resulted in five active isolates of K2161, K5406, K5901, K5917 and K6110. These isolates have a high level of pyrrolnitrin-producing ability and are associated with various degrees of phytotoxicity (Fig. 8 and Table 2). These results indicated that K413 was not only potent but also nontoxic to all the crops being tested.

During the evaluation of these isolates, it was noted that K5406 was strongly active against *Pythium aphanidermatum* (Fig. 9). One of the active compounds against *P. aphanidermatum* produced by K5406 has been purified and will be identified later. This discovery leads scientists to further consider manipulating these isolates or a mixture of these to handle various types of plant diseases in the future.

Apart from the utilization of microorganisms as fungicides, DCB is also aware of the potential of developing the active antibiotic from microorganisms. There are 11 antibiotics currently being used in fungal control (Table 3). The focus of DCB has been on the actinomycetes that produced active compounds to discover new and patentable compounds. Recently, a Streptomyces sp. Y31042-1 has shown a strong antifungal activity against many of our target pathogens from the dual culture (Fig. 10). One of the active compounds from the mycelial extract of Y31042-1, ACW3, has been identified as a glycoprotein with a molecular weight of 1053. It has amino acids in the polypeptides (data not shown).

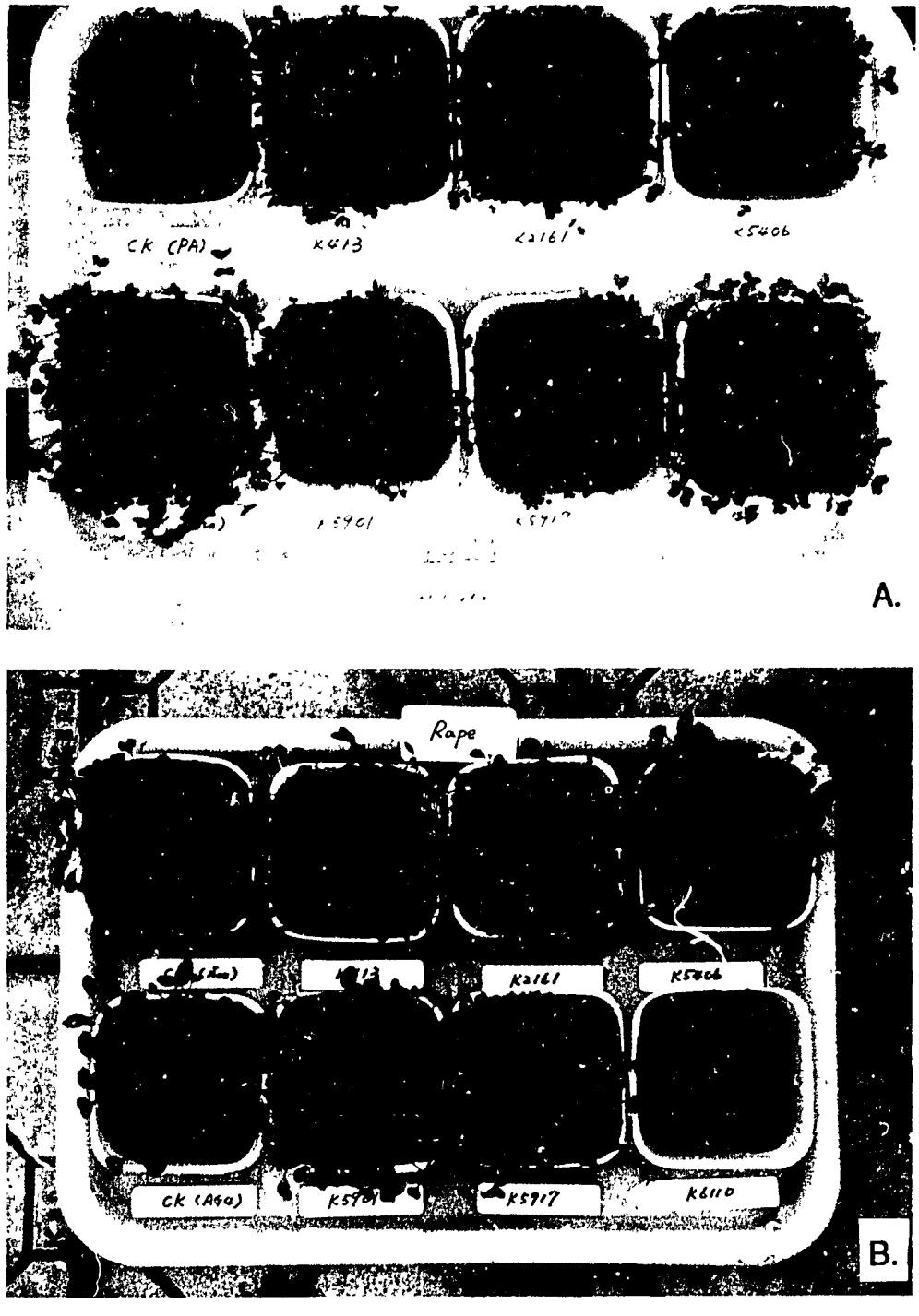

Fig. 7. Comparisons of six pseudomonad isolates on the control of *Pythium aphanidermatum* infection on cabbage (A) and *Rhizoctonia solani* AG4 on rapeseeds (B)

The minimal concentration of ACW3 to inhibit various plant pathogenic fungi is listed in Table 4, indicating that this glycoprotein has a wide spectrum of activity. More importantly, the antifungal activity of ACW3 is highly stable under high temperature. For instance, its activity can be maintained

after being autoclaved or treated with organic solvents. Such a stable nature will be important in field application. Further development of this compound in the area of genetic engineering and the modification of its structure has scientific potential. Its potential use in agriculture lies in field evaluation as well as in reduced production cost to make large-scale application feasible.

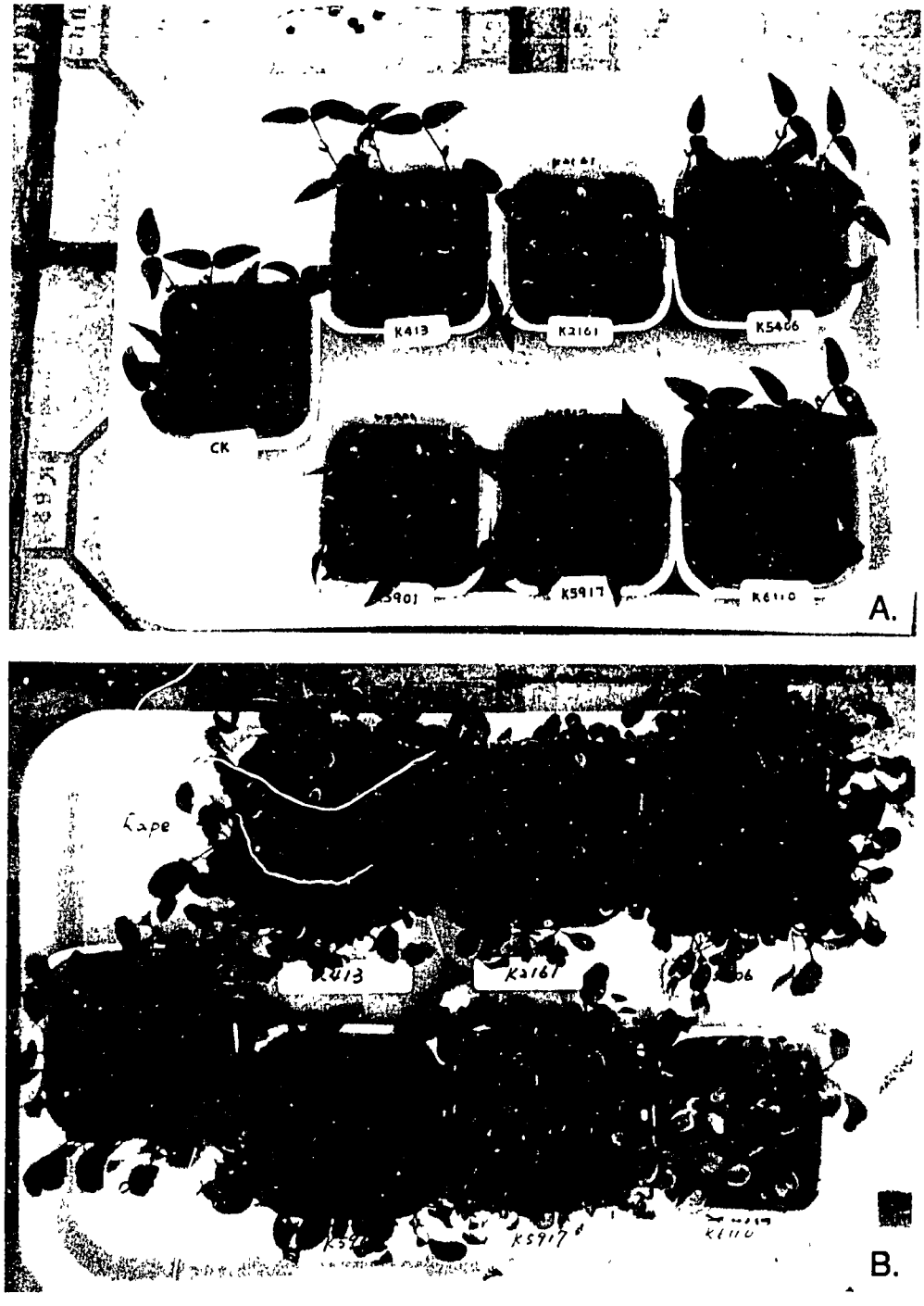

Fig. 8. Effect of six pseudomonad isolates on seed germination of mungbean (A) and rapeseeds (B).

Table 2. Effect of six pseudomonad isolates on seed germination of various plant species.

	Germination rate (%)[a]					
Isolate	Rape	Radish	Cabbage	Cucumber	Mungbean	Alfalfa
K413	65a[b]	53a[b]	86ab[c]	89a[d]	91ab[d]	55a[c]
K2161	39bc	48b	92a	91a	71b	42b
K5406	54ab	42c	92a	87a	100a	59a
K5901	45bc	21d	90a	93a	78ab	63a
K5917	68a	17e	88ab	98a	98a	57ab
K6110	33c	4f	82b	87a	93ab	61a
CK	42bc	19e	92a	91a	100a	70a

[a] The same letter indicates no significant difference at $P = 0.05$ level.

[b] Each value is the average of two replications of 200 seeds each.

[c] Each value is the average of three replications of 200 seeds each.

[d] Each value is the average of three replications of 15 seeds each.

Table 3. Antibiotics used in plant disease control.

Antibiotic	Classification	Producing microorganism	Main suitable disease
Blasticidin S	Nucleoside	*S. griseochromogenes*	Rice blast
Kasugamycin	Aminoglycoside	*S. kasugaensis*	Rice blast
Polyoxins	Nucleoside amino acid	*S. cacaoi* var. *asoensis* contg.	Sheath blight of rice
Validamycin	Aminoglycoside	*S. hygroscopicus* subsp. *limoneus*	Sheath blight of rice
Griseofulvin	Aromatic	*P. griseofulvum*	Early blight of tomato
Cycloheximide	Alicyclic	*S. griseus*	Downy mildew of onions
Ezomycin	Nucleoside amino acid	Unclassified *Streptomyces* sp.	Stem rot of kidney bean
Streptomycin	Aminoglycoside	*S. rimosus*	Fire blight of apple and pear
Chloramphenicol	Aromatic	*S. venezuelae*	Bacterial leaf blight of rice
Novobiocin	Glycoside	*S. spheroides* and *S. niveus*	Bacterial canker of tomato
Cellocidin	Aliphatic	*S. chibaensis* and *S. reticuli* var *aquamyceticus*	Leaf blight of rice

Table 4. Antifungal activity of compound ACW-1, ACW-2 and ACW-3.

Test fungus	MIC[a] (µg/ml)		
	ACW- 1	ACW-2	ACW-3
Alternaria tenuis	>200	>200	>200
Botrytis cinerea	>200	>200	6.25
Colletotrichum musae	>200	200	6.25
Fusarium oxysporum f. sp. *cubense*	>200	>200	6.25
Fusarium oxysporum f. sp. *niveum*	>200	100	6.25
Fusarium oxysporum f. sp. *raphani*	>200	200	12.50
Phoma asparagi	>200	100	0.78
Phytophthora capsici	>200	>200	25
Pythium aphanidermatum	>200	200	25
Pythium spinosum	>200	>200	12.50
Pythium sylvaticum	>200	>200	25
Rhizoctonia solani AG1	>200	100	1.56
Rhizoctonia solani AG4	>200	>200	6.25
Sclerotinia sclerotiorum	>200	200	12.50
Sclerotium rolfsii	>200	>200	100

[a]Minimal Inhibitory Concentration (MIC).

