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9. ABSTRACT
This report covers the China visit of a seven man International Rice Research Institute team of scientists in October 1976. The team included a plant breeder, a plant pathologist, an entomologist, a plant physiologist, and agricultural economist, and two soil scientist-agronomists. The major geographic areas included in the intinerary of the team were the Peking area, the Yangtze River valley, and Kwangtung province. In each geographic area the scientists visited four general types of institutions: academies, institutes, and universities; field experiment stations; production fields in communes; and historical and cultural institutions. Areas of rice research and production that most impressed the team are the excellence of Chinese farming; the close association between research, education, and farm production; the effective resource use and management, including waste recycling; the refinement of crop intensification as a means of increasing food production; the excellence of pest management systems; and the broad diversity of rice genetics resources. The report notes the mutual benefit that would come from scientific exchange between China and research and educational institutions in other countries. As many as three crops a year are grown in some areas of southern China and in all regions a crop in addition to rice is commonly grown in the winter months. The principles governing China's rice cropping systems could be helpful in developing similar means of crop intensification in other countries.

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RICE RESEARCH AND PRODUCTION IN CHINA: an IRRI team's view

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The responsibility for all aspects of this publication rests with the International Rice Research Institute.

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PREFACE

THE PEOPLE'S REPUBLIC OF CHINA (PROC) with about 36 million hectares of rice and an annual production of more than 120 million tons of paddy is the world's largest rice-producing country. Rice in China is grown as far north as 53°N latitude, probably the northernmost limit of commercial rice production in the world. China's rices are grown in remarkably intensive cropping systems. One summer rice crop is grown in some areas of north China, two crops in the Yangtze river valley, and as many as three crops in some areas of south China. And in all those regions a crop in addition to rice is commonly grown in the winter months.

During the past 14 years grain production in China increased at an average annual rate of 3.5%. That rate of increase provided China with rice to meet national needs and permitted some exports to other Asian countries. Such an achievement is worthy of study and emulation by other rice-growing countries in Asia.

Since its inception the International Rice Research Institute has had a keen interest in China's rice production and in the research base that made that production possible. Among the parents of the first IRRI varieties were rices that came originally from China. There appears to be great genetic diversity in the native rices of China, which through scientific exchange could be incorporated into varieties of untold value to rice farmers in the developing countries of Asia. Likewise, the principles governing China's rice-based cropping systems could be helpful in developing similar means of crop intensification in other countries.

Unfortunately formal communication between rice scientists and agricultural leaders in China and their counterparts in other countries was limited until recently. The first formal exchange between the PROC and IRRI was in 1972 when seeds of IR20 and other prom-

ising IRRI lines were presented to a Chinese trade delegation by President Ferdinand E. Marcos of the Republic of the Philippines. That exchange was followed by my 1974 visit to China as a member of a plant science delegation organized by the U.S. National Academy of Sciences. The Agricultural Society of the People's Republic of China was the host for this delegation. During this visit I was able to see the progress that scientists and farmers had made in extending the climatic and agronomic conditions under which rice grew well in China. The visit also initiated the first direct exchange of rice seeds between IRRI and Chinese research organizations. Seeds of IRRI varieties and advanced breeding lines were exchanged for comparable genetic materials from China.

The 1974 trip also gave me, as Director General of IRRI, an opportunity to extend a formal invitation to Chinese officials to expand exchange of rice genetic resources, publications, and scientific personnel. It was obvious that such exchanges could be of mutual benefit.

In March 1976, a distinguished group of eight Chinese scientists and administrators led by Mr. Yang Li-Kung, vice minister of Agri-

IRRI Director General N. C. Brady (left) talks with Dr. Huang Yun Mai (right), vice president of Chung-Shan University, Kwangchow. Mr. Wu Tung-Chiang, director, Kwangtung Branch, Agricultural Association of China, is at Dr. Brady's left.

culture and Forestry of the PROC, visited the Philippines. They spent 25–27 March at IRRI reviewing research and training activities and discussing possibilities for future cooperation. Seed and publications were exchanged. Scientists among the Chinese group led by Mr. Wu Tung Chiang, chairman of the Kwangtung Academy of Agricultural Sciences, returned to IRRI for more in-depth discussions 3–7 April 1976. During those March–April discussions, tentative arrangements were made for a reciprocal visit by IRRI scientists to the PROC. A formal invitation for this visit, which took place the following October, was subsequently extended by the Agricultural Society of the PROC. A seven-man team of IRRI scientists and research leaders accepted this invitation and visited China 7–26 October 1976. This publication is a brief report of the IRRI team's experiences in China.

The trip to China was educational and enjoyable. It was apparent that the Chinese have made great progress in narrowing the gap between knowledge and practice in rice production. The IRRI team was impressed with the effective utilization by Chinese farmers of natural and man-made resources to produce rice and associated crops. Likewise, we appreciated the opportunity to meet many distinguished

Mr. Ma Ling, Deputy Director of the Bureau of Foreign Affairs of the Ministry of Agriculture and Forestry, and Mr. Lin Shih-Cheng, Rice Breeder and Deputy Researcher of the Academy of Agriculture and Forestry, make a presentation to IRRI Director General N. C. Brady.

agricultural leaders and scientists, and to discuss their successes in rice research and practice. The exchange of views, seed, and publications was most welcome as was the development of plans for future exchange, cooperation, and collaboration.

In each major geographic area included in the tour, the IRRI team was privileged to visit important historical and cultural institutions. These reminded us of the rich cultural heritage of the Chinese and of their continuing struggle to improve and enrich their own lives and those of their neighbors.

We were most impressed with the hospitality of our hosts at each of the locations visited. Their personal kindnesses to the IRRI team were greatly appreciated as were the delicious Chinese dinners and luncheons served in our honor.

It was hoped that the visit reported in this publication would be the first of an increasing exchange among rice and cropping systems scientists by IRRI and the PROC, and those hopes are being realized. Following the October 1976 visit, two other teams of IRRI scientists accepted invitations to visit China, and a Chinese team of scientists visited IRRI for a period of one month.

Insects, diseases, and other enemies of the rice plant are not respecters of national boundaries. If agricultural scientists are to help farmers control or manage these enemies, the flow of genetic materials, research methodologies, publications, and scientific manpower must increase across national borders. The China – IRRI exchange of visits has initiated such a flow.

IRRI is grateful to the PROC agricultural leaders and scientists for their keen desire to accelerate these exchanges. They will benefit rice farmers of the world and especially those in the developing countries of Asia.

N. C. BRADY
Director General

Top: Scientists and administrators from China visit IRRI screenhouse to see work on screening rices for resistance to the different biotypes of the brown planthopper. March 1976.

Bottom: IRRI scientists visit field trials for new rices at the Chinese Academy of Agricultural Sciences in Peking, China. October 1976.

SUMMARY

THE PEOPLE'S REPUBLIC OF CHINA (PROC) is the world's largest rice producer. Some 120 million tons of rice produced annually helps feed the country's more than 800 million people and allows some rice exports to other nations. Scientists at the International Rice Research Institute (IRRI) have, since the Institute's inception, sought an opportunity to visit China to see their rice production in action and to observe the research system that helped make it possible. This report covers the China visit of a seven-man IRRI team of scientists, 7–26 October 1976.

The IRRI team's visit was in response to an invitation by the Agricultural Society of the People's Republic of China. That invitation followed a trip to China by IRRI's Director General in 1974 and visits to IRRI by teams of Chinese scientists and administrators in March and April 1976. The IRRI scientists who visited China are listed in Appendix 1. They included a plant breeder, a plant pathologist, an entomologist, a plant physiologist, an agricultural economist, and two soil scientist-agronomists.

The major geographic areas included in the itinerary of the IRRI team were the Peking area, the Yangtze River valley, and Kwangtung province. The specific areas visited within each major area are listed in the detailed itinerary in Appendix 2.

TYPES OF INSTITUTIONS VISITED

In each geographic area, the IRRI team visited four general types of institutions and had an opportunity to talk with the staffs responsible for them. Those included academies, institutes, and universities; field experiment stations; production fields in communes; and historical and cultural institutions.

The highlight of each visit to the research institutes and field experiment stations was the subject matter discussions among the visiting IRRI scientists and their Chinese counterparts. Visits to laboratories and field research sites were usually followed by organized small-group discussions in each of the four general subject areas:

- plant breeding and variety improvement,
- plant protection (diseases and insects),
- plant physiology, and
- agronomy and farm management.

The small-group discussions were encouraged by the Chinese and permitted much more detailed interchange than would have been possible in large group discussions. During visits to production fields, there was also free and frank exchange of information and ideas. At some field sites there was time for small-group discussions of farm practices related to the four major subject-matter areas.

MAJOR IMPRESSIONS OF THE IRRI TEAM

The IRRI team lists seven areas of rice research and production that most impressed them during their short visit to China:

1. excellence of Chinese farming and the relatively narrow gap between knowledge and practice;
2. intimate association between research and education, and farm production;
3. effective resource utilization and management, including waste recycling;
4. refinement of crop intensification as a means of increasing food production;
5. excellence of pest management systems;
6. broad diversity of rice genetics resources in China; and
7. mutual benefit that would come from scientific exchange between China and research and educational institutions in other countries.

Excellence of rice farming: the narrow knowledge-practice gap

No other Chinese accomplishment impressed the IRRI team as much as farmer use of known technology to increase the production of rice and associated crops. The knowledge-practice gap is narrow. As soon as research and field tests demonstrate the validity of a new technology, or the high yield potential of a new variety, farmers quickly put it into practical field production.