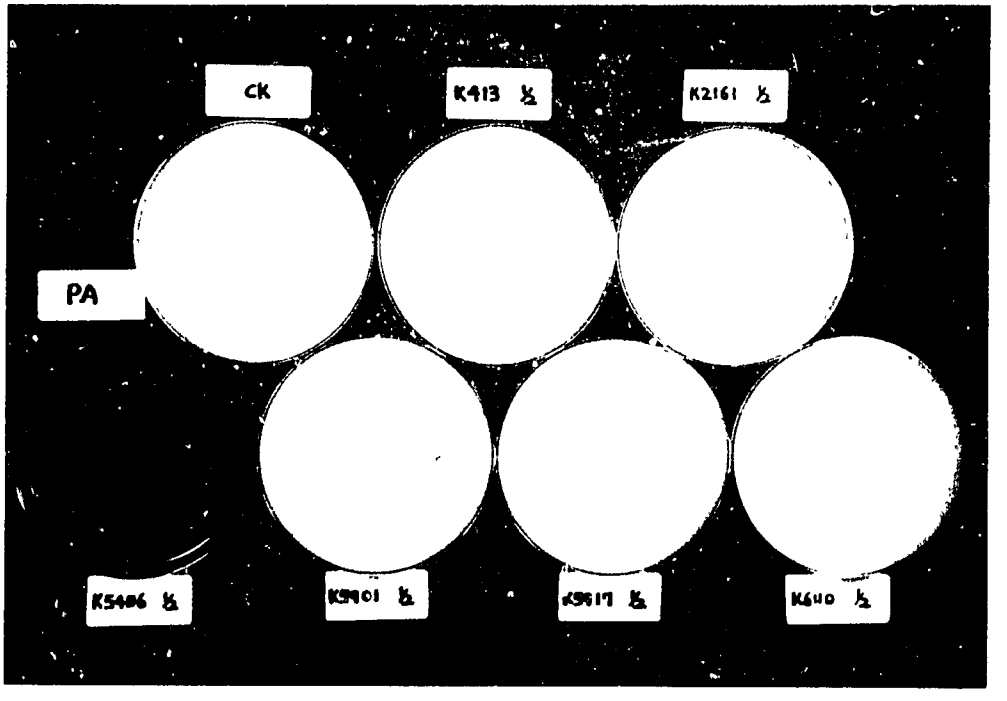

Fig. 9. Effect of autoclaved cultural broth of six pseudomonad isolates on the mycelial growth of *Pythium aphanidermatum*.

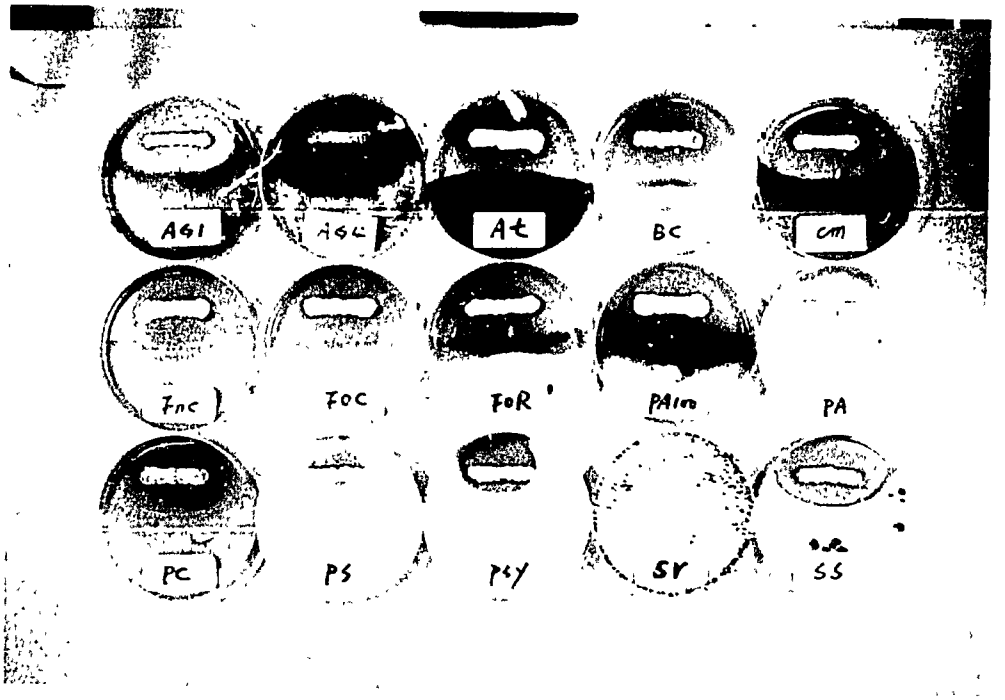

Fig. 10. The antifungal spectrum of a Streptomyces sp. Y31042-1.

Artificial Seed Technology

The concept of artificial seed was introduced in the United States (Murashige 1977). A mass production of somatic embryos with proper polymer encapsulation might have the potential to compete with the real seeds. Recent advances in artificial seed technology have been documented, that somatic embryogenesis could be used for clonal propagation of plants (Ammirato 1983a and b; Kitto and Janick 1985a, b and c; Redenbaugh et al. 1986). In vegetable production, high labor cost and the nature of plants (e.g., monocotyledons) have restricted a further development of hybrid seeds. From genetically engineered plants, high-value crops and other hybrid vegetables were produced through cell fusion where micropropagation and greenhouse cuttings or conventional hybridization techniques are difficult. Artificial seed technology may provide an alternative for mass production.

Through the strong support of the Council of Agriculture (COA), DCB has initiated a program of developing artificial seed technology. The initial target was to develop: a) mass propagation system for lettuce with a bioreactor, and b) an encapsulation device for the delivery of the somatic embryo. Much effort has been dedicated to the development of a more efficient method for the micropropagation of lettuce (Koevary et al. 1978; Pink and Carter 1987; Reinert and Bajaj 1977; Sasaki 1982; Webb et al. 19[illegible] [illegible]helmore 1985). However, culturing lettuce cells in the past was primarily done by growing ca[illegible] r plate and little information was available on growing cells in a liquid suspension culture. In a sha[illegible] ask culture, a method has been developed to grow lettuce calli in solution and reached a high regeneration frequency that can be doubled in the suspension (Fig. 11). This system provided a basis for us to propagate lettuce embryos in a bioreactor. In the delivery system, encapsulating the plant material to maintain viability still needs to be perfected.

Artificial seed technology is difficult to develop. For example, somaclonal variation, shelf life of the encapsulated embryo, interference of field microclimates, and other factors, have further complicated the work, but the need to develop such a technology is essential to propagate vegetables of high value.

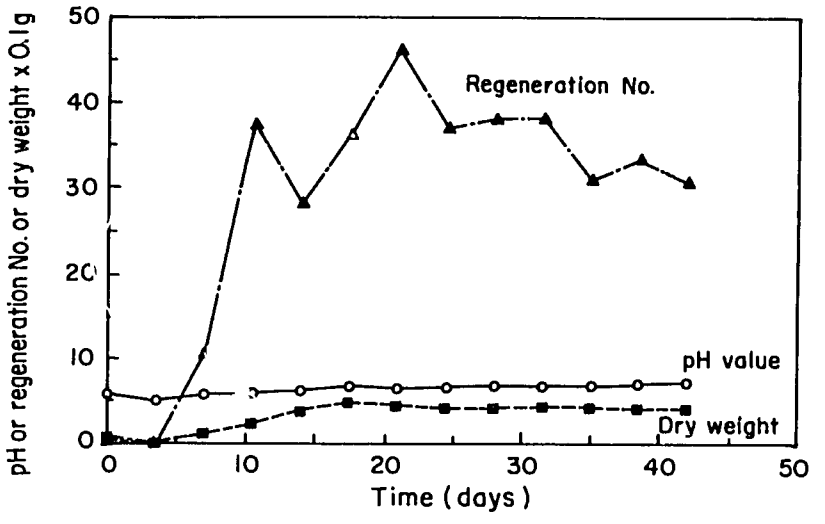

Fig. 11. The changes of growth, regeneration frequency and pH of lettuce calli cultured in a liquid suspension culture.

Transgenic Plant Technology

Traditionally, plant breeding has achieved its goal of breeding superior plant varieties through gene recombination by cross pollination among varieties. This is followed by a schematic selection process with a built-in selection pressure. However, such processes are limited by the source of the gene which normally exists in the population of a given species. If a gene has to be transferred from a different species or from microorganisms to the plants, then the molecular biology must be utilized to compensate for the inadequacy of the traditional breeding technology. In the literature, current advances in herbicide-resistant plants (Greef et al. 1989), insect-resistant plants (Vaeck et al. 1987) and in viral-resistant plants (Anderson et al. 1989) have suggested that a new era of plant breeding has begun. In Taiwan, the work on transgenic plant technology has been conducted in the Institute of Molecular Biology, Academia Sinica, mostly on transgenic rice and other model plant systems. Work has also been initiated at the National Chung-Hsing University and National Taiwan University. However, the scale and the intensity of the work are still in an early stage although initial efforts are commendable.

In DCB, the agrobacterium-mediated T-DNA transfer to express a bacteria GUS gene in tobacco plant was successfully demonstrated in 1988. A similar procedure may be applied in the transformation of tomato or other agronomically important dicotyledon crops. In vegetable production, insect resistance and viral resistance may be of significance. Since we have been involved in B.t.k development, it is only natural for us to select toxin genes with uniquely high potency or broad spectrum for transfer to vegetable plants. Vaeck et al. (1987) reported that in NH2-terminal, half of the B.t. toxin gene was adequate to have full toxicity, i.e. between amino acid positions 29 to 607. In the same report, it was also suggested that a shorter B.t. toxin gene can be expressed more efficiently in the plant to provide a higher level of protection against insects. Therefore, in our laboratories, the B.t. toxin genes currently isolated from K2074 and K2178 and both (by gene fusion) will be further trimmed to a shorter size for future transfer to vegetables. However, the resulting B.t. toxin-producing plants may induce plants. This is done by isolating the coat protein genes of these viruses, making DNA from the viral RNA

and then injecting them into these crops. The idea is to produce the coat protein genes in plant cells and to capture the infected viral RNA within the cells before the RNA is reversely transcribed into DNA and subsequently incorporated into nucleus DNA. The success of such a process could result in significant improvement in both banana and papaya production in Taiwan. Such a system has been successful in generating TM- resistant tobacco (Register and Beachy 1988). Recent reports on the discovery of TMV coat protein gene inserted plants also showed tolerance to other less related viruses (Anderson et al. 1989). We see no reason why we cannot try to insert the coat protein genes isolated from banana bunchy top virus or papaya ringspot virus into vegetables to check the cross protection against the viruses of vegetables.

Conclusions

Although biotechnology is still in its infancy in Taiwan, its impact can be enormous on agriculture in the future. Over the past 10 years, agricultural biotechnology has been primarily conducted in multinational companies and many of the important techniques and information are patented and proprietary. This poses a danger to the developing countries since future agricultural technology advancement may no longer be freely available.

To build a strong research base in Taiwan and to team up with experts in the agricultural field will be essential to maintain a progressively advancing biotechnology system. This could mean survival for future generations. DCB has limited resources such as personnel ; however, the insistence of mission-oriented research and an open-minded approach to the problem have built an effective team to work on important agricultural problems. We urge institutions to support and collaborate with other institutions domestically or internationally to develop the potential of agricultural biotechnology. Together, we will be able to forge advancement of vegetable production technologies for the benefit of all people.

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Application of Tissue Culture to Plant Science in Taiwan

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Abstract

The advantages of tissue culture for agricultural research on higher plants have been widely recognized, and tremendous progress in these techniques is being made in many developed countries. This paper summarizes the techniques that have been applied in the field of agriculture in Taiwan, including: 1) virus elimination and production of pathogen-free plants; 2) rapid multiplication of superior plants; 3) production of haploids and homozygous diploid plants by anther or pollen culture; 4) production of interspecific hybrids by test tube fertilization and embryo rescue; 5) production of secondary metabolites via callus or cell suspension culture; 6) production of new genetic resources by somaclonal variation; 7) preservation and international movement of germplasm; and 8) protoplast technology and gene transfer.