China's agricultural accomplishments appear to have been the result of conscious national policies to emphasize agricultural production. Chairman Mao's popular saying: "Place overall emphasis on agricultural production and develop other industries appropriately to support agricultural production," appears to have been the guiding principle that has emphasized agriculture. He suggested greater emphasis on what is known throughout China as the *eight-point charter for agricultural development* as the means to increase agricultural production. That charter covers:

1. soil,
2. fertilizers,
3. water management,
4. varietal improvement,
5. economic management,
6. plant protection,
7. field management, and
8. farm machinery

Evidence of the attention given to each of the eight points was seen at the research institutions and in the communes where the rice is produced. The high priority given to agriculture was always obvious to the IRRI team.

With so short a stay in the PROC, it is difficult to ascertain completely why the Chinese have been so successful in realizing the adoption of high-yielding technologies. But one factor that undoubtedly encourages adoption is the degree to which detailed management decisions appear to be made at the commune level, and within them at the brigade and production-team levels. Coupled with some wage incentives for hard work and productive output, this focus on decision making at a local level provides some motivation, which more-centralized systems would not provide.

Another factor that undoubtedly influences technology adoption is the rigorous discipline that seems to characterize the working systems. Peer opinions apparently reinforce official policies, thereby encouraging the adoption of improved practices and varieties.

Integration of research, education and production activities

One factor identified by the IRRI team as accounting for the prompt adoption by farmers of new research findings was the remarkably close association between scientists and educators, and the workers at the *grass roots* of production. Research scientists at the institutes and research stations commonly spend time each year working with farmers. Likewise, work on farms at the production-team or brigade level is a required experience for all faculty members and students of agricultural colleges. Such associations force priority attention of the researchers and educators to the practical problems of farmers,

and encourage the problem-solving approach to agricultural research at the expense of the discipline orientation that is more common in other countries.

The extent of involvement of commune, brigade, and production-team leaders in actual field testing and research also impressed the IRRI team. Research scientists work closely with those leaders in identifying research needs, and then the leaders participate actively in the research implementation. This effective integration of research and production assures that the researcher focuses on the problems faced by the farmers. At the same time the farmers can quickly utilize the research findings, contributing further to the narrowing of the knowledge-practice gap commented on in the previous section.

The IRRI team noted that recognition is being given to the role of basic research in solving some of China's rice production problems. In addition to the current emphasis on applied research, additional sophisticated, fundamental research will be necessary to further increase the yield potential and to assure protection from rice pests and diseases. This will likely require an increase of institute-type research and some reorientation toward research to gain basic understanding of biological processes involved in rice production.

Effective resource utilization and management

Much progress has been made in China to effectively utilize soil and water resources for the production of rice and associated crops. The IRRI team was impressed with the extent and quality of the irrigation schemes seen. Timely on-farm delivery and management of irrigation water are assured by systematic land leveling and ditch construction, much of which is accomplished by human labor during the winter season. Likewise, land-drainage systems had been installed to permit water removal from poorly drained soils. The effective control of water is one of the essential features of China's successful crop production programs. Furthermore, the timely use of human labor to do much of the construction of improved water management systems is a practice that other countries in Asia might well consider.

Chinese farmers have been markedly successful in recycling wastes from crops, animals, and humans. The universal employment of composting techniques to assure this recycling was one of the most impressive features of the IRRI team's visit. Farmers use not only animal wastes and plant residues for composting but also commonly add human wastes, weeds, and sludge from creek beds and ponds. This labor-consuming but chemical-energy saving technique has helped

China attain high rice production without proportionately high rates of chemical-fertilizer application. While China's forthcoming availability of much larger quantities of nitrogen fertilizers may reduce somewhat the pressures to recycle wastes, China sets an example for the world in waste recycling and, in turn, fertilizer-nutrient conservation.

Crop intensification

One of the primary features of Chinese agriculture viewed by the IRRI team was the universal objective of keeping at least one crop on the land throughout the crop growing seasons. The high ratio of population to land makes it essential that natural resources, including sunlight, be used to the extent possible. The IRRI team was impressed by the intensive cropping systems in use, not only at experiment stations, but in fields at the communes in each area visited.

In north China, rice is one of the summer crops grown in rotation with wheat and other winter crops. Careful management is required to obtain high yields of both the rice and wheat. Japonica rices, which are day-length sensitive, are used to assure rice harvests in time to prepare the land for the following winter crops. These two-crop systems are made possible by rice varieties with relatively short growth duration.

In the Yangtze river valley, Chinese scientists and farmers have developed increasingly intensified cropping systems. South of the Yangtze three crops are grown, two of which are rice. The first rice crop is usually a short-season, day-length-insensitive, indica variety. It is followed immediately by a short-season, low-temperature-tolerant, day-length-sensitive japonica variety, which matures in time to permit the early sowing of the winter crop. This system results in combined annual grain harvests of from 10 to 13 t/ha. It is a good example of effective applied research coupled with timely crop culture, and excellent utilization of human and natural resources.

In Kwangtung province two crops of indica-type rice followed by a winter crop has been a common practice for some time. At experiment stations, trials are under way in which three crops of rice as well as a winter crop are being grown. This system is also being tested on some farms. Its success is dependent upon the availability of high-yielding, short-season varieties resistant to insects and diseases. Exchanges of rice genetic resources with other national programs and with IRRI could help provide the needed host-plant resistance for these varieties. Arrangements were made for the screening of

IRRI lines to ascertain their resistance to pests in Kwangtung province.

A common feature of China's intensified cropping systems observed by the IRRI scientists was the short turnaround time between crops. Immediately following the harvest of one crop the land is quickly plowed and prepared for the next crop. The need for minimizing turnaround time has encouraged the development of machines to harvest and transplant the rice. In the Shanghai area about 20% of the rice is transplanted by machines. The importance of small-scale mechanization to enhance cropping intensity was well illustrated for the IRRI team.

Pest management systems[1]

Pest management techniques used in the production of rice in China are more extensively developed than for most countries in tropical Asia. The Chinese have developed integrated pest management practices that use cultural, chemical, and mechanical inputs. The three inputs combine to keep rice fields reasonably free of weeds. Likewise, each has made significant contributions toward the management of insects and diseases. A balanced approach, not dependent entirely on one technique, has been found to be most successful.

A key element in China's rice insect- and disease-management programs is their system of monitoring. Fields are examined regularly by mobile monitoring teams. The presence of threatening levels of pests is reported along with suggested means of control. Farmers apply corrective treatments only when they are told that the problem exists. Pesticides are used commonly, not as prophylactic agents, but to control pests known to be present. Likewise, at least in an experimental way, biological agents have been developed and are being released for the management of some rice pests. For some pests the Chinese appear to have used biological means of control more extensively than in any other rice-growing country.

The Chinese scientists are increasing their research efforts to breed genetic resistance to the more important rice pests into new rice varieties. Their attempts to do so can be greatly enhanced by cooperation with scientists at IRRI and cooperating national research organizations. Chinese plant breeders and pest management specialists are especially eager to exchange plant materials having appropriate host resistance. The IRRI team identified breeding for genetic resistance to pests as a research area in which the Chinese will likely make great strides during the next decade.

Diversity of rice genetic resources

The IRRI scientists were much impressed with the diversity of rice genetic resources in China. Rices with high yield potential were observed in each area visited. Likewise, rices with short growing seasons were noted as was the continuing search by PROC scientists for varieties with even shorter growth duration. While genetic resistance to some rice diseases and insect pests was noted, there was an obvious need to incorporate even broader resistance from other sources.

The IRRI team did not observe any conservation centers for rice genetic resources although the team was told that such facilities exist. Keen interest was expressed by Chinese scientists and administrators in the possibility of markedly expanding the exchange of rice genetic resources with IRRI and with other national research organizations. Such expansion would be welcomed and appreciated.

Mutual benefit from exchanges

The IRRI scientists, as well as their Chinese counterparts, were unanimous in the opinion that a marked increase in the exchange of plant materials, scientific publications, and scientific personnel would be mutually advantageous. China has much to offer the rest of the world in rice research and production techniques. Not only scientists associated with IRRI but cooperators in the research programs of many rice-growing countries could gain much from visits to China to see practical rice production as well as the effective links between research, extension, and farmers' practices.

The exchange of plant materials could also be helpful to Chinese scientists. They are eager to incorporate insect and disease resistance in their new varieties. This can be done with genetic resources at IRRI and in national rice research institute programs that are known to be resistant to important insects and diseases. Likewise, genetic materials known to be tolerant of adverse soils or extreme temperatures would be very useful to Chinese scientists.

IRRI will welcome increased scientific personnel exchanges to increase the exchange of information on and from research in the PROC and at IRRI. The IRRI team strongly supports the suggestion that long-term visits be encouraged to permit Chinese scientists to spend several months at IRRI. Likewise, IRRI scientists could gain much from involvement as companion researchers working with Chinese colleagues during the rice-growing seasons.

SUGGESTED AREAS OF COOPERATION BETWEEN PROC & IRRI

The IRRI team's visit to China was highly successful from the point of view of the team members. The Chinese hosts were gracious and helpful. They cheerfully answered questions that permitted an understanding of their complex and highly successful rice-growing systems.

Discussions with Mr. Ma Ling, and with the agricultural research leaders in the five areas visited, indicated a common interest in cooperation between agricultural research organizations in the People's Republic of China and IRRI in the following areas:

- *Rice genetic resources collection and preservation.* An exchange of visits by scientists and of genetic material would be mutually beneficial.
- *Breeding.* An exchange of advanced breeding lines and varieties should be of interest to both parties.
- *Program organization.* The Chinese expressed interest in IRRI's GEU program. IRRI is interested in China's cropping systems work. Exchange of visits by scientists in those areas can be considered.
- *Research techniques.* The Chinese progress in developing means of biological control of rice plant pests is of interest to IRRI scientists. IRRI can assist Chinese breeders with the anther culture technique for breeding.
- *Conferences, seminars, symposia.* IRRI will issue formal invitations for Chinese participation in all appropriate gatherings of rice scientists.
- *Training.* IRRI will formally invite Chinese participation in research-oriented training and would welcome opportunities for fellows and scientists to gain experience in China.

ENVIRONMENT AND RICE CULTIVATION IN CHINA

CHINA'S LAND SIZE and complex topography provide great variability in environment. Northernmost China, at about latitude 53°N, is along the Heilung River where it flows north of Moho, Heilungkiang province. China's southernmost point is the Tsengmu Reef at about 4°N, but the mainland extends only to about 20°N, south of which is Hainan Island, located between 18 and 20°N (Fig. 1).

The plains and plateaus of China are the most important land areas for agriculture. China's three major plains are the Northeast plain, the North China plain, and the Middle-Lower Yangtze plain, with a total area of about a million square kilometers. Covering roughly 10% of China's territory, the plains constitute its principal farming area, its most densely populated area, and the region where cities are most numerous.

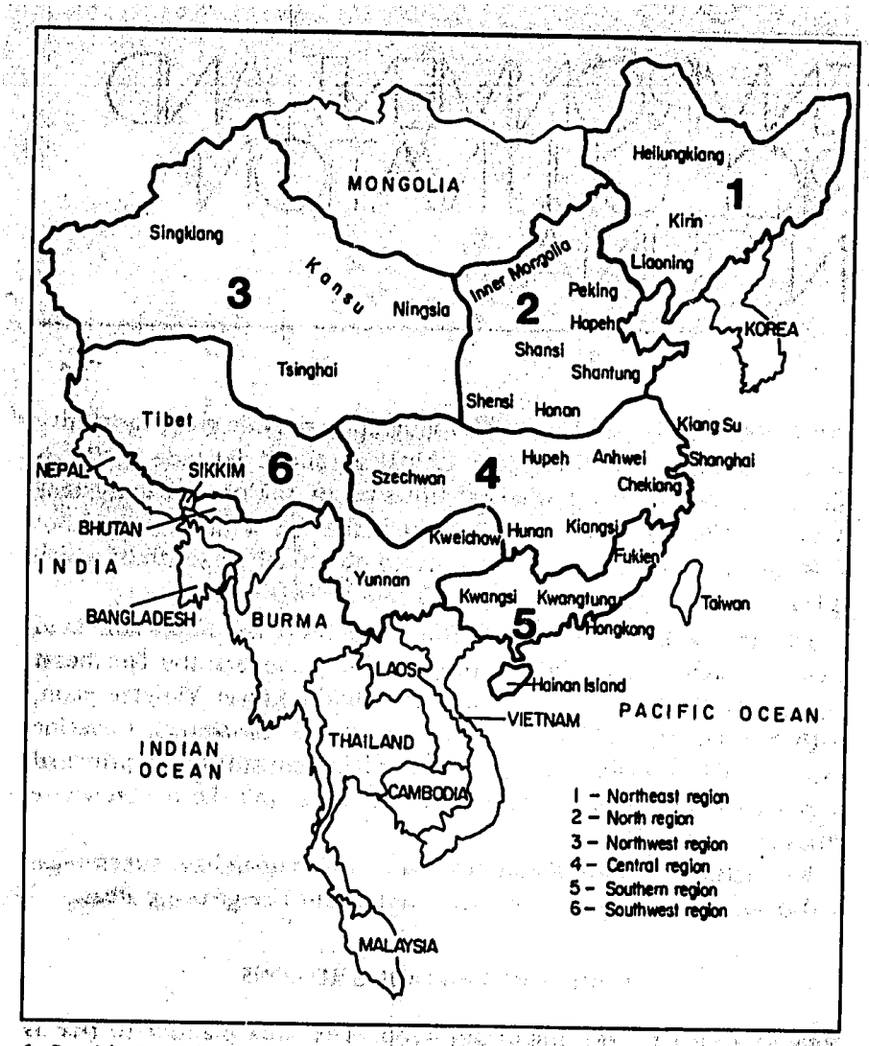
Kwangtung, Fukien, Kwangsi Chuang, and Yunan have subtropical and tropical climates and constitute important rice-growing areas.

CHINA'S RICE-GROWING REGIONS

Rice is China's most important crop. The area planted to rice is about 36 million hectares, which is about 25% of the total area planted to cereal crops and tubers. The national average rice yield is about 3.4 t/ha, which is two to three times higher than the average for other cereals. Because of its high productivity, rice production accounts for about 45% of the total grain and tuber production.

Northern region

The Northern region is divided into three subregions: Northeast, North, and Northwest. Only japonica rice is grown and, depending



1. People's Republic of China. Outline map denoting the rice-growing regions according to climate.

on climate, early or medium maturing varieties are used.

In Heilungkiang province, Northeast subregion, the daily mean July temperature exceeds 20°C and permits rice to be grown in the summer. Rice was once grown at Moho, at 53°N, and is still grown in Aihwei county at about 50°N, which is considered the northernmost area for rice-growing in the world. The rice crops become more popular in Kirin and Liaoning provinces, south of Heilungkiang province. However, only one rice crop a year is possible

in most places in the Northeast subregion and rice is considered a minor crop.

The North subregion covers Peking municipality; Hopei, Shansi, Shensi, Shantung, and Honan provinces; and the Inner Mongolia autonomous region. Peking is at about 40°N, and, historically, only one crop a year is grown. There is, however, an attempt to introduce a two-crop system with one crop of rice and one crop of wheat. The IRRI team observed a good rice crop at the ripening stage in fields of the Double Bridge People's Commune near Peking.

Central region

The major rice-growing areas of the Central region are the plains along the Yangtze River, where both japonica and indica rices are grown. In the northern area of the Yangtze, two rice crops a year followed by green manure are common. In the southern area of the Yangtze, two rice crops are followed by green manure, wheat, barley, or rapeseed. Indica rice is normally grown as the first rice crop and japonica rice as the second rice crop.

At two communes in Wu-Shi — the Cheng Tsuo People's Commune (Syi-tan Brigade) and the Mei-Tsuo People's Commune — some indica varieties were seen that were planted as the second rice crop and were ready for harvest. In that area japonica is predominant as the second rice crop and normally gives higher yields than indica. The two communes were trying indica as the second rice crop because indica matures a few weeks earlier than japonica. The time saved permits earlier wheat planting and higher wheat yields. When the timing of planting the first rice crop is a limiting factor in a three-crop system, barley is grown as the third crop because barley matures about 10 days earlier than wheat. The Mei Tsuo People's Commune allocated land for the third crop as 7% for rapeseed, 26% for wheat, 28% for green manure, and 39% for barley.

The Hsu Hang People's Commune, Shanghai, grows two rice crops followed by wheat, barley, or rapeseed. The first rice crop normally gives higher yields than the second rice crop (Table 1). Note that a larger area was planted to the second rice crop in 1965 and 1975, and the reverse was true in 1957.

People in the Central region seem to prefer japonica rice to indica. The reasons for that are higher yields (but not always), good cooking quality, higher degree of cold tolerance, higher price, and higher milling percentage. In Peking, Nanking, Wu-Shi, and Shanghai, the IRRI team was served japonica rice at every meal.

Table 1: Rice cultivation in Shanghai, from data displayed in the Exhibition Hall of Agriculture, Shanghai, China, October 1976.

Year	Area (000 ha)	Yield (kg/ha)
	First crop	
1957	40	3518
1965	68	4733
1975	145	5610
	Second crop	
1957	16	1620
1965	90	3285
1975	201	4433

Southern region

The Southern region comprises Fukien and Kwangtung provinces, and Kwansi Chuang autonomous region. The climate of the region is subtropical to tropical and indica rice is grown almost exclusively.

Until recently, two rice crops followed by peanuts or sweet potato were common. There are now experiments with three rice crops followed by wheat, broad beans, soybeans, or rapeseed. Experiments at the Cereal Crops Institute, Academy of Agricultural Sciences, Kwangtung Province, have demonstrated that three rice crops a year produce between 2.25 and 3.0 t/ha more grain than two rice crops a year. The recorded maximum production in experimental fields at the Institute is about 24 t/ha per year for three rice crops plus a wheat crop, and about 23 t/ha per year for three rice crops plus a soybean crop.

Three rice crops a year have been grown for about 80 years in Hainan but the practice was not popular until 1973–1974. Three rice crops a year are now being grown on only about 53,000 ha – 27% of the entire paddy field – in Kwangtung province. The target for three-crop cultivation in Kwangtung province is 33% of all paddy fields by 1980.

Constraints faced in achieving this target are:

- Time is needed to train farmers in the new cropping system.
- New varieties suited to the new system are needed.
- More fertilizers are required.
- Better control of diseases and insects is essential.
- More mechanization is indispensable to such an intensive farming system.

There is, however, the alternative of two rice crops a year with increased yield per crop so that two crops would produce the same quantity of grains that the three crops would.

Three crops of rice plus wheat (early maturing Mexican variety) were observed at the Tai Li People's Commune, Nang Hai county, and two crops of rice plus wheat (local variety) were seen at the Shin Hwa People's Commune, Hwa county.

Southwest region

The Yunnan-Kweichow plateau in southwestern China covers mainly eastern Yunnan province and the major part of Kweichow province. The plateau's elevation gradually decreases from about 2,000 meters in the west to about 500 meters at the eastern edge. The climate is humid with abundant rainfall. Temperature varies with altitude according to the general rule that at the same latitude, the temperature drops by 5 to 6°C with every 1,000-meter increase in altitude. Thus, indica rice is grown in low-altitude areas, and japonica rice is grown in high-altitude areas. Between those two areas, both indica and japonica are grown. Very little rice is grown in the Tibet autonomous region.