Production of Pathogen-free Plants

The aseptic requirement of the tissue culture process produces plants that are genetically free of bacterial and fungal diseases. The shoot and root apices are frequently devoid of viral particles or contain very low concentrations of these (Kassanis 1957). Thus, meristem or shoot tip culture techniques are frequently being used to eliminate viruses from plants. The uppermost fraction of an infected plant's meristem (usually around 100 μm in size), which is often free of viruses, is used as the explant source.

When virus-infected plants are kept at higher-than-normal temperatures, the virus may be partially or completely inactivated without damaging the host plants (Berg and Bustamante 1974). In this case, a large portion of the shoot tip may be taken as the explant if the plant has been pretreated with heat. Larger explants are not only more rapidly excised but are also more heat resistant and able to grow rapidly. Thus the combination of heat pretreatment and meristem cultures are to be recommended (Wang 1985). Heat treatment and treatment with antiviral agents such as virazole (Simpkins 1981) prior to meristem culture have been used successfully to slow down or halt the spread of viruses into the meristematic tissue, further assuring pathogen elimination (Chu 1990).

Tissue culture research was initiated by Taiwan governmental organizations about 25 years ago. In Academia Sinica, National Taiwan University (NTU) and Taiwan Agricultural Research Institute (TARI), various methods have been developed for mass propagation and virus elimination of many agricultural and horticultural crops. Many methods for mass propagation and virus elimination of these plants have been established. For example, a reliable method for propagation of banana through axillary

bud proliferation from suckers and methods of obtaining virus-free plants through shoot tip culture, and in vitro tuberization for mass production of seed potatoes were established in 1970 at NTU and Academia Sinica (Ma and Shu 1972, Wang 1977). Extension work for production of virus- or pathogen-free potato tubers and bananas has been maintained by Taiwan Seed Service (TSS) and Taiwan Banana Research Institute (TBRI). Healthy and virus-free sweet potato seedlings were obtained through the combination of heat treatment and shoot tip culture techniques in TARI (Liao et al. 1982).

Rapid Multiplication of Superior Plants

Meristem shoot tip or bud culture provides an effective means for rapid propagation of almost any particular genotype in many plant species. The advantages of employing this technique include efficient clonal propagation of a large number of disease-free plants due to the aseptic procedures. A very good example is the bulbil culture of *Pinellia ternata* B. This medicinal herb has been used widely for thousands of years in China to prevent vomiting and provide analgesic and sedative effects. The tubers collected from plants growing naturally in the mountains are insufficient for medicinal use. The tissue culture method was therefore used to mass propagate these plants. Adventitious buds or protocorm-like bodies were regenerated directly from cultured bulbil without intervening with the callus. Vegetative propagation of adventitious buds and protocorm-like bodies could be maintained by alternate solid-and liquid-medium culture (Fig. 1 and 2). Theoretically, 1.7×10^{27} plantlets could be produced from single bulbil by this technique within 1 year based on the production and rapid growth of protocorm-like bodies and adventitious buds. Tissue culture has the potential for clonal propagation of *P. ternata* plants for commercial use (Tsay 1989).

Pearl orchid (*Anoectochilus formosanus*), a miniature orchid, is famous for its medicinal uses. The whole plant is used for curing pneumonia, diabetes, high blood pressure and many other diseases. In fresh form, they fetch NT$1,000-3,000/kg. The orchid is disappearing in its native habitat in Taiwan where it grows at elevations of 600 - 1800 m mainly under forest canopies. Tissue culture was therefore used to propagate it.

Pearl orchid can be propagated by 1) Seed germination: Both immature and mature seeds of pearl orchid can be germinated in an artificial medium. Seed pods are obtained by hand pollination between different plants. It takes 50-60 days for seeds to germinate into rhizomes and finally plants. 2) Stem culture: Pieces of stem carrying at least one node are cultured in vitro to obtain new plants (Fig. 3). Cultures are kept at 25-27°C with 16 hours of daylight and subcultured and doubled at 4-week intervals (Liu 1987). In the last 3 years over 500,000 plants have been propagated by the TSS, and those plants were successfully cultivated at altitudes of 500-1800 m by farmers.

Many plants have been propagated successfully by tissue or organ culture in Taiwan in the last 10 years. These include strawberry, orchid, garlic, pineapple, cucumber, chrysanthemum, litchi, rose, banana, ginger, ginger flower (Fig. 4), anthurium (Fig. 5), potato, papaya, tea, *Azalea*, *Gysophila* spp., *Ficus* spp., *Actindia chinesia*, *Citrus* spp., *Dysosma pleiantha*, *Bupleurum falcatum*, *Pinellia ternata*, *Anoectochilus formosanus*, *Rehmannia glutinosa*, *Platycodon grandiflorum*, *Sasafras randaiense*, bamboo, jojoba, ginseng, passion fruit, *Stevia rebaudiana*, *Zizania latifolia*, and asparagus. Ginseng, local high price herb *D. pleiantha* and bamboo tissue culture techniques were thoroughly studied in Academia Sinica in the last few years. Somatic embryogenesis has been found in callus of ginseng. Plantlets derived from somatic embryoids flowered precociously and set miniature fruits. Culture of these in vitro-formed miniature fruits on a defined medium produced a mass of fruit-like structures (Chang 1980). Plant regeneration through embryoid formation from *D. pleiantha* was achieved, and the in vitro protocols obtained can be used as routine method for propagating this endangered herb (Chuang and Chang 1987). Plant regeneration through somatic embryogenesis from inflorescence-derived calli has been achieved in three bamboo species (Yeh 1986a, b, Yeh 1987).

Fig. 1. Adventitious buds or protocorm-like bodies were regenerated directly from cultured bulbil of *Pinellia ternata*.

Fig. 2. Ability of vegetative propagation of adventitious buds and protocorm-like bodies could be maintained by alternate solid- (Fig. 1) and liquid-medium (Fig. 2) culture.

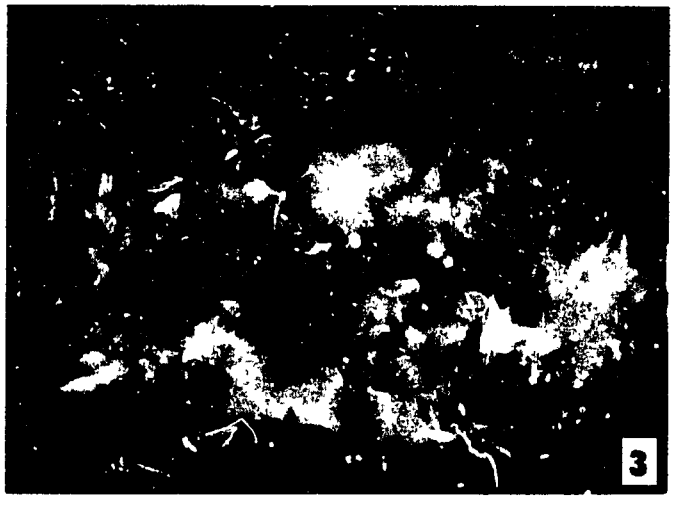

Fig. 3. Mass propagation of pearl orchid through shoot tip and node culture.

Fig. 4. Mass propagation of ginger flower through bud culture.

Fig. 5. Mass propagation of anthurium through leaf-derived protocorm-like bodies cultured in liquid medium.

Production of haploids and homozygous diploid plants by anther or pollen culture. Anther culture has been adopted for genetic fixation and selection of promising progeny lines derived from hybrid populations. Hybrids, plants from either F_1 or relatively advanced generations, are anther-cultured from callus to doubled haploids. Pure lines developed from the culture would carry the traits of parental lines. The breeding cycle may therefore be shortened by five to six generations when the haploid breeding method is used instead of conventional cross breeding. At present there is a serious deficiency of germplasm in plant breeding. This problem can be solved, at least partially, through the transfer of valuable alien genes of wild types into cultivated plants to enrich the genetic background of cultivars necessary for crop improvement. Anther culture is a useful tool for this purpose. During the last decade, much progress has been achieved in rice and asparagus anther culture in this country. To increase the induction frequency of anther-derived rice plants, NTU and TARI systematically investigated various factors influencing the responses of anthers in culture (Chen et al. 1986, Gau et al. 1990, Tsay and Chen 1984, Tsay et al. 1986a, b, Yeh and Chang 1987, Yeh and Tsay 1988, Wang 1985). These factors include 1) anther donor plant, 2) developmental stage of microspore to be cultured, 3) anther condition before

culturing, 4) composition of culture medium, 5) cultural environment, 6) anther wall, 7) texture of pollen callus, 8) ontogenesis of haploid plants, 9) mechanism of albino plant formation, 10) genotypic variance and 11) ploidy level of derived plants and chromosome doubling. For example, with the improvement of culture medium and cold shock treatment, callus induction frequency has been increased from 16 to 67% (Fig. 6) (Lin 1984). Under appropriate conditions the breeding efficiency (number of green plants produced per 100 cultured anthers) reaches about 15. Large-scale extension work on anther culture application is carried out at TARI. More than 30,000 anther-derived green plants can be produced in a year from field evaluation (Fig. 7) (Huang et al. 1985, 1988). In asparagus, the techniques for regeneration of haploid plants from cultured anthers was successfully established (Fig. 8). More than 10,000 anther-derived green plants have been produced since 1981. About 100 super-male plants (Fig. 9) have been selected for combining ability test and all-male seed production (Fig. 10) (Tsay 1983, Tsay and Hsu 1986). TARI is also involved in projects of haploid plant formation from anther culture of sweet potato, corn, papaya, passion fruit and bamboo. Among them, haploid plants have been successfully induced from corn, papaya and bamboo (Fig. 11, 12 and 13) (Tsay 1986, Tsay and Su 1985, Tsay et al. 1990).

Tube Fertilization and Embryo Rescue

When transfer of genetic materials between plants is desired, conventional sexual hybridization should be attempted first. If this fails, test tube fertilization or embryo rescue can be tried. In the case of prezygotic incompatibilities, which showed that the pollen failed to germinate, to grow sufficiently through the style or failed to enter and fertilize the ovule, test-tube fertilization proved successful in obtaining the hybrid seeds. For those postzygotic incompatibilities which showed poor or no endosperm development, embryo abortion results. Rescuing the embryo before abortion takes place is considered valuable in crop breeding.

Normal plants were successfully obtained from embryo culture of *Carica* hybrid (*C. cauliflora* × *C. papaya*), and embryogenic callus was induced as well (Chen et al., 1990a, 1990b). Large quantities of embryos and plantlets have been induced from those embryogenic calli (Fig. 14). Field evaluation of these F_1 plants, dwarf and early-maturing, showed that they were phenotypically resistant to the ringspot virus. Research will put emphasis on backcrossing these hybrids to the recurrent parent for the recovery of a favorable genetic background.

Production of secondary metabolites via callus or cell suspension culture. There is a great potential in using plant cell cultures to produce novel products not produced by the intact plants from which the cultures were derived. Studies now indicate that plant cell cultures can synthesize not only such products, but in some cases valuable compounds never before detected on any plant species. For example, forskolin is an important pharmacological compound that possesses activity against high blood pressure, intraocular pressure, and thrombocyte aggregation. The formation of forskolin by suspension cultures of *Coleus korskohlij* was reported by German scientists. Other examples including the compounds with antiinflammatory activity in *Podophyllum versipelle* cell cultures, the production of proteolytic enzymes in cultured milkweed (*Ascelpias syriaca*) cells, and commercially producing the antihypertensive drug ajmalicine by a *Catharanthus roseus* cell culture have also been reported. Hundreds of secondary metabolites especially for those compounds such as medicinals have now been isolated and produced from plant tissue and cell suspension culture in many developed countries.

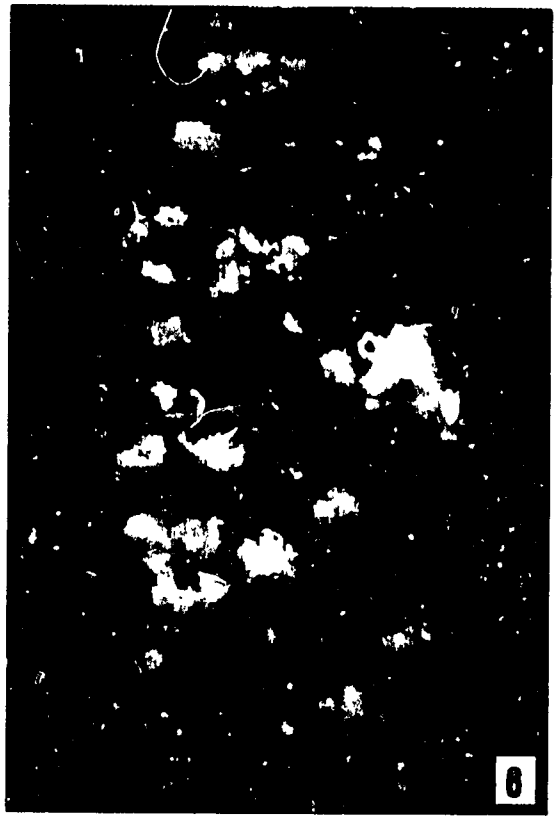

Fig. 6. Pollen-derived callus or embryoids induced from cultured rice anthers.

Fig. 7. Large scale extension work on anther culture application is carried out at experimental farm of TARI.

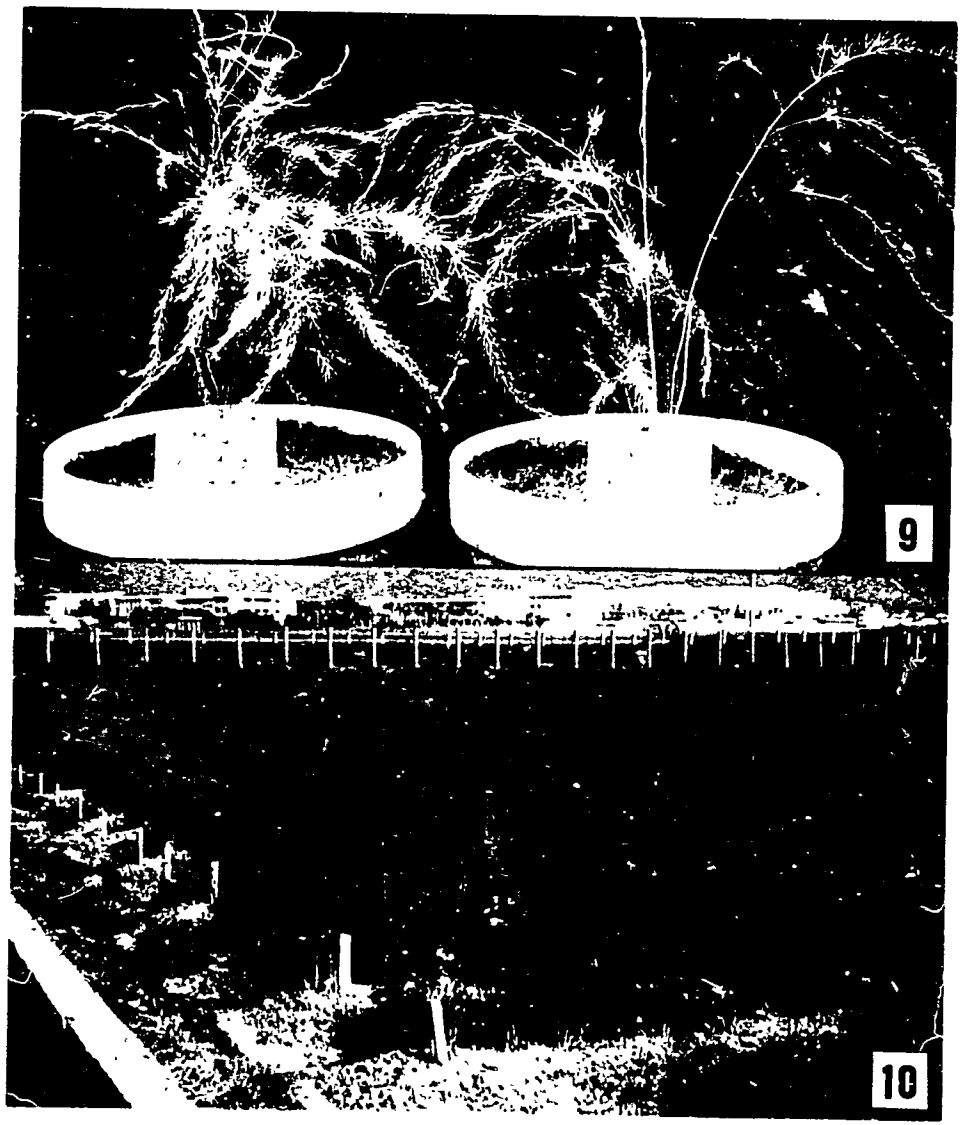

Fig. 8. Haploid plants induced from asparagus anther culture.

Fig. 9. Super-male plants are selected for combining ability test and all-male production.

Fig. 10. More than 250 combinations of all-male asparagus progenies are evaluated for disease and insect resistance at the experimental farm of TARI.

Fig. 11. Haploid plant induced from maize anther culture.

Fig. 12. Haploid plant induced from papaya anther culture.

Fig. 13. Haploid plant induced from bamboo anther culture.

Production of new genetic resources by somaclonal variation. Among various techniques now available for producing plant genetic resources, the use of somaclonal variation produced from cell and tissue culture for plant modification is a relatively new and very attractive area of research. Numerous variants have been recovered using tissue culture selection procedures (Tsay et al. 1986b). Today, the genetic variation generated from plant cell and tissue as well as the application of mutagenic treatments contributed a wide field of study within in vitro culture. Variants could now be easily isolated from cell cultures without any mutagenic treatment, and plant cell cultures and the induced plants themselves are inherently genetically unstable.

Tissue culture is considered a better source of mutants than conventional mutation breeding for the following reasons: 1) From conventional mutation breeding, large numbers of seeds are subjected to irradiation or chemical mutagen treatments. This requires a large field space and protoplast culture. It is easier to handle a large number of cells or protoplasts in a small volume. For instance, 100 ml of rapid growing asparagus cells in suspension culture contains 108 cells. Mutant selection can be done easily by culturing cells treated with a selective agent and thus can economize on space. 2) Tissue culture work can be carried out at any time of the year, whereas growing plants in the field may be restricted by environmental factors. 3) Reproducible selection schemes can be employed in cell or protoplast suspension culture as uniform culture environment can be employed or manipulated.

The application of somaclonal variation technologies on crop improvement depends on the production of a large number of regenerated plants. To meet such a purpose, a system that would enable the cultured explants to show a high differentiation ability must be developed. Among the many factors involved, the explant part to be cultured (e.g. immature embryos) is considered the most essential for any plant species. In view of this, TARI is now working on immature embryo culture of rice and corn (Liao 1987, Tsay 1988, Lin 1989, Lan 1990). Thousands of plants can be regenerated and this showed that this method is one of the best ways to produce new genetic resources (Fig. 15 and 16). Many programs on somaclonal variations in rice anther culture are going on at Academia Sinica and NTU. A system for selection of antimetabolic-resistant cell lines from callus-derived rice anther was established in NTU (Chen and Chen 1979). Cell lines and regenerated plants with salt tolerance from rice anther-derived calli have been reported by Academia Sinica (Woo et al. 1985). Somaclonal variations are also exploited in ginseng tissue in Academia Sinica. A few somaclones with unique flowering characteristics have been found and are kept as materials for further study of flowering. Plantlets derived from sugarcane tissue culture have been reared into flowering plants at the Taiwan Sugar Research Institute (TSRI). Several somaclones with promising agronomic characteristics have been selected from these field-grown plants (Liu and Chen 1976). Methods for obtaining embryoids in callus and suspension cell and plant regeneration from those callus- or suspension cell-derived protoplasts have also been established in TSRI (Chen et al. 1988a, b).

Preservation and international movement of germplasm. Gaining considerable interest now is the value of tissue culture in shipping plants internationally. Increasingly larger numbers of germplasm or production materials are being shipped in vitro. The aseptic condition maintained in the transport and storage, guaranteeing freedom from insects, bacterial and fungal pathogens, virtually eliminates quarantine procedures at most entry points.

Many crop species that are valuable as gene pools for breeding are lost each year by neglect or by mass eradication of their habitats for alternative uses. There is an urgent need to preserve these endangered crop species. The aim of germplasm preservation is to ensure the availability of useful germplasm for the future. For this purpose, meristem or shoot tip tissues are becoming increasingly used for the storage of valuable germplasm. The procedures include plant materials being aseptically cultured in vitro, and modified nitrogen and sucrose levels to slow down growth rate. Growth retardants

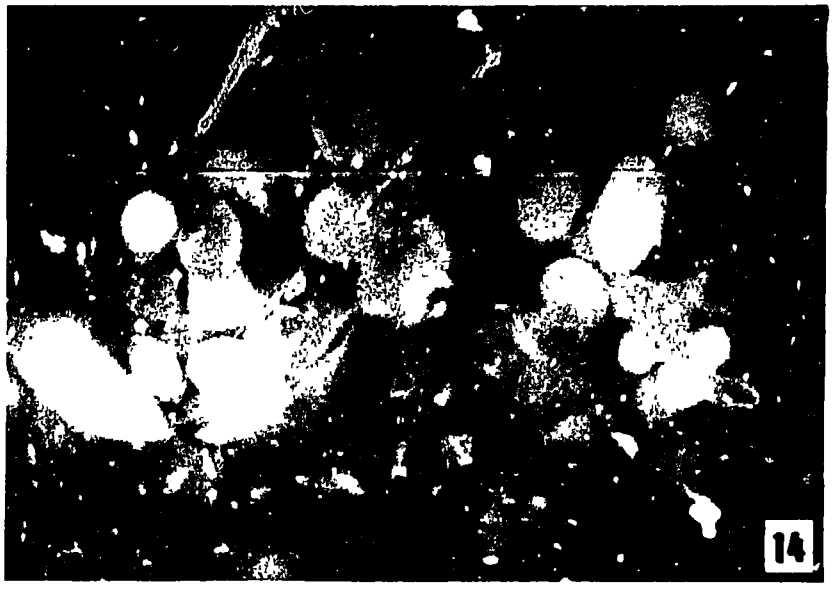

Fig. 14. Large quantities of embryoids could be induced from embryogenic callus of hybrid embryo of *Carica papaya* × *C. cauliflora*.

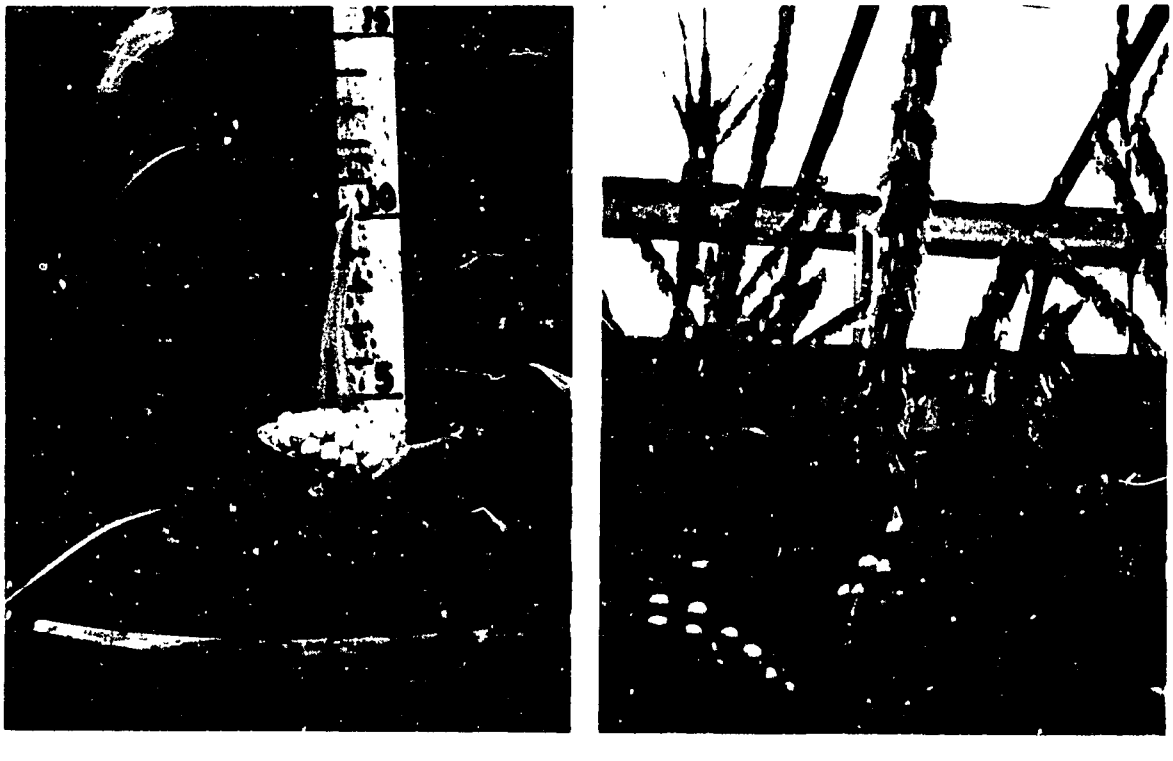

Fig. 15a and b. Abnormalities such as early maturing and dwarf type plants (Fig. 15a) and development of female flowers in the tassel (Fig. 15b) were observed among plants induced from maize immature embryo-derived callus.

as regulators are also being assessed and show promise at this stage. When possible, lighted refrigerated growth chambers are used to maintain the cultures Improved culture techniques are continually being developed to slow down the culture's growth rate and reduce the need for culture maintenance (Chu 1990). Shoot tip culture technologies are now being used to preserve potato and sweet potato germplasm at TARI.