CLIMATE OF THE RICE-GROWING REGIONS

Monthly mean temperature and monthly rainfall data at seven sites from north to south in China are in Table 2. More detailed climatic data for Kwangchow appear in Table 3.

In most places in the Northeast region, the monthly mean temperature goes above 20°C in July and August, which permits rice to be grown. In the south, the monthly mean temperature is above 10°C even in winter, and luxuriant vegetation thrives year around. The moderate temperature in winter permits a wheat crop after harvest of rice.

Frost-free days are an important index for crop planning. Frost-free days are 220 in Nanking and 244 in Shanghai. In the northern part of Kwangtung province because of high altitudes and a cold current there are only about 225 frost-free days.

In the inland area, the continental type of climate causes great fluctuation in temperature not only between day and night but from year to year. Nanking, for example, has a mean temperature of 27.5°C in July with a daily maximum temperature that normally goes as high as 38°C. In low-altitude areas, annual rainfall varies

Table 2. Monthly mean temperature and monthly rainfall at seven locations in China.

Location	Latitude (°N)	Month												Mean
		J	F	M	A	M	J	J	A	S	O	N	D	
							Monthly mean temperature (°C)							
Harbin	45°45'	-18.3	-14.7	-4.7	5.8	13.3	19.2	22.2	21.1	14.5	4.4	-5.8	-15.6	3.3
Changchun	43°52'	-17.2	-12.5	-4.4	6.7	14.2	20.3	23.6	22.2	15.0	7.0	-4.4	-13.9	4.4
Liaoyang	41°27'	-12.0	-8.3	0.0	9.5	16.7	22.5	25.6	24.5	17.5	9.7	-0.3	-9.5	8.1
Peking	39°57'	-3.9	-1.7	5.6	13.3	20.6	23.9	26.7	25.0	21.1	13.3	3.9	-1.7	12.2
Nanking	32°05'	2.2	3.9	8.6	14.5	20.3	24.5	27.5	27.2	22.8	17.2	10.6	4.4	15.3
Shanghai	31°12'	4.2	4.7	8.6	14.5	20.0	23.6	27.8	27.8	23.4	18.6	12.2	7.0	16.1
Kwangchow	23°10'	13.3	14.2	16.7	22.0	26.7	27.8	29.2	29.2	28.1	23.9	20.3	16.4	22.2
							Monthly rainfall (mm)							
Harbin	45°45'	5	5	10	23	43	94	112	104	46	33	8	5	488
Changchun	43°52'	8	8	15	20	51	104	183	135	61	38	15	8	645
Liaoyang	41°27'	8	8	18	28	69	84	183	170	64	36	28	15	709
Peking	39°57'	3	5	5	15	38	86	211	155	64	18	8	3	611
Nanking	32°05'	41	51	76	102	81	182	206	117	94	51	41	30	1072
Shanghai	31°12'	48	58	84	94	94	180	147	142	130	71	51	36	1135
Kwangchow	23°10'	46	69	91	150	252	269	252	244	137	58	41	36	1645

Table 3. Monthly mean temperature, monthly rainfall, monthly daily mean solar radiation, monthly daily mean sunshine hours at Kwangchow (23°10'N), Kwangtung province, China.

	Month												Mean (annual)
	J	F	M	A	M	J	J	A	S	O	N	D	
Temperature (°C)	13.3	14.2	16.7	22.0	26.7	27.8	29.2	29.2	28.1	23.9	20.3	16.4	22.2
Rainfall (mm)	46	69	91	150	252	269	252	244	137	58	41	36	1645
Solar radiation (cal/sq cm per day)	239	215	213	247	288	326	394	373	356	355	299	253	297
Sunshine hours	4.5	3.1	2.5	3.2	5.1	5.3	7.5	7.1	6.6	7.0	6.6	5.4	5.3

regularly with latitude from about 500 mm in Kirin province, to from 1,500 to 2,000 mm in Kwangtung province.

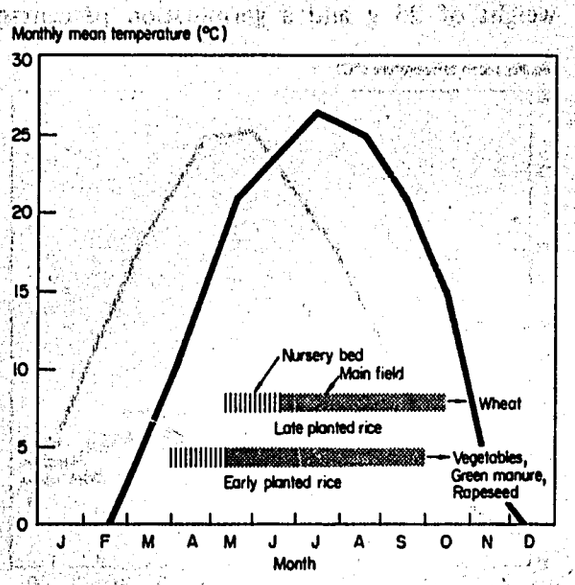
Monthly daily mean solar radiation at Kwangchow ranges from 213 cal/sq cm per day in March to 394 cal/sq cm per day in July with an annual daily mean of 295 cal/sq cm per day.

RICE CULTIVATION SYSTEM AND TEMPERATURE

An all-out effort to control rivers and to construct irrigation and drainage facilities for agriculture is a tradition of China. There is great emphasis on water conservation for agriculture and it is almost a rule to irrigate fields of any crops in China. Thus, temperature becomes the major climatic determinant for crop cultivation. In this sense, agriculture in China is in sharp contrast with that of Southeast Asian countries where the rainfall pattern is the major determinant in crop cultivation.

Peking area

In the Peking area, only one rice crop is grown, followed by winter crops (Fig. 2). Early-planted rice produces higher yields than late-planted rice. For example, at the Double Bridge People's Commune



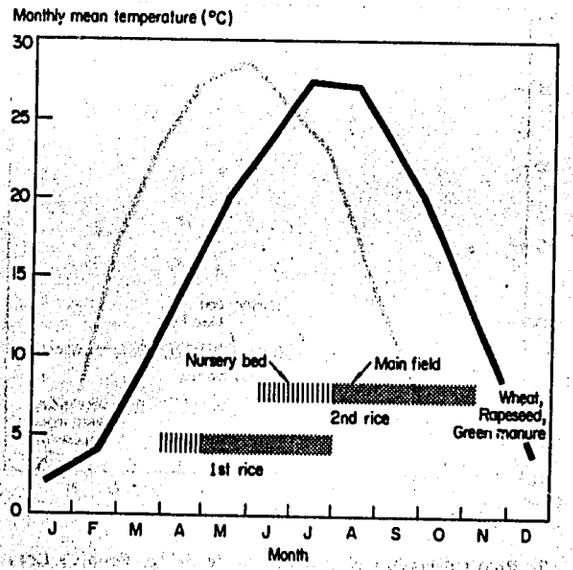
2. Rice cultivation system at Double Bridge People's Commune, Peking, China.

the early-planted rice produced 7.5 t/ha, and late-planted rice produced 6 t/ha. To gain time the nursery bed for the early-planted rice is protected against low temperatures with a plastic film. The late-planted rice is normally followed by wheat, which produces a yield of about 4 t/ha. Early maturing, high-yielding rice varieties allow more time for wheat to grow as a winter crop.

Nanking and Wu-Shi area

In the Nanking and Wu-Shi areas two crops of rice are grown and followed by winter crops such as wheat, rapeseed, or green manure (Fig. 3). Indica varieties are grown as the first rice crop because the first crop matures in July when the temperature is high and the indica varieties are more adapted (than japonicas) to high temperatures during the ripening period. The nursery bed of the first crop may or may not be covered with a plastic film. The duration of the nursery bed is about 30 days. In the second rice crop, japonica varieties are normally grown although indica varieties were seen planted on a limited area.

A characteristic of the second rice crop is the practice of *double transplanting*. In the first nursery bed, seeds are sown at a density of about 113 g/sq m and grown for 30 days. Assuming a 1,000-grain weight of 25 g and a germination percentage of 80%, the plant



3. Rice cultivation system in Nanking and Wu-Shi areas in China.

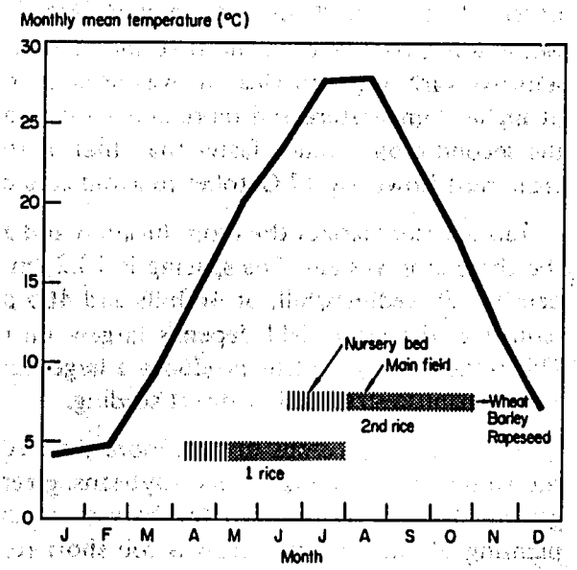
density becomes 0.4 plant/sq cm. In the second nursery bed seedlings are planted at a density about one-third of that in the first nursery bed and are grown for 20 days. The purpose of double transplanting is to get high yields with a shortened time in the field.

Later at Kwangchow, however, the IRRI team was told that double transplanting is no longer practiced in Kwangtung province because it requires a larger area for nursery beds and more labor than single transplanting.

The slogan *three colors of rice fields in one day* characterizes the extremely intensive rice cultivation in China. Quite often in the Nanking and Wu-Shi area harvesting of the first rice crop and transplanting of the second crop are done on the same day, or with only a one-day interval between the two crops. *Three colors of rice fields in one day* depicts the crop harvested in the morning when the field is yellow, the color becoming black as the field is plowed and harrowed, and the color changing to green when transplanting is complete by the evening of the same day.

Shanghai area

Because of similarities in climate in the Nanking and Wu-Shi areas and the Shanghai area, the rice cultivation system is similar (Fig. 4). Because the second rice crop is exposed to low temperatures at



4. Rice cultivation system at Hsu Hang People's Commune, Shanghai, China.

Table 4. Duration in days of nursery bed, main field, and ripening stages in the Shanghai, China, area.

	Duration (days)			
	Nursery bed	Main field	Ripening	Total
1st rice	25	60– 70	30	85– 95
2nd rice	40–45	90–95	45	130–140
Wheat		200		
Total		350–365		

late stages of growth, it is imperative that the second rice crop flower by 22–23 September. Table 4 summarizes duration of the nursery bed, main field, and ripening stages.

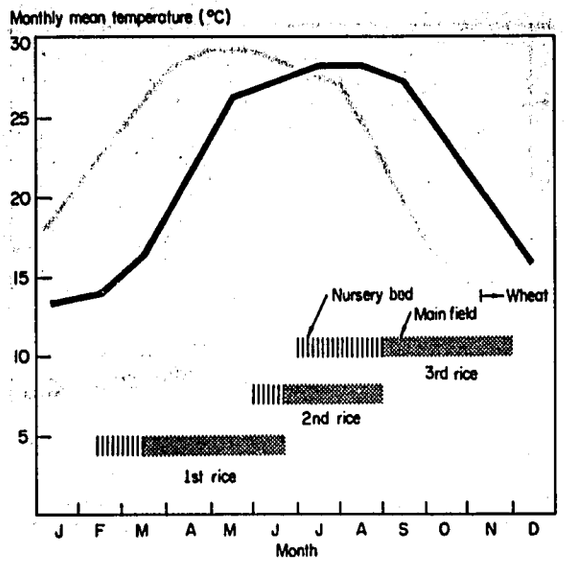
Indica varieties grown as the first crop are not photoperiod sensitive and japonica varieties grown as the second crop must be cold tolerant. The phytotron of the Institute of Plant Physiology, Shanghai, was being used for screening about 70 rice varieties for cold tolerance at flowering time.

Kwangchow area

In Kwangchow province, two rice crops and one winter crop are normally grown in one year but three rice crops and one winter crop have been popularized since 1973–1974. In a three-rice-crop system, observed at Tai Li People's Commune (Fig. 5), variety Kuan Lu Ai No. 4 was grown as both the first and second crop. A photoperiod-sensitive variety (Kuan Hua Ai) was used as the third crop. Because of higher temperature and more abundant solar radiation, growth of the second crop is much faster than that of the first crop. The third crop must flower by 17 October to avoid cold damage.

Table 5 summarizes the crop duration and approximate yields for the three-crop system. The spacing is 13.2 cm X 16.5 cm and plant density 10 seedlings/hill, or 46 hills and 460 plants/sq m. As a consequence, the crop yield depends largely on main culms (Table 6). The transplanting system produces a large number of panicles with a small panicle size just like direct seeding.

After the three crops of rice, more than 100 days remain during the winter during which wheat, soybeans, green manure, or *Azolla* is grown. The period between the harvest of the third crop and the planting of the first rice crop is too short for wheat. To overcome this, an early maturing, modern wheat is grown, and either the wheat



5. Rice cultivation system at Tai Lai People's Commune, Nan Hai County, Kwangtung province, China.

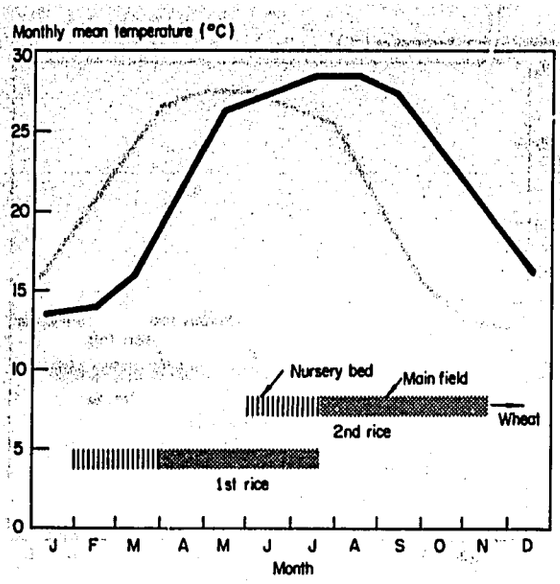
seeds are broadcast between the rows of the third rice crop, about 10 days before the rice harvest, or the wheat seedlings are grown in a nursery bed for 15 to 30 days, after which the seedlings are transplanted into main fields (Tai Li People's Commune).

Table 5. Crop duration and yields in the three-rice-crop-cultivation system in Kwangchow province, China.

Crop	Duration (days)			Grain yield (kg/ha)
	Nursery bed	Main field	Total	
1st rice	20–25	95–100	120	6,750
2nd rice	15–20	60– 70	85	6,000
3rd rice	60	85	145	5,250
Total		240–255		18,000

Table 6. Yield components of three crops of rice at Tai Li People's Commune, Nan Hai county, China.

Crop	Panicles (no./sq m)	Grains (no./panicle)	Filled grains (%)	1,000-grain wt (g)
1st	450–525	75–80	74	25–26
2nd	450–600	55–60	83	24–25
3rd	450–600	55–60	85	22–23



6. Rice cultivation system at Shin Hwa People's Commune, Hwa county, Kwangtung province, China.

Currently, however, a system of two crops of rice and one winter crop is most common, even in Kwangtung province. At the Shin Hwa People's Commune, two crops of rice and one crop of wheat are grown (Fig. 6). For the first crop, the variety is Cheng Chu Ai or Che Yie Chin, and for the second crop the variety is Kuan Er Ai or Che Yie Chin. A local wheat variety called *Fan Swe* is grown after the second crop. The commune tried growing modern (Mexican) wheat on a small scale and obtained much higher yields compared with a local variety.

Table 7. Comparison of yields at two communes in Kwangtung province, China.

Crop	Tai Li People's Commune Nan Hai County (t/ha)	Shin Hwa People's Commune Hwa County (t/ha)
1st rice	6.75	4.50
2nd rice	6.00	4.35
3rd rice	5.25	1.50
Wheat	3.75	1.50
Total	21.75	10.35

Table 7 compares yields at two communes visited. Note that the Tai Li People's Commune produces two times more grain a year than the Shin Hwa People's Commune. Because soil fertility, level of cultural practices and other factors affect grain yield, interpretation of the difference in yields of the two communes is not attempted. The yield data in Table 7 do, however, show a wide range of annual production. It is noted that even the Shin Hwa People's Commune yields are much higher than the national average rice yield for 1971–75, which was about 3.4 t/ha.

AGRICULTURE AND RICE PRODUCTION IN CHINA

THE PRIMARY OBJECTIVE of agricultural development in China is to achieve an adequate supply of food grain for its large and growing populations. The success in achieving that objective can be related to policies that have encouraged an increase in grain production, a decrease in year-to-year fluctuation in grain output, and a vastly more equitable distribution of output.

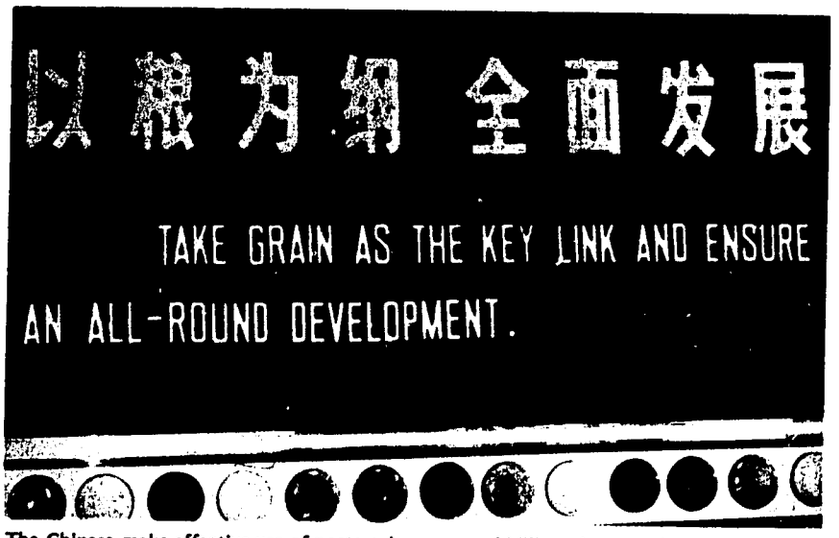
Normally countries have food policies that are either producer biased or consumer biased. The Chinese created incentives for increased food production, while at the same time providing food grain at low cost to consumers. That achievement has been discussed in depth in other reports. The focus of the IRRI team was on the rice production system and on the research and training activities that support that system.

AGRICULTURAL PRODUCTION AND RESOURCE USE

The guiding principles of Chinese agricultural production are set down in two quotations from Mao Tse-tung, which were heard frequently,

- "Take agriculture as the foundation, and industry as the leading factor."
- "Take grain production as the key link and ensure an all-around development in agriculture."

Those statements date not from the revolution in 1949 but from 1962. As with many other developing countries, China attempted to achieve rapid industrialization during the 1950's. The failure of the *Great Leap Forward* and a series of poor harvests in the period 1959–61 resulted in greater priority for agricultural production.