In some cases the meristem tissues can also be preserved at -196°C. At this temperature they can be stored without further care and with no change in their metabolic or genetic characteristics for many months or possibly, for hundreds of years. Preservation by freezing with liquid nitrogen may eventually become the ultimate method of storing elite disease-free germplasm. The first report on the successful freeze preservation of shoot tips was made with carnation (Seibert 1976). During the last few years, meristems or shoot tips of a number of plant species, e.g., apple, carnation, cassava, pea, peanut, potato, strawberry and tomato, have been successfully cryopreserved (Kartha 1984).

In the last decade, much attention has been given to the freeze preservation of cells. Since the first success was reported in 1968 by Quatrano, who froze cells of flax to a temperature of -50°C while maintaining viability at a level of 14%, methods and techniques for cell and tissue conservation have improved. The number of species succumbing to freeze preservation as cells has expanded to over 30 (Withers 1984). Information gaps are many in available literature. More has to be learned about cryopreservation.

Protoplast technology and gene transfer. In recent years, the rapid development of protoplast fusion and culture has enabled scientists to create somatic hybrid plants from sexually incompatible species. This technique is used to produce germplasm previously unavailable to plant breeders.

The utilization of protoplast technology for crop improvement is currently limited owing to the inability to regenerate plants from isolated protoplasts of most of the important crop plant species. The reproducible plant regeneration from cultured protoplasts is a prerequisite for utilization of genetic manipulation techniques such as somatic hybridization and gene transfer. Remarkable progress has been made in the last decade in the isolation and culture of protoplasts and the regeneration of plants from such protoplasts for a number of species. To establish a simple and reproducible protoplast culture system, NTU, Academia Sinica, TSRI and TARI have successfully regenerated plants from rice, sugarcane and asparagus protoplasts (Chen et al. 1988). In all these cases, special suspension cultures with fast growing ability have to be selected to obtain dividing protoplasts. Scientists of Academia Sinica have successfully isolated protoplasts from embryoids and leaves of ginseng. Prolonged culture of embryoid-derived protoplasts proliferated into callus and a mass of embryoids formed and developed into plantlets (Chen et al. 1990).

Most plant breeders desire to add only a few improved characteristics into their crop rather than incorporate entire genomes. A system which will enable the transfer of only desirable genes would be a tremendous help in plant improvement programs and would probably revolutionize plant breeding. It is not surprising that recently developed "genetic engineering" techniques have attracted considerable attention, especially since basic research showed that genes can be successfully cloned, transferred and expressed in recipient plant cells. Successful gene transfers have been accomplished by using Agrobacterium's Ti-plasmid as the vector. However, the effect of the Ti-plasmid is mostly limited to dicotyledonous plants. Other transfer systems such as microinjection, electrofusion, electroporation, particle gun, laser gun, treated protoplast by x- or r-ray, electrophoresis, and use of virus and liposome as a vector are under evaluation in Academia Sinica, NTU, TSRI and TARI now.

Conclusion

Tissue culture technology will play a major role in future product development, especially in agriculture. The progress achieved in the development of tissue culture has helped in the improvement and commercial production of plants that conventional methods cannot achieve.

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Vegetable Crop Protection in Taiwan

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Abstract

Vegetables grown in Taiwan are subjected to the ravages of various plant pathogens and insect pests due to the warm and humid environment, intensive cropping patterns and other conditions favorable to these pathogens and pests. To sustain and protect vegetable production, control of plant diseases and insect pests is of prime importance. A major control method on which farmers have relied heavily for many years is the application of pesticides. This method arouses great concern about toxic residue accumulating on vegetables. Efforts have been directed towards prevention of pesticide residue, including proper and safe use of pesticides, establishment of pesticide tolerance level, and the establishment of pesticide residue monitoring and prevention stations. Other measures such as biological and microbial control, soil amendment, integrated pest management, and planting of pathogen-free seedlings and resistant varieties have also been developed and implemented to alleviate the use of pesticides. A continuous effort to strengthen crop protection is required to safeguard the production of vegetables both in quantity and quality. Enhancement of various aspects of vegetable crop protection is discussed.

Introduction

Agriculture is an important sector of the economy in Taiwan, although agriculture's contribution to the gross national product has been declining (Fig. 1). In the past four decades, agriculture production has been greatly improved due to breeding or introduction of new crop varieties, mechanization of farm activities, improved cropping systems including specialized vegetable production area program, improvement of pest control, pesticide residue and resistance monitoring system. Vegetables are gaining increasing importance among various agricultural crops grown in Taiwan, because of the considerable increase in cropping areas planted to them and the increase in their yield and consumption in the past 40 years (Fig. 2). Vegetables also provide a variety of essential nutrients for the human diet.

Presently, there are about 130 vegetables planted in Taiwan (Huang and Hung 1988) either year-round or in seasonal pattern. They are cultivated mostly in warm lowlands with a few in the cool uplands and protected facilities. The planting acreage of vegetables was 74,299 ha in 1950 and increased considerably to reach 220,279 ha in 1978. It has, thereafter, fluctuated slightly between 220,000 and 240,000 ha. In 1988, the acreage of vegetables totaled 215,563 ha which ranked second to that of rice, the leading crop at 471,065 ha. However, production of vegetables exceeded that of rice and totaled over 3 million t (PDAF 1989). This was a four-fold increase over the production in 1950. Consumption of vegetables also increased from 64 kg per capita in 1950 to 122 kg in 1988. The value of vegetables in 1988 was over 31 billion NT dollars which ranked third following rice and fruits (PDAF 1989), and accounted for 23.13% of the total crop value.

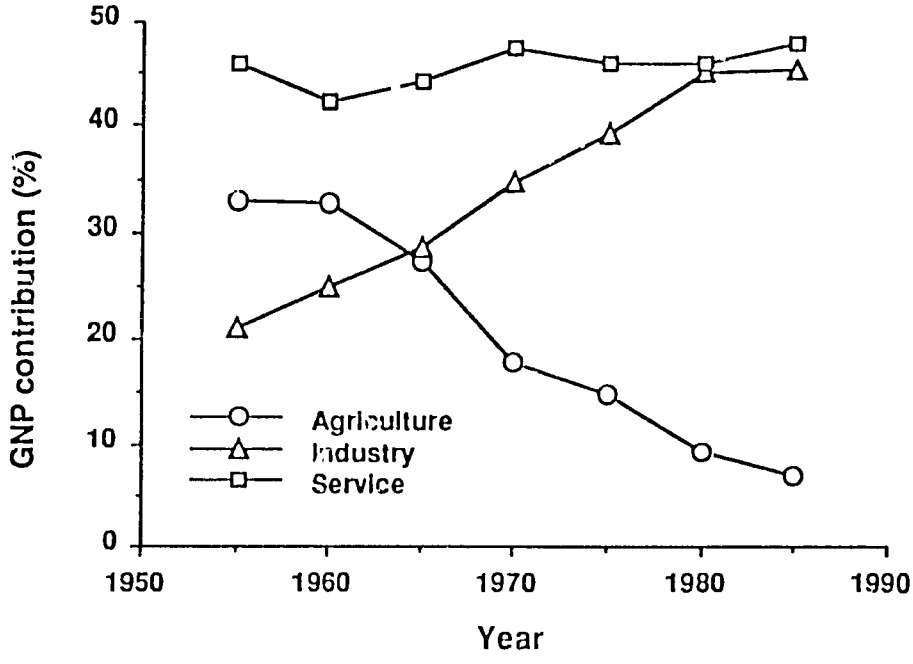

Fig. 1. GNP contribution in Taiwan.

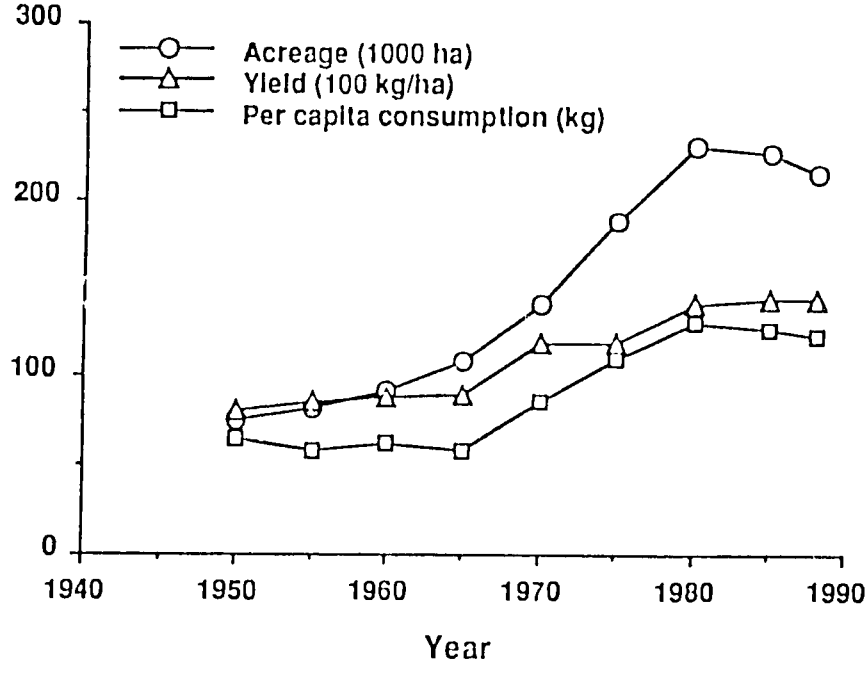

Fig. 2. Vegetable acreage, yield and per capita consumption in Taiwan.

Because of the warm and humid environment, intensive cropping systems and other favorable conditions in Taiwan, plant diseases and insect infestations have always been a great concern in vegetable production. Various plant pathogens and insect pests have occurred in all kinds of vegetables, causing considerable crop losses. Competition from weeds also weakens the survival and the growth of vegetables. Weed control is therefore of prime importance to sustain and improve vegetable production both qualitatively and quantitatively.

Pest control has relied heavily on the application of pesticides mainly because pesticides are easy to use and have a broad spectrum and fast effect. Although the use of pesticides has greatly contributed to the increase in production of vegetables, its excessive and continuous use pose a great danger to human health with the accumulation of toxic residues in the vegetable crop. Prevention of the accumulation of toxic chemical residues, therefore, has become a priority in the crop protection program. Emphasis has been placed on proper and safe use of pesticides. Preharvest monitoring and postharvest inspection of pesticide residue on vegetables have been carried out since the 1960s. Other control measures have also been developed and implemented to alleviate the use of pesticides. These include biological and microbial control, application of soil amendment, integrated pest management, planting of pathogen-free seedlings and breeding for resistant varieties.

In this paper, we present the current status of vegetable diseases and insect pests and their control in Taiwan. Future needs for the improvement of vegetable crops and protection in terms of research and extension services will also be discussed.

Current Status of Diseases and Insect Pests of Vegetables

A list of some important diseases and insect pests on major vegetables and some common weeds found in vegetable planting in Taiwan is arranged according to crop groupings (Table 1). Vegetables include cruciferous, cucurbitaceous, leguminous and solanaceous crops as well as onion, garlic and ginger. Common and scientific names of insects and weeds are presented and diseases and their causal agents are given in the Table.