The Chinese make effective use of posters, banners, and billboards to emphasize the goals of the people often using the quotes of Chairman Mao to constantly remind – and encourage – the people to develop Chinese agriculture.

An annual increase in China's grain production was reported for the past 14 years (1962–75) and from what the IRRI team observed 1976 will continue that trend. The average annual rate of growth of grain output during the 1962–75 period was 3.5%, with the most rapid growth experienced in the first part of that period. That achievement must be interpreted in the context of China's meager resource base.

China can be characterized as a labor surplus economy. The labor supply is large relative to the supply of capital and the cultivated land area. Only about 15% of the land area is cultivated and the arable land per capita is extremely small, even when compared with most other developing Asian countries (Table 1). In six communes visited by the IRRI team the number of workers per hectare ranged from 5 to 8, which reflects a population density and labor force availability comparable to East Asia and to about 25% of the farms (but only 2% of the farming area) in South and Southeast Asia (e.g., Java). Most farms in Asia have less than half as much labor per hectare as China.

A lack of capital goods of all types, inadequate transportation facilities, and limited cultivated land area per worker characterized the Chinese agricultural resource situation after the revolution. In the process of raising agricultural production, emphasis was given

Table 1. Arable land per capita among 10 most-populated countries in Asia, 1970.[a]

Country	Total population (000)	Agricultural population (000)	Arable land[b] (000 ha)	Arable land per capita (ha)
Burma	27,748	17,675	18,920	0.682
Thailand	36,161	27,663	12,900	0.357
India	538,810	364,774	165,680	0.307
Pakistan	53,514	43,881	19,235	0.359
Japan	103,499	21,321	5,796	0.056
Philippines	36,849	26,531	6,579	0.179
China, People's Republic	759,609	508,938	126,095	0.166
Indonesia	121,198	84,839	18,000	0.149
Bangladesh	60,675	52,787	99,097	0.150
Korea (South)	32,107	17,132	2,298	0.072

[a]Ranked from top to bottom by arable hectares per agricultural worker.
[b]Arable land refers to land under temporary crop and permanent crops and land temporarily fallow or lying idle.

to raising the productivity of the existing cultivated area through an increase in yields and an expansion in the area multiple cropped. In 1962, it was decided that China's limited capital resources should be concentrated in those areas that were most likely to show the highest production response to modern inputs. Thus, priority in input use was given to what has come to be known as the *high and stable yield areas.* The IRRI team traveled primarily in those areas, which are said to represent about 11% of China's cultivated land.

The postrevolution development of agriculture in the high and stable yield areas can be divided into two phases. The first covers the period from 1949 to 1965 and the second, continuing phase covers the period from 1966.

The first phase was marked by much experimentation with agricultural organization and culminated in the establishment of the commune system in 1958. During that period, increased production and infrastructure development depended almost exclusively on the mobilization of rural labor. For example, labor was used to increase yields through recycling of wastes and composting, and to construct canals, levees, and dams to control water. Rural electrification permitted mechanization of operations that were mechanically efficient — pumping water, grain processing, threshing — and thereby freed labor to be used elsewhere. Effective irrigation and drainage enhanced the productivity of labor and set the stage for the rapid increase in the use of modern inputs.

The second phase of agricultural development is characterized by the spread of modern, fertilizer-responsive varieties, increased use of chemical fertilizer, and mechanization of additional operations. Expanded use of chemical fertilizers and mechanization raised productivity without reducing the labor inputs. Chemical fertilizers are applied in addition to, not as a substitute for, organic compost. Mechanization is used principally to reduce the time period between the harvest of one crop and the planting of another. Mechanization, coupled with the development of short-season varieties, has in some cases saved enough time to grow an additional crop in a year. Thus, the savings in labor per crop results in increased labor per hectare per year.

An eight-point charter for agricultural development summarizes the goals of intensive agricultural production. In simplest terms, the objective of China's agricultural policy is to maximize agricultural output per unit of land by relying primarily on available local resources, particularly human labor. The institutional organization of agriculture provides the mechanism for implementing that objective.

THE ORGANIZATION OF PRODUCTION

The major administrative and planning units in agriculture are the province, the county, and the communes. Plans are worked out at each level for supplying inputs such as electricity and water to the commune at nominal fees, and for purchasing and distributing the agricultural surplus of the commune.

Since 1958 the people's commune has been the basic unit of local government. The commune compares with a township or municipality encompassing a market center and a number of satellite villages. The population of the communes visited ranged from 21,000 to 73,000 and had from 11 to 17 people per cultivated hectare.

The commune is organized into a series of brigades and production teams, with the production team equivalent in size to a village. As with any village organization, there is again wide variation in size. Typically, from 25 to 50 families — 50 to 100 workers — in a production team cultivated from 8 to 16 hectares of land in the commune production units visited. (It should be noted, however, that the IRRI group traveled only through densely populated rice-producing areas.)

The central authority of government extends through a network of cadre or party officials all the way down to the production team.

Plans for production and input use are often decided upon jointly by leading farmers, technicians, and the cadre. The cadre provides the basic link in assuming that decisions made at the lowest level are properly coordinated with production plans and targets at the higher levels.

The basic unit of accounting is the production team. Each member of the labor force earns a certain number of work points per day. The criteria for assigning work points, such as age and physical fitness, vary considerably from one commune to another. After production costs and an amount for the public fund (including funds for purchase of equipment, operation of schools, etc.) are set aside, the commune income is divided among the members according to the work points earned. In two communes that provided detailed data, about 50% of commune gross income was distributed to the people giving an annual per-worker income of about US$200. That income excludes earnings from private plots assigned to each family, which account for about 7% of total cultivated land.

There are four features of the commune organization that merit particular attention — the mobilization of labor, the mobilization of rural savings, the allocation of resources, and the link between agricultural and nonagricultural activities.

Mobilization of labor

The active labor force is about 10% larger in China than in other Asian countries, mainly because of a much higher participation of women. Furthermore, in the commune, the labor force tends to work longer hours per day and more days per year. The total labor input from a given population is perhaps twice as large in China as in other countries. This is possible because the labor force, when not working directly in agricultural production, is assigned to tasks involving capital investment. It is possible also because of constant encouragement to work hard, and because of incentives for hard work in terms of both work points earned and other less-tangible assets.

An important point is that for all jobs undertaken by the individual, regardless of the contribution to productivity, the same daily work points are earned. A large share of the labor input can be mobilized for capital investment, the benefits from which are not immediately realized. Labor can also be assigned to activities that give a low, but positive return. In this context, it would appear that many of the more profitable capital investment activities have now

been completed. For example, the initial use of the labor force to develop the irrigation and drainage network must have had an extremely high payoff. But the benefits from placing the irrigation system in underground pipes to conserve water and land must be of a much lower order of magnitude.

Mobilization of rural savings

A second feature of the commune structure is the facility with which resources can be mobilized for investment. In most developing economies rural savings rates are typically 5% or less, reflecting a lack of opportunity for productive investment. In the communes the IRRI team visited, between 10 and 15% of the total value of output was being set aside for the *public fund.* Money from that fund supports the educational and health system, the elderly, and other public services.

The Chinese public fund system contrasts sharply with the procedure in the free-market economies of providing public services, such as education and health, through the central government, usually at inadequate levels of support. About half of the commune *public fund* is reinvested in agricultural machinery and equipment. The fund's low rate of interest, about 2.5%, partly reflects the fact that there is no inflation in prices from year to year. The high rate of savings is possible because the savings are reinvested in the community, and hence directly benefit those doing the saving.

Allocation of resources

In free-market economies the pricing system is the mechanism for resource allocation. In the commune, price also plays a role but a rather different role. There is no land rent to pay and labor is not hired for a wage. Through the work-point system, labor, not land, becomes the residual claimant on profits earned. All other items purchased and sold have a price and price does influence decisions in the use of inputs and the product mix.

However, in the case of food grain production, in particular, producers are encouraged to achieve certain production goals even if this means lower profits. For example, rice is sold at a low price to consumers, and through a rationing system everyone is guaranteed an adequate supply. The government subsidizes rice prices to encourage production. Even at the subsidized price, however, there are more attractive alternatives to grain production. But, it is more or less understood that the bulk of the cultivated land in grain

production will remain in grain production, and that every effort will be made by the commune to steadily increase the quantity of surplus grain sold to the State.

Agriculture and nonagriculture linkages

The link between agricultural and nonagricultural activities in the commune reflects the dynamic nature of commune development. There appears to be relatively little movement of labor between the rural and urban areas, but in the rural areas there is significant growth of a labor force working in small-scale industries at either the commune or brigade level. Those industries are designed principally to provide the necessary inputs and services (e.g., cement, tools, tractor repair) for agricultural development. Some products such as agricultural chemicals are *exported* to other communes. Some communes manufacture component parts such as those for tractors and bicycles. In other cases, cottage industry or local handicraft-making is an important *sideline* activity. In the communes visited the growth of nonfarm activities during the past decade has absorbed a large share of the addition to the labor force through population growth, but the absolute level of labor in agriculture seems to have remained fairly constant.

During harvest periods, agriculture has first priority. In the communes factory workers and school children help with the harvest and in urban areas factories can be called upon to supply labor to nearby communes free of charge.

The commune structure has facilitated the mobilization of labor in a labor-surplus society for production and capital investment. The development of small-scale industry in the rural sector provides the opportunity for productive investment of capital and for more productive use of surplus labor. Yield gains due to investment in agricultural infrastructure had, however, been almost fully exploited in the communes visited, and further gains in grain production will depend almost completely on the development and application of the new crop technology.

RICE TECHNOLOGY

The development of short-season varieties (70 to 100 days from transplanting to harvest) was a major contributor to the 20% growth in rice area cropped during the past two decades. Rice is now grown extensively in the northern area of China in rotation with wheat.

The area double-cropped annually with rice has also extended northward to the Yangtze river and plans are now underway to expand the area growing three crops of rice a year in Kwangtung province.

Improved irrigation (and drainage) is another key factor that has permitted the intensification of rice cropping systems. It also encouraged the use of fertilizer. Research in the development of a dwarf, fertilizer-responsive, indica rice variety began in 1956 and by the mid-1960's, dwarf indica varieties were being widely grown.

Good water control and adequate labor have permitted careful attention to agronomic practices — seed selection, development of strong and healthy seedlings, proper depth of transplanted seedlings, share spacing, proper water management, deep placement of fertilizer to obtain maximum efficiency, and frequent spraying of the crop to control insects.

Many of those agronomic practices are details to which the average Asian farmers pay little attention. But rice is a crop that responds to intensive care and management. It would be difficult to measure the impact of additional labor inputs on yields on a task-by-task basis, but in a well-controlled water environment the addition of 100 to 200 man-days of labor per hectare in care-of-crop practices could result in an additional 500 kg of rice per hectare. Until there are better alternative uses for labor, there is no need to determine which tasks are least productive.

As previously noted the focus in mechanization is on equipment that saves time and labor during the period between harvest of one crop and the transplanting of the next crop. This explains, for example, why China has been one of the first countries to develop and popularize the rice transplanter. Conversely, it explains why in weed control, where there is less time pressure, the Chinese use hand and hand-tool methods instead of herbicides.

Yields reported in the communes visited averaged about 10 t/ha per year for all grain, and about 5 t/ha for a single crop of rice. The question has been raised as to whether or not the *high and stable yield areas* have reached a ceiling with respect to total production per hectare. It appears that major infrastructure development has been completed, and that there is little scope remaining for raising yields through additional investment. However, some latitude remains for raising yields through improved technology. The Chinese researchers speak of targets ranging up to 15 or 20 t/ha, a level of production currently being achieved only in isolated areas. This level can probably be reached over a wider area through a combination

of varietal improvement and increased fertilizer input, but the most urgent need is for varieties that are resistant to major pests and diseases (particularly the brown planthopper), which are becoming more of a problem with intensification of cropping.

PROSPECTS OF RICE PRODUCTION IN CHINA

Chinese rice production is now highly dependent on organic manures, including the use of night soil, and compost or farmyard manures. It is interesting to compare Chinese rice cultivation today with Japan's experience.

In Japan, good irrigation and drainage facilities were provided for rice farming more than 100 years before Japan's modernization started. Between 1920 and 1930, national average rice yield reached about 3 t/ha before introduction of chemical fertilizers. That national average of 3 t/ha was achieved by use of organic manures. Compare that with the 3.4 t/ha national average in China today.

To increase Japan's national average rice yield from 3 t/ha to 6 t/ha there was improvement of lowly productive soils, heavy application of nitrogen fertilizers, and better control of diseases and insects, in addition to breeding of improved varieties.

At its current yield level of 3.4 t/ha, China appears to be well ahead of Japan in terms of varietal improvement. China already has semidwarf varieties that do not lodge at high nitrogen levels. If China can manufacture more chemical fertilizers and achieve better control of diseases and insects (by variety or by management), it has great prospects for increased rice production within a much shorter time than Japan.

RESEARCH AND EDUCATIONAL INSTITUTIONS

SINCE THE CULTURAL REVOLUTION, the demand for immediate relevance has dominated the agricultural research and extension systems in China. Likewise, education has been focused almost entirely upon job-related training and upon subjects of immediate practical concern to human welfare. This *application* orientation has made possible the prompt utilization at the farm level of new research findings. It has assured immediate attention by researchers to practical production problems. And it has helped students at all levels focus on agriculture and on the solution of practical farming problems.

Because of this problem-solving orientation of agricultural research and education, the focal point for attention is *out in the countryside* where the problems exist. The staff and faculty of each research and educational organization visited by the IRRI team indicated they were spending some time each year at the *grass-roots* level, learning from the peasants and cooperating with them and with local researchers on common projects.

EDUCATIONAL SYSTEMS IN CHINA

Education through junior high school is compulsory in China, in elementary and junior high schools located at the production unit, production brigade, commune, county, and township level. The IRRI team visited an elementary school and a junior-middle school in Mai-Tsien county. The elementary school classes were teaching the alphabet, the abacus, and music. In the junior-middle school, classes were on the method of rice variety selection, fermentation of feeds, and the various parts and functioning (outdoor demonstration) of a diesel engine.

After junior high school all students are assigned to communes, factories, or other appropriate places. Education beyond junior high school is based on the recommendation (for individuals) by those organizations and is based on overall performance including political ideology. Those who complete high school are again assigned to practical work and a similar procedure of selection is followed for university education. High school graduates frequently get on-the-job training and undertake highly specialized work without further formal training.

Before the cultural revolution the university requirement was 4 to 5 years. It is now 3 years with attention to practical learning and emphasis on short courses. The teaching materials are based on Chinese rather than on foreign texts, lecture materials are prepared jointly by teachers, and no formal diploma is given.

The IRRI group visited Chung Shan University, originally a College of Agriculture founded more than 50 years ago and named after Dr. Shun Yat Sen. The College of Agriculture moved to a new campus in 1950 and the Chung Shan University now specializes in arts and sciences. The arts include Chinese literature, history, philosophy, economics, and foreign languages. The sciences include mathematics, physics, chemistry, biology, geography, and metal sciences. The university has more than 3,000 students on campus, about 10,000 students attending short courses, and a teaching staff of 1,000.

The University practices open-door teaching, which means most of the teaching is in the field with students sent to production brigades or production units to conduct experiments. All teaching materials are indigenous, with foreign teaching material used only if local material is not available.

The theoretical part of the course work is always related to practical problems and academic courses are not offered. The entomology courses — 110 students studying entomology — include insect classification, insect physiology, applied entomology, and insect pathology (microbiology).

The last half-year at the university includes thesis work. Thesis topics are generally based on special production problems but in a few cases theoretical subjects related to production are also selected.

OPEN-DOOR RESEARCH POLICY

Rice research in China is carried out at each administrative level. This ranges from the institutes of the prestigious Academy of Sciences

(Academia Sinica) and of the Academy of Agricultural and Forestry Sciences to the thousands of field testing groups in provinces, communes, brigades, and production teams throughout the country (see Figure 1). Some research on rice was under way at each of the locations visited by the IRRI team from Peking to Kwangchow. Such research is coordinated through what is termed an *open door policy.* This requires that a major part of research be done in the field where the problems are and that peasants and farmers participate in the research work. It is not uncommon to find 80 to 90% of a research organization's staff assigned to work in farm fields at least some time during the year. The general research organization has evolved so as to minimize any hierarchy. In many institutes it was difficult to distinguish the head of a program from his assistant or associate scientists. Team leaders were often introduced as *responsible persons.*

This *grassroots* participation by scientists or research institutes and faculty and students of universities places focus on the problem rather than on position, academic training, or prestige. Many agricultural researchers have no formal advanced training in their discipline; some are high school graduates who have learned research techniques on the job.

The basic Chinese research concept is to do problem solving based on:

- Self reliance, wherein a problem is studied and the solution first sought locally. Requests upward for recommendations and information are made only when necessary, and then one level at one time. The scientist-technicians in the organizations collaborate closely.
- Interlevel cooperation, where brigade and production teams have study *points* (sites) for their work. Scientists from the higher-level research organizations may also work at these *points* to cooperate with and help the lower-level workers. The stay of scientists at a *point* may be from a few months to several years — until a problem is solved or a new system developed. The interlevel personnel interaction is maximized by a *three-togetherness concept,* the sharing of food, shelter, and work.
- Integration of research and production, which is achieved by coordinating leadership, which consists of leading cadres, leading peasants, and technical personnel; research emphasis, which is equally on investigation, production, and utilization of agricultural products; and control methods through the emphasis of testing, demonstration and extension.

This problem-solving approach to research expedites the pathway of research, through extension to production. For example, an effective method of insect control can be developed, popularized and adopted throughout wide areas within one year.