Table 1. Some important vegetable pests and common weeds in Taiwan.

Crop group	Common name	Scientific name
A. Crucifers		
Insects:	Black cutworm	*Agrotis ypsilon*
	Cabbage aphid	*Brevicoryne brassicae*
	Cabbage looper	*Trichoplusia ni*
	Cabbage pyralia	*Crocidalomia binotalis*
	Cabbage webworm	*Oebia undalis*
	Diamondback moth	*Plutella xylostella*
	Green peach aphid	*Myzus persicae*
	Imported cabbage worm	*Pieris rapae crucivora*
	Leafminer	*Liriomyza bryoniae*
	Striped flea beetle	*Phyllotreta striolata*
	Tobacco cutworm	*Spodoptera litura*
	Turnip aphid	*Lipaphis erysimi*

Continued...

Table 1. Some important vegetable pests and common weeds in Taiwan.

Crop group	Common name	Scientific name
Diseases:	Bacterial black rot	*Xanthomonas campestris* pv. *campestris*
	Black spot	*Alternaria brassicae*
		Alternaria raphani
	Club root	*Plasmodiophora brassicae*
	Downy mildew	*Peronospora brassicae*
		Peronospora parasitica
	Fusarium wilt	*Fusarium oxysporum* f. sp. *conglutinans*
		Fusarium oxysporum f. sp. *raphani*
	Sclerotinia rot	*Sclerotinia sclerotiorum*
		Whetzelinia sclerotiorum
	Soft rot	*Erwinia carotovora* var. *atroseptica*
		Erwinia carotovora var. *carotovora*
		Erwinia chrysanthemi
	Virus diseases	Cauliflower mosaic virus
		Cucumber mosaic virus
		Turnip mosaic virus
	Root knot nematode	*Meloidogyne incognita*
B. Cucurbits		
Insects:	Cotton aphid	*Aphis gossypii*
	Cucurbit leaf beetle	*Aulacophora femoralis*
	Indian cabbage moth	*Margaronia indica*
	Melon fly	*Dacus cucurbitae*
	Southern yellow thrips	*Thrips palmi*
Diseases:	Anthracnose	*Colletotrichum lagenarium*
	Bacterial spot	*Pseudomonas lachrymans*
	Downy mildew	*Pseudoperonospora cubensis*
	Fusarium wilt	*Fusarium oxysporum* f. sp. *niveum*
	Gummy stem blight	*Mycosphaerella citrullina*
		Mycosphaerella melonis
	Phytophthora blight	*Phytophthora melongenae*
		Phytophthora melonis
	Powdery mildew	*Erysiphecic horacearum*
		Sphaerotheca fuliginea
	Virus diseases	Zucchini yellow mosaic virus
		Cucumber mosaic virus
		Watermelon mosaic virus-1
		Cucumber green mottle mosaic virus
		Tomato mosaic virus
	Root knot nematode	*Meloidogyne incognita*

Continued...

Table 1. Some important vegetable pests and common weeds in Taiwan. (Contin

Crop group	Common name	Scientific name
C. Legumes		
Insects:	Leaf miner	*Phytomyzus* spp.
	Pea aphid	*Acyrthosiphon pisi*
	Pea leaf miner	*Phytomyza horticola*
	Pod borer	*Maruca testulalis*
	Smaller green leafhopper	*Empoasca formosana*
	Soybean stem miner	*Agromyza phaseoli*
	Two-spotted spider mite	*Tetranychus urticae*
D	Ascochyta blight	*Ascochyta pinodella*
		Ascochyta pisi
	Bacterial blight	*Psudomonas syringae* pv. *pisi*
	Choanephora wet rot	*Choanephora* spp.
	Fusarium root rot	*Fusarium solani* f. sp. *pisi*
	Fusarium wilt	*Fusarium oxysporum* s. sp. *pisi*
	Kidney bean rust	*Uromyces appendiculatus*
	Leaf blight	*Xanthomonas compestris* pv. *phaseoli*
	Powdery mildew	*Erysiphe polygoni*
	Seedling blight	*Rhizoctonia solani*
	Southern blight	*Sclerotium rolfsii*
	Virus diseases	Soybean mosaic virus
		Bean yellow mosaic virus
		Cucumber mosaic virus
		Pea mosaic virus
D. Solanaceous vegetables		
Insects:	Beet armyworm	*Spodoptera exigua*
	Cotton aphid	*Aphis gossypii*
	Eggplant borer	*Leucinodes orbonalis*
	Kanzawa spider mite	*Tetranychus kanzawai*
	Southern yellow thrips	*Thrips palmi*
	28-Spotted lady beetle	*Henosepilachna vigintioctopunctata*
	Tomato fruit worm	*Helicoverpa armigera*
	Two-spotted small green leafhopper	*Chlorita biguttula*
Diseases:	Anthracnose	*Colletotrichum* spp.
	Bacterial spot	*Xanthomonas campestris* pv. *vesicatoria*
	Bacterial wilt	*Pseudomonas solanacearum*
	Blossom end-rot	Calcium deficiency

Continued...

Table 1. Some important vegetable pests and common weeds in Taiwan.

Crop group	Common name	Scientific name
	Early blight	*Alternaria solani*
	Gray leaf spot	*Stemphylium solani*
	Late blight	*Phytophthora infestans*
	Leaf mold	*Cladosporium fulvum*
	Phytophthora blight	*Phytophthora capsici*
	Powdery mildew	*Erysiphe cichoracearum*
	Virus diseases	Cucumber mosaic virus
		Tomato mosaic virus
		Sweet pepper vein banding mosaic virus
		Sweet pepper mosaic virus
		Potato virus Y
	Root knot nematode	*Meloidogyne incognita*
E. Onion and leeks		
Insects:	Beet armyworm	*Spodoptera exigua*
	Bulb mite	*Rhizoglyphus robini*
	Leaf miner	*Liriomyza cepae*
		Phytomyza atricornis
	Onion thrips	*Thrips tabaci*
Diseases:	Fusarium bulb rot	*Fusarium cepae*
	Purple blotch	*Alternaria porri*
	Rust	*Puccinia allii*
F. Garlic		
Insect:	Onion thrips	*Thrips tabaci*
Disease:	Virus disease	Garlic mosaic virus
G. Ginger		
Diseases:	Blast	*Piricularia zingiberi*
	Leaf spot	*Phyllosticta zingiberi*
	Soft rot	*Pythium myriotylum*
	Root knot nematode	*Meloidogyne incognita*
H. Common weeds		
	Aquatic startwort	*Stellaria aquatica*
	Bale persicaria	*Polygonum lapathifolium*
	Barnyard grass	*Echinochlor crus-galli*
	Black night shade	*Solanum nigrum*
	Common purslane	*Portulaca oleracea*
	Crabgrass	*Digitaria adscendens*

Continued...

Table 1. Some important vegetable pests and common weeds in Taiwan.

Crop group	Common name	Scientific name
	Goosegrass	*Eleusine indica*
	Joy weed	*Alternanthera nodiflora*
	Jungle rice	*Echinochloa colonum*
	Long-leaved paspalum	*Paspalum longiflolium*
	Mexican ageratum	*Ageratum houstonianum*
	Palmate morning glory	*Ipomoea cairica*
	Purple nutsedge	*Cyperus rotunda*
	Rorippa indica	*Rorippa atrovirens*
	Slender amaranth	*Amaranthus viridis*
	Small goosefoot	*Chenopodium serotinum*
	Thorny amaranth	*Amaranthus spinosus*
	Violet crabgrass	*Digitaria violascens*

Vegetable Diseases

Vegetable diseases are caused by different kinds of plant pathogens including bacteria, fungi, viruses, nematodes and mycoplasma-like organisms (MLOs). Much effort has been devoted to the investigation of fungal and bacterial diseases and their control, whereas less attention was paid to virus, nematode and MLO diseases, especially the last two.

Diseases caused by soil-borne plant pathogens have been a serious problem in growing vegetables and can result in the total destruction of the plants in a severely infected field. Clubroot induced by *Plasmodiophora brassicae* Wor. has become serious in some crucifers in recent years and has resulted in considerable losses when susceptible varieties were grown in infected fields. The disease infects mustard, Szechuan mustard, Chinese cabbage, pak-choi and rapeseeds (Hsieh and Yang 1985).

Fusarium oxysporum (Schl.) Snyder and Hansen and *F. solani* (Mart.) App. & Wr. are two soil-borne fungi causing economically important diseases of many crops, such as Fusarium wilt of tomato, eggplant, broad bean and some cucurbits, Cruciferae yellows of kale, mustard and radish, and Fusarium wilt and root rot of garden pea. Several species of Phytophthora also cause severe diseases of root and aerial parts of some cucurbits and solanaceous plants when high amounts of moisture are present in the environment. Examples of these species are late blight of tomato [*P. infestans* (Mont.) de Bary], Phytophthora blight of tomato, sweet pepper (*P. capsici* Leonian), cucumber and watermelon (*P. melonis* Katsura), and Phytophthora rot of eggplant (*Phytophthora melongenae* Sawada). Other fungi such as Mycosphaerella spp., Pythium spp., *Rhizoctonia solani* Kuhr., *Sclerotinia sclerotiorum* (Lib.) de Bary and *Sclerotium rolfsii* Sacc. are also important soil-borne pathogens of vegetables. Bacterial wilt caused by *Pseudomonas solanocearum* E. F. Smith is also a very important soil-borne disease of several solanaceous crops (Hsu 1977). The disease has often been the limiting factor in tomato production in summer or warm seasons.

The magnitude of damage that a soil-borne disease can do to a crop of economic importance has inspired many research efforts in the past 15 years in Taiwan. Attention also stems from the evidence of increasing incidence of vegetable diseases due to soil-inhabiting pathogens. The factors contributing to the spread of the pathogens are: (1) repetitive cultivation of the same crop on the same land, (2) heavy

use of chemical fertilizers, (3) depletion of organic matter in the soil, and (4) gradual increase in soil acidity in certain areas.

Anthracnose, downy mildew and powdery mildew are important diseases affecting aerial plant parts of vegetables. Anthracnose caused by Colletotrichum spp. infects many vegetable crops of different families. Downy mildew, inflicted by several species of Peronosporaceae fungi, is prevalent in cool and humid climates and is severe especially on cucurbits [*Pseudoperonospora cubensis* (Berk. et Curt.) Rostow] and crucifers (*Peronospora brassicae* Gaum.). Powdery mildew prefers dry weather and infects garden pea (*Erysiphe polygoni* DL.) and cucurbits [*E. cichoracearum* DL. *Sphaerotheca fuliginea* (Schlecht.) Poll.].

Bacterial diseases inflicted by Erwinia spp. and Xanthomonas spp. can heavily reduce vegetable yield if environmental conditions are favorable or if infected seeds are planted. Most notable diseases are black rot of crucifers (*X. campestris* pv. *campestris* Dowson), bacterial spot of tomato (*X. campestris* pv. *vesicatoria* Dye) and soft rot of vegetables [*E. carotovora* var. *carotovora* (Jones) Dye].

Viruses are also limiting factors in vegetable production. More attention has been paid to the investigation of viral diseases in cucurbits, tomato and sweet pepper. Zucchini yellow mosaic virus (ZYMV), watermelon mosaic virus-1 (WMV-1), cucumber mosaic virus (CMV) and cucumber green mottle mosaic virus (CGMMV) occur on several cucurbits, including cucumber, bitter gourd, bottle gourd, sponge gourd, wax gourd, pumpkin, melon and watermelon. Among them, ZYMV is the most prevalent and important in cucurbit cultivation in Taiwan, followed by WMV-1 and CMV (Hseu et al. 1987, Chang et al. 1987). CGMMV is severe only in bottle gourd (Wang and Chen 1985). Tomato mosaic virus (ToMV), potato virus Y (PVY) and CMV are important viral pathogens in tomato, pepper and sweet pepper. Sweet-pepper vein banding mosaic virus also causes severe damage in sweet pepper production. Other important viruses include turnip mosaic virus, garlic mosaic virus and onion yellow dwarf virus.

Investigation of diseases caused by nematodes and MLOs has been negligible. Known MLO diseases are witches' broom of tomato, cucurbits and legumes. Southern root-knot nematode [*Meloidogyne incognita* (Kofoid & White) Chit.] causes severe damage on tomato, ginger root and cucurbits.

Vegetable Insect Pests

Insect pest infestation also contributes to the reduction of vegetable yield and degradation of vegetable quality. Severe caterpillar infestation damages vegetables. Kung (1984) listed 25 major insects infesting vegetables between 1976 and 1980. Among them, ten species often cause severe damage and require employment of extensive control measures. These species are diamondback moth, imported cabbage worm, cabbage webworm, tobacco cutworm, striped flea beetle, melon fly, green peach aphid, cabbage aphid, turnip aphid and cecid fly. Black cutworm, bean pod borer, larger crucifer caterpillar, cucurbit leaf beetle, black cucurbit leaf beetle, vegetable weevil and stone leek leaf miner can also cause considerable damage. In the past decade, bryony leaf miner, southern yellow thrips, onion thrips, cotton aphid and beet armyworm have become important pests.

Diamondback moth is the most important pest of crucifers (Chen and Su 1982). Its larvae feed on the foliage of crucifers from seedling stage to harvest and greatly reduce both yield and quality of the produce. A lot of attention has been paid to its bionomics and control. Imported cabbage worm, cabbage webworm, tobacco cutworm, striped flea beetle and aphids are also major pests of crucifers (Tao and Lee 1981). Radish can be severely damaged by cabbage webworm. Melon fly is an important pest of cucurbits and can cause year-round infestation (Fang and Chang 1984). Tobacco cutworm also feeds

on melon. Green peach aphid is a polyphagous insect which not only feeds on crucifers but also transmits virus diseases (Su 1982). Cotton aphid is also polyphagous. Although it is not as important as green peach in causing damage itself, it can transmit virus and increase the spread and severity of the virus disease (Su 1982). Bryony leaf miner, a highly polyphagous insect feeding on 36 families of crops, causes severe damage on cruciferous vegetables and infects some cucurbits and tomato in Taiwan (Lee, et al. 1989). Southern yellow thrips is presently the most economically important thrips infesting vegetables and occurs commonly on cucurbits, especially watermelon and wax gourd (Wang 1989). Beet armyworm has a host range of over 40 crops and is an important pest of green onion, tomato, melons, cowpea and garden pea (Chen and Chang 1989).

Over the past three decades, major insect pest fauna have changed due to the following factors: 1) shifting of agricultural ecosystem, economic structures and social demands, 2) changes in crop varieties and cropping system, and 3) effects of agrochemicals, i.e. fertilizers and pesticides. For instance, tobacco cutworm was a threat to crucifers every year prior to 1953, but is now a minor pest (Tao and Lee 1981) possibly because of the use of pesticides. Diamondback moth has become a key pest of crucifers since the 1960s. This may be because it has high reproductive potential and has developed resistance to pesticides which also suppressed its parasitoids.

Vegetable Diseases and Insect Pests in Protected Facilities

In recent years, there has been an increasing trend towards protected cultivation of vegetables including hydroponic production. In 1988 cultivation areas totaled 824 ha. Change from open-field cultural practices to this type of cultivation also changes infestation patterns of plant pathogens and insect pests. However, not much research has been done in these areas.

Seed-Borne Diseases

Diseases transmitted by seeds also cause serious problems in vegetable cultivation. They may inhibit seed germination, hamper seedling survival and affect plant growth. Infected seeds can also serve as a primary source of disease inoculum. Examples of seed-borne diseases are Fusarium wilt and root rot of garden pea, black rot of cabbage, bacterial spot and early blight of tomato, pea seed-borne mosaic virus disease, GMMV disease of bottle gourd, and CMV, TMV and ToMV diseases of tomato and sweet pepper, etc. Research on seed-borne diseases and their control has been very scarce. In recent years, a selective medium, starch-methionine antibiotic (SMA) medium, was developed for the detection of *X. campestris* pv. *campestris* in crucifer seeds and soils in Taiwan (Huang and Hsu 1987).

Control of Vegetable Diseases and Insect Pests

To combat diseases and infestation damage of vegetables, various control measures have been tried according to the nature of the vegetable pests and pathogens. Investigations of vegetable diseases and insect pests and the development of their control have been conducted by researchers from various agriculture-related agencies including research institutes, district agricultural improvement stations (DAISs) and universities. Through extension programs, control methods and techniques are demonstrated to the farmers and other information regarding vegetable protection is provided. Both the Council of Agriculture (COA) and the Taiwan Provincial Department of Agriculture and Forestry (PDAF) have been funding vegetable research and extension programs. The annual budget for vegetable protection from 1986 to 1990 is shown in Table 2.

To sustain and protect vegetable production, pesticides have been applied. Application of pesticides is a major control method which has contributed to the increase in yield and improvement of the quality

of vegetables. Nevertheless, it not only accounts for the increase of the cost of investment, but also causes toxic residue of pesticides to settle in vegetables. Moreover, the adaptation and resistance of pathogens and insects to pesticides is increasing, making most pesticides ineffective.

Table 2. Annual budget (US$) for research and extension vegetable protection.[a]

Year	Research	Extension
1986	180,300	39,000
1987	86,300	242,400
1988	71,500	407,000
1989	124,000	130,500
1990	346,000	12,000

[a]Safe use of pesticides and residue monitoring budget (US$ 600,000) not included.

In recent years, various nonchemical control methods (Table 3) have been developed for the establishment of an integrated pest management (IPM) system. These include use of the techniques of soil amendment, mass rearing and release of parasitoids and predators, mass culture and formulation of parasitic pathogens, utilization of plastic mulch and protected cover, synthesis of sex pheromones and attractants, and utilization of tissue culture for the production of pathogen-free seedlings, etc. With the aid of these techniques, pesticide applications have been reduced significantly. The ultimate goal of vegetable protection is to breed for resistant varieties which provide the most efficient control.

Table 3. Nonpesticidal insect pest control methods on vegetables.

Crop	Target pest	Method	Demonstration area (ha)
Crucifers	Tobacco cutworm	Sex pheromone	1,400
	Beet armyworm	Sex pheromone	650
Cabbage	Diamondback moth	Parasitoids:	200
		Apanteles plutellae	
		Diadegma semiclausum	
Cucumber	Melon fly	Attractant:	
		Methyl eugenol and cuelure	14,000
		Paper bag	100
Green onion	Beet armyworm	Pathogen:	100
		Metarrhizium anisopliae	
Vegetables	Soil-borne diseases	S-H soil amendment	1,710

Chemical Control

Application of pesticides has long been and still is a reliable method in controlling vegetable pests. Recommended pesticides are tested in the field in two to three localities. Their residue levels are determined to establish tolerance levels of crops and preharvest safety intervals for different crops. Pest

control recommendations are compiled according to the "Plant Protection Manual" which is revised every 2-3 years. Some examples of recommendations for training of vegetable farmers are shown in Table 4. To ensure efficient and safe use of pesticides, proper timing of chemical control and management schedule for major pests on vegetables has been determined. Color plates and fact sheets for each major pest have also been prepared and used in the farmers' education programs. Heavy use of pesticides arouses great concern on the part of the consumers about toxic residue, so farmers were obliged to follow proper recommendations for chemical control, especially observing the preharvest safety interval.

Table 4. Pest control in cabbage.

Growth stage	Application sequence	Target pest	Pesticides	Dilution/ dosage (ha)	Preharvest safety interval (days)
Early stage	1	Diamondback	50% Phenthoate EC	1:1,000	15
		moth, aphid	40.64% Carbofuran F	1:1,200	15
	2	Diamondback	50% Phenthoate EC	1:1,000	15
		moth, aphid	40.64% Carbofuran F	1:1,200	15
Mid stage	3	Aphid	31.6% Flucythrinate EC	1:8,500/0.2 L	15
			50% Cartap SP	1:1,000	10
		Downy mildew	72% Curzate-M	1:750/2 kg (seedling bed)	21
	4	Aphid	31.6% Flucythrinate EC	1:8,500/0.2 L	15
		Diamondback moth	50% Cartap SP	1:1,000	10
Late stage	5	Diamondback moth	10% Permethrin EC	1:2,000/0.5 L	4
		Downy mildew	80% Maneb WP	1:400/2.5 kg	7
	6	Diamondback moth	25.3% Mevinphos EC	1:500/2 L	3
		Cabbage worm	3% *Bacillus thuringiensis* WP	1:1,500/0.6 kg	1

As infested weeds are inevitable in vegetable fields, they are controlled by applying herbicides. The plant Protection Manual recommends herbicides useful against weeds occurring in the fields.

To ensure the safety of vegetable produce, a monitoring program of pesticide residue on vegetables was established in 1966. Currently, 19 field assistants from the Taiwan Agricultural Chemicals and Toxic Substances Research Institute (TACTRI) are dispatched and stationed at six district agricultural improvement stations. They are responsible for sampling vegetables from the field and wholesale markets and analyzing the pesticide residue. When violations are detected, a farmer's education on pesticide safety will follow. Continuous sampling will also be conducted to enforce the regulations. If violations are detected frequently in the same vegetable-growing area, or a serious illegal residue is found in a commodity, action will be taken immediately to implement administrative sanction. Usually, the Residue Prevention Station will submit the violation list to the PDAF, the authority on pesticide regulation enforcement, which will initiate sanction in the form of seizure or injunction. The pesticide inspection team of the county/city governments then carries out the regulatory sanction.

Biological and Microbial Control

Parasites and predators of pathogens or insects are important in reducing pest populations. A notable example is the control of diamondback moth (DBM). Larvae of DBM feeding on leafy parts of cruciferous plants severely affect vegetable production in both quality and quantity. More than 35 insecticides are recommended for its control (Anon. 1987). Because of heavy use of nonselective insecticides, DBM has developed resistance to most of the insecticides (Cheng 1986). Biological control using parasitoids was therefore adopted. The Asian Vegetable Research and Development Center (AVRDC) has imported a parasitoid (*Diadegma semiclausum*) from Indonesia, and obtained a local parasitoid (*Apanteles plutellae* Kurdj.) (Talekar and Yang 1989). These two parasitoids were mass-reared and tested in a screenhouse. The result showed that, a month after transplanting of cabbage, parasitism on DBM was about 13%. It increased to 65.4% before harvesting. Yield of treated cabbage was doubled in comparison with that of nontreated cabbage. The imported parasitoid has been released and its population established at an altitude above 1000 m.

Entomopathogens are useful microbial control agents against insect pests. *Bacillus thuringiensis* Berl. is an entomogenous bacterium. When sporulating, it produces exotoxins and endotoxins that are able to paralyze and kill insects. The bacterium has been commercialized and used extensively as a microbial control agent of insect pests on many crops. Among them is the DBM. Two kinds of commercialized product of this agent are recommended in the Plant Protection Manual for its control.

Other entomopathogens such as *Nomuraea rileyi* Farl., *Metarrhizium anisopliae* Metsch. and *Beauveria bassiana* Bals. are also effective microbial agents. They have been tested against beet armyworm on green onion in Ilan Hsien from 1986 to 1988. Significant controlling effect was obtained from these microbial agents, the last two fungi having exhibited better control than insecticides (Kao and Tsai 1989).

Sex Pheromone and Attractant

Sex pheromone is a type of hormone produced by female insects to attract the males. Some insect sex pheromones were artificially synthesized and utilized in the field to detect and reduce insect pest population. In 1985 sex pheromone traps were used to control the population of beet armyworm in green onion fields in Ilan Hsien. It not only reduced by 75% the worm population, but also delayed the occurrence of population peak 1 month during summer (PDAF 1988). The measure has since been adopted in growing green onion. Sex pheromones of DBM and tobacco cutworm have also been synthesized (Chow and Lin 1983). Sex pheromone traps have been used as a means to control tobacco cutworm and beet armyworm. About 1500 ha/year of vegetable planting areas have been applied with pheromones to control the cutworm, and about 700 ha to control the armyworm. The government has financially supported their development and field demonstration.

Attractants can be used to trap insect pests which are then killed by pesticides in the trap. Traps containing cuelure have been set up to control melon fly attacking various cucurbits (Liu 1989).

Soil Amendment

A soil amendment called S-H mixture consisting mainly of agricultural and industrial wastes has been developed by the researchers in the National Chung-Hsing University for successful control of Fusarium wilt of watermelon (Sun and Huang 1983) and radish yellows (Huang et al. 1986). It is also effective in reducing the incidence of clubroot of green petiole pak-choi (Yang and Hsieh 1985), bacterial wilt of tomato (Chang and Hsu 1988), Phytophthora blight of cucumber (Lin and Wu 1985), and Pythium damping off and root rot of cucumber (Lin and Lo 1988). Nursery soil amended with 2%

calcium carbonate or 3% mineral ash for cultivating plantlets of Chinese cabbage can reduce the incidence of clubroot (Huang and Hsieh 1987).

Integrated Pest Management (IPM)

IPM combines all available methods including chemical, biological, physical and cultural methods to control diseases and insect pests. This helps prevent or reduce the use of pesticides as the only disease control method. An example of IPM is the control of the radish yellows disease. Huang et al. (1986) reported that the disease could be controlled by planting benomyl-dressed seeds in infested soils which were amended with 1% S-H mixture plus 1% cabbage residue (chopped leaves) before planting. This control measure could reduce not only disease incidence but also increase radish yield. Phytophthora blight of cucumber could be controlled by amending the soil with chicken manure or S-H mixture and then treating with Ridomil MZ (Lin and Wu 1985). Control of melon fly of bitter gourd could combine the use of attractant trap containing insecticide and paper bagging of 2 to 3 cm long bitter gourd at fruiting stage (Fang and Chang 1987). This not only improved crop quality but also increased its yield and market value.

Production of Pathogen-Free Seedlings

Tissue culture is an effective method to produce pathogen-free seedlings. The production of garlic in Taiwan has been severely affected by virus diseases. Since 1972, effort has been devoted to the development of virus-free garlic bulbs, and shoot apical meristem culture has since been adopted. Meristem-derived plantlets of Fengshan selected No. 1 and 2 were multiplied mostly in the lowlands during the fall-winter period. About 55,000 bulbs of foundation stocks were thus obtained in 1988. To speed up the multiplication process, multiplication of virus-free clones was also attempted in the highlands during summer (Lin and Tseng 1988).

Breeding for Resistant Varieties

Disease and pest resistant varieties offer the safest and most effective means of controlling diseases and insect pests. Vegetable breeding has been conducted by various agricultural agencies in Taiwan including research institutes and DAISs. Cooperative breeding has also been performed between agencies and AVRDC. In 1982 ASVEG No. 1 Chinese cabbage was registered and named in Taiwan (PDAF 1988). It was a variety resistant to downy mildew, bred by AVRDC and tested by the Fengshan Tropical Horticultural Experiment Station and Taipei, Taichung and Tainan DAISs. In 1986 a new processing tomato resistant to ToMV and root knot nematode was registered and named Tainan 3. This variety was bred by AVRDC and tested by Tainan DAIS (PDAF 1988). Taiwan Seed Improvement Station also bred a new fresh market tomato variety, T.S.S. No. 1, which is resitant to bacterial wilt of tomato caused by *P. solanacearum* (PDAF 1988).

Future Needs of Vegetable Crop Protection

Improvement in vegetable crop protection strategies requires a collaborative effort among various agriculture agencies and scientists such as entomologists, horticulturists, plant pathologists and plant breeders as well as extension personnel. Continuous effort is needed in research on new and existing diseases and insect pests, and their biology and control. Improvement of control methods and extension services is also required to enhance farmers' will to combat vegetable pests. Emphasis is also placed on the continuous prevention of pesticide residue to settle on vegetables to ensure the safety of vegetable

consumers. In recent years, rapid advancements in biotechnology have allowed the application of DNA probe, monoclonal antibody, ELISA technique, RFLP methodology and protein analysis for the classification and detection of plant pathogens and insects and the identification of genes. Tissue culture and genetic engineering techniques can be used to identify and manipulate genes and applied to breeding for resistance. Use of these advanced technologies should be promoted. A list of guidelines for the improvement of vegetable crop protection strategies follows:

- Strengthening of education and monitoring processes on the safe and proper use of pesticides.
- Designing a pest control calendar presenting all available protection methods against major and minor pests for each crop or variety.
- Extension of research on biological and microbial control agents including insect parasitoids and predators and other antagonistic microorganisms.
- Extension of research on nonpesticidal control techniques including the use of insect sex pheromone and attractant, soil amendment and cross protection, etc.
- Strengthening of the studies on seed-transmitted diseases and insect pests and development of technology including tissue culture for the production of pest-free vegetable seeds and seedlings.
- Improvement of cropping system and promotion of organic farming to boost vegetable production and help reduce use of pesticide and investment input.
- Strengthening of the integrated pest management system.
- Strengthening of breeding for resistant varieties and cooperation between vegetable protection specialists and breeders.
- Promotion of the application of biotechnology in detection and diagnosis of diseases and insect pests and improvement of crop resistance.
- Strengthening of seed and seedling quarantine procedures.
- Exchange of information and personnel with foreign countries in respect to pest management and collection and propagation of pest-free seeds and seedlings with the assistance of AVRDC.

Since AVRDC has been actively participating in resistant variety breeding programs in Taiwan, it is suggested that the role of AVRDC be expanded and its cooperative tie with agriculture agencies in Taiwan both in research and extension services be strengthened and promoted.

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ROC Agricultural Missions in Developing Countries

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Committee of International Technical Cooperation

Initiation

The 1960s gained prominence in modern history as an era when 32 African countries became independent, 17 of them in 1960 alone.

To promote friendship, understanding and relations with these newly independent African countries, a pilot project, christened "Operation Vanguard," was launched by the Republic of China in 1960. This project, with special emphasis on agriculture, later developed into what it is now, the International Technical Cooperation Program of the Republic of China.

The unprecedented program for agricultural cooperation was based initially on two considerations:

- Many African countries, with more than 80% of their populations engaged in agricultural production and which are abundant in agricultural and natural resources, were still importing grain and other foodstuffs. They had to step up agricultural development to provide adequate food supplies for their growing populations.
- With the wealth of experience in agriculture, the Republic of China expected this program to help increase food production by transferring agricultural experience and technologies to African countries.

To execute this cooperation program, ROC organized the Committee of International Technical Cooperation, composed of representatives from the Ministry of Foreign Affairs, the Ministry of Economic Affairs, the Council of Agriculture and the Taiwan Provincial Government.

The program was carried out in accordance with the technical cooperation agreements signed between the Republic of China and other countries. Each agreement, valid for a period of 2 years, is renewable and amendable after mutual consultation.

Scope of Cooperation

Initially, technical cooperation with African countries was confined to agriculture. It was met with a warm welcome by these countries because it was geared toward resolving the people's actual needs. Later on, the program was expanded to cover animal husbandry, veterinary medicine, fishery (fishing and aquaculture), handicraft, pottery, food processing (sugar production, oil extracting), entomology and pest control, highway engineering, and others. Over the years, the program extended to countries

in the Middle East, Southeast Asia, Central and South America, and other developing areas. Actual conditions and considerations lead to further development and expansion of this epochal undertaking.

Highlights of the Program

Under this program, agricultural technical missions have been established in cooperating countries. These missions conduct demonstrations, undertake technology transfer and hold training courses in Taiwan for technicians from other countries.

Technical Missions to Other Countries

Chinese technical missions stationed abroad operate under two principles: First, provision of technical know-how and experience. Second, provision of a sufficient number of local people to work closely with Chinese technicians in the field.

The mission takes into account the existing local conditions and needs as well as available resources in the locality while formulating concrete projects.

The first agricultural mission was dispatched to Africa in November 1961. As of February 1990, 37 such technical missions staffed by a total of 327 technicians are posted in 27 countries as follows:

(1) 5 missions in 4 African countries with 86 members.

(2) 9 missions in 5 Central American countries with 84 members.

(3) 8 missions in 7 Caribbean countries with 48 members.

(4) 3 missions in 2 South American countries with 33 members.

(5) 9 missions in 7 Asian-Pacific countries with 56 members.

(6) 3 missions in 2 Middle East countries with 20 members.

Technical Training for Foreign Personnel

ROC believes that a suitable pool of trained people is essential for the successful transfer of technical know-how which the Chinese mission can provide. In addition to the field training of the local counterparts working with the missions, the ROC government also holds various technical training courses in Taiwan for foreign technicians for the purpose of advancing their agricultural skills.

From March 1962 to December 1989, 154 technical courses were offered for a total of 1280 participants from 82 countries. Besides agricultural skills development, courses on sugarcane refining, edible oil extraction, pottery, fishing, fish and shrimp propagation, hog raising, handicraft, electrical installing, acupuncture, antique identification, and others were made available. Training durations usually ranged from 3 weeks to a few months. All these courses put special emphasis on field operation and observation.

Achievements and Prospects

Agriculture

Grain. Most cooperating countries imported grain before the arrival of the Chinese agricultural missions. The missions helped improve the production of rice and other staple food crops, making the

best of all available resources. Food production in a few of these countries has even exceeded domestic consumption, making it possible to export surplus supplies.

Fruit and vegetable. Such crops are essential to the daily diet; they contribute to the vitamin and mineral requirements of the body. Advanced agricultural skills are required for growing them in various environments. Crop varieties adaptable to local conditions in cooperating countries and improved cultural skills have been introduced by Chinese missions.

Fish and shrimp propagation and hog raising. Artificial propagation for fish and shrimps and artificial insemination of hogs have also been transferred by Chinese missions to their host countries. These modern scientific techniques are widely hailed by the host governments for their contributions to food production.

Handicrafts

Most countries cooperating with ROC produce materials for handicraft products such as wood, bamboo and rattan. Chinese handicraft missions train local workers in making various handicraft articles and novelties in the local style. They have helped improve the livelihood of local artisans and made local raw materials more profitable commodities.

Others

In addition to the missions mentioned earlier, other missions specializing in fields such as sugar refining, edible oil extraction, tea manufacture, road construction, power generation, and medical services have also been sent abroad. Their performance has won unstinting acclaim as well.

Based on international economic development, evolving needs and past experiences, the scope of the program will be expanded with the missions continuing to upgrade country expertise to meet rising expectations. The program is expected to continue developing friendly relations with cooperating countries under the principle of reciprocity.

Breakdown of Specialized Training Courses and Observation Tours Conducted by ROC Missions (March 1962 - December 1989)

Item of training courses and observation tours	Number of times	Number of participants	Number of countries
Agricultural techniques	178	1,584	81
Fishery	43	103	24
Animal husbandry	17	54	18
Handicrafts	6	15	1
Sugar industry	2	31	2
Ceramics	6	26	12
Electrical engineering	2	4	2
Acupuncture	9	13	4
Industrial & mining	7	22	4
Others	19	38	10
Total	289	1,854	82

General Workshop Recommendations

Research Areas of Collaboration

Germplasm

1. Publish joint catalogs or publications on germplasm.
2. Continue germplasm exchange and improvement of channels of information and materials distribution.
3. Increase collaboration on collection of vegetables in general.
4. Utilize local quarantine and seed-testing facilities for genetic resource activities.

Biotechnology

Hold more in-house discussions to develop collaborative proposals on biotechnological applications in vegetables especially in the areas of disease and pest resistance, disease diagnostics, tissue culture, and artificial seeds, with attendant concern for patent rights and vested interests taken into consideration.

Plant and Disease Control

1. Effect joint exploration, evaluation and utilization of biological control agents.
2. Explore the possibility of cooperatively developing a manual or booklet on the safe use of chemical pesticides and IPM in vegetables.

Crop Management

1. Prepare a monograph on Taiwan's current cropping systems.
2. Organize joint working group on off-season vegetable production (Note:Also listed under Collaborative Research).
3. Develop proposal on integration and demonstration of mechanization and automation in vegetable production.

Variety Improvement and Seeds

1. Identify ROC counterpart institutions for pepper research (Note: Also listed under Collaborative Research).
2. Develop working group on pepper research (Note: Also listed under Collaborative Research).

Aspects of Cooperation

Collaborative Research

1. Involve academic sector on joint research proposals.
2. Organize working groups on specific subject matter areas or commodities for research (immediate priorities on off-season vegetable production; pepper research; vegetable quality for domestic and export; standardization of quality).
3. Greater involvement and participation of AVRDC staff in national planning meetings.

Workshops, Conferences

1. Continue and enhance the organization of joint workshops and conferences - (more formal planning needed).
2. Develop mechanism for mutual scheduling of visits and seminars by visiting scientists (AVRDC and ROC institutions).

Personnel Exchange

Explore possibilities of short-term personnel exchange and training programs.

Information Sharing

Encourage AVRDC/ROC scientists to publish their results in peer-reviewed international scientific journals, in particular those frontline journals that are included in the science Citation Index of the Institute of Scientific Information (ISI) based in the United States.

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