Popularization extension programs

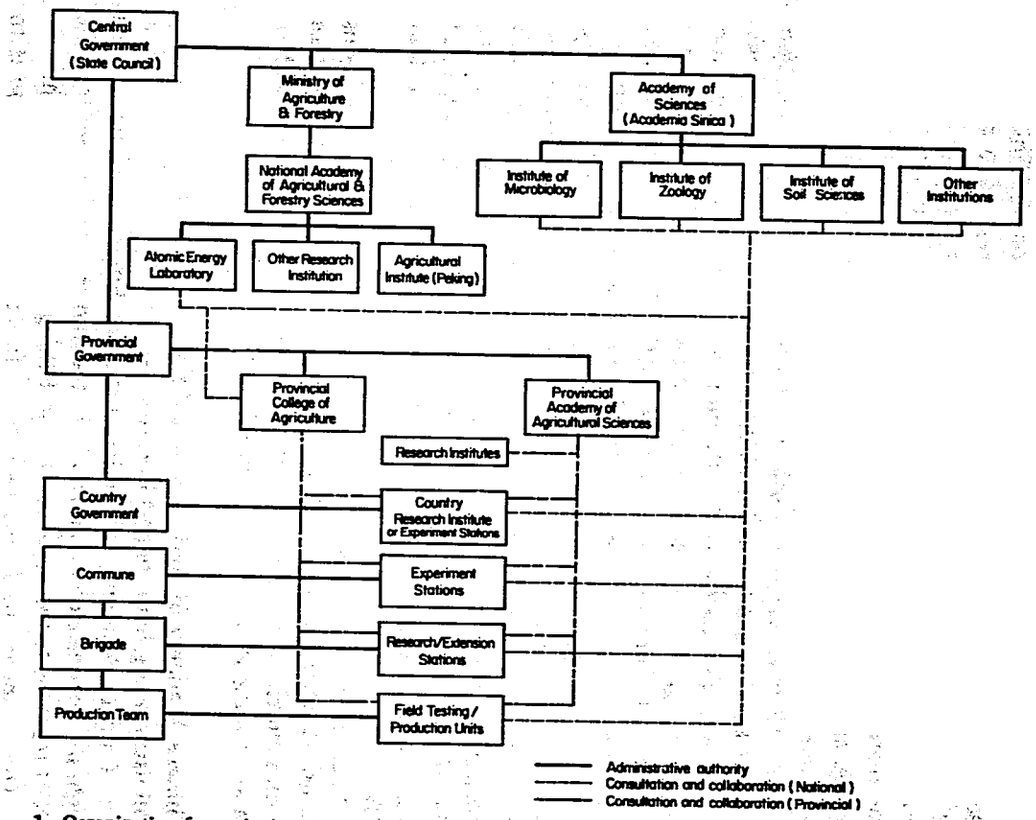
Positive results of agricultural research are rapidly translated into action programs. Extension activities, collectively called popularization, effectively characterize the priority associated with the importance of preparation, dissemination of information, and implementation of new practices for the benefit of the masses. Because research is primarily associated with problem-solving, and is characteristically implemented at local levels, a direct relationship between research and popularization programs is encouraged. The interaction is further strengthened by the fact that most researchers and their university students have a direct contact and personal involvement with specific problems at the local, farm-production level.

NATIONAL LEADERSHIP AND COORDINATION

Leadership for rice research on a national level is provided through two ministerial level organizations that report to the State Council of China (see Figure 1):

- the Chinese Academy of Sciences, which has research institutes throughout the country, and which also works in conjunction with provincial and municipal governments, and
- the Ministry of Agriculture and Forestry, which administers some applied research institutes directly and which coordinates activities of the provincial agricultural research academies and institutes, and the numerous field research and testing stations located at the county, commune, and brigade levels.

The Ministry and the Academy, both of which are of ministerial level, work in close collaboration. As previously mentioned, scientists from the institutes administered by the Academy of Sciences often work at Ministry-administered institutes and at cooperating provincial-, county-, or commune-level organizations. In general, the Academy is oriented toward basic research — mostly the problem-solving type — while the Ministry and cooperating local research institutes and field stations emphasize the applied aspects of agricultural research. A few research institutes are administered jointly by the Academy of Sciences and a provincial or municipal government.



1. Organization for agricultural research and general higher education in the People's Republic of China.

Academy of Sciences (Academia Sinica)

The Academy of Sciences, a cabinet-level national institution, administers quality research institutes at several locations in China. Rice research is carried out at many of those institutes, three of which the IRRI team visited: the Institute of Microbiology and the Institute of Zoology, both in Peking, and the Soil Science Institute, Nanking. The Institutes of Genetics and of Botany also do rice research in Peking, and their scientists participated in group discussions with the IRRI scientists.

While all rice research is said to be oriented toward the solution of practical rice production problems, the institutes of the Academy of Sciences give considerable attention to gaining basic information needed to solve the problems. For example, scientists at the National Institute of Zoology, work on synthetic diets for parasites and predators, on sex pheromones and juvenile hormones, and on synthesis of new insecticides. At the National Institute of Microbiology the work is on genetics, on the enzymology of microorganisms and their role in agricultural and industrial production, and on the basic research required to integrate short term and long term projects. The Soil Science Institute, jointly sponsored by Academia Sinica and Kiangsu province, concentrates on studies of soil characteristics that affect crop production.

Each of the institutes visited gave up-to-date research publications to the IRRI team, which attests to the importance given to written communication among scientists working at the institutes administered by the Academy of Sciences.

Chinese Academy of Agricultural and Forestry Sciences (Ministry of Agriculture and Forestry)

The Chinese Academy of Agricultural and Forestry Sciences is the highest-level research organization in the Ministry of Agriculture. The IRRI team visited its headquarters in Peking to see rice research.

The Academy performs two major functions. One function is to carry out agricultural research in many subjects, not only at headquarters but in cooperation with field research units. The second function is coordination of regional and national research and field testing programs. Examples of that coordination are the regional networks for North and South China, which have been set up for testing the performance of rice varieties and lines. The Academy has no administrative control over research at the provincial and local levels but nevertheless carries out its coordinating function (Figure 1).

Chinese Association of Agriculture

The Chinese Association of Agriculture, which was host to the IRRI team, includes scientists, administrators, and general agriculturists, and looks after the overall agricultural development of China. The Association provides additional educational expertise at national, provincial, and local levels and has a major educational commitment to emphasize a *three-in-one principle* of involvement of scientific leaders, technicians, and the masses. The Association organizes educational meetings, publishes extension-type literature, and in general serves in a coordinating role in the preparation and dissemination of educational materials. Parallel to the research work, it organizes short-term classes and other training for technical personnel in the production units.

PROVINCIAL AND MUNICIPAL ACADEMIES OF AGRICULTURAL SCIENCE

There is one or more provincial academy, or institute, of agricultural science in each province, which are administratively responsible to the provincial or municipal government. Some were formerly agricultural research institutes in Peking, but they are now located in the provinces so as to be close to the problems they were set up to solve. Others were set up by the provincial or municipal governments.

Provincial academies serve the provinces much the same as the Academy of Agricultural and Forestry Sciences serves at the national level. Provincial academy scientists perform some research in their laboratories and on their experimental fields, but much of their work is done *at the grass roots* in cooperation with scientists, technicians, and farmers. The provincial academies perform a coordinating role as exemplified by province-wide rice variety and line performance tests.

As in the case with the Academy of Agriculture and Forestry the provincial academies have no administrative control over research units at the level of the commune, production brigade, or production team.

The IRRI team visited provincial academies of agricultural science in Kiangsu and Kwangtung, the Shanghai Institute of Agricultural Sciences, and the Shanghai Institute of Plant Physiology. The research at those provincial- and municipal-level organizations was strongly oriented toward the solution of rice production problems in their

respective geographic areas. Heavy emphasis was placed on cooperation with local research units.

Kwangtung Academy of Agricultural Science

Most of the research work of the Kwangtung Academy of Agricultural Science is done away from the headquarters in field stations administered at the county commune or brigade level. Teams of scientists are sent to problem areas, or to areas where they want to test a new concept, system, or practice. Their work is performed in cooperation with experiment stations, or field testing stations that are administratively under the control of the lower level governmental units.

When it is deemed desirable to initiate cooperation between the Academy and a given field unit, approval is obtained from the provincial Agricultural Bureau, thus assuring cooperation from the field units.

Kiangsu Academy of Agricultural Science

The staff of the Kiangsu Institute of Agricultural Science does most of its research work in the field. The Institute headquarters is in Nanking but about two thirds of their work is in the field. The field research is done at four integrated centers located in the province or at 14 *centers* for special research located wherever specific problems exist. The 14 *centers* do not remain at specific locations but move to the problems.

Agricultural research in the province is done through a four-level scientific network that includes

- research institutes in each county,
- experiment stations in more than 80% of the communes,
- production research teams in 60% of the brigades, and
- production research groups in 60% of the production teams.

The Institute also cooperates with colleges and production and industrial units. Researchers from the grass roots (poor and middle-class peasants and farmers) are invited to work at the Institute for on-the-job training. Special courses are organized for as many as 200 *grass roots researchers* at a time.

Shanghai Academy of Agricultural Sciences

The Shanghai Academy of Agricultural Sciences has 400 scientists. Of those, 130 do *grass roots* work with local leaders and peasants. The 130 researchers work at 38 research centers in counties just outside Shanghai at the commune or brigade levels, and at 360

liaison locations at production-team levels.

Institute researchers stress that they use the open-door method of doing research in cooperation with people at the commune, brigade, and production team level on the *three-in-one principle.*

LOCAL-LEVEL RESEARCH AND TESTING

An important administrative unit within a province is the county, which in turn is made up of several communes. Within each commune is a number of production brigades and within each brigade is a number of production teams. There is considerable autonomy in managing agricultural production at both the brigade and production-team levels, but the agricultural research and extension complex provides considerable linkage between the commune and county and provincial governments.

In each province a research and testing system carries out agricultural research testing and extension work. Agricultural experiment stations are established at the commune level and in some areas stations are found at the production-brigade level. To supplement the work of the experiment stations, a number of field testing units are generally set up at the production brigade level. These in turn are supplemented by small research groups stationed with production teams.

This comprehensive network of testing sites, when reinforced with field work carried out in cooperation with the staff of provincial academies of agricultural sciences, and with university faculty and students, provides an impressive array of applied research and extension activities. It is common to have 1,000 or more scientists, technicians, managers, and peasants involved at least part time, in agricultural research within a given commune.

A brief description of a county research institute, a brigade experiment station, and a production team field test site illustrates the activities of local level research units.

Hwa County Research Institute of Agricultural Sciences

The Hwa County Research Institute of Agricultural Sciences, founded in 1959, represents the first level of institute research at the county level. The Institute has 25 research workers, 30 cadres, 150 staff members, and 250 mou (16.7 ha) of experimental land.

The institute has groups working in

- plant breeding,

- fertilizer-soil,
- cash crops,
- plant protection,
- animal husbandry, and
- microorganisms doing primarily antibiotic production.

The Institute also has a school for agricultural technology that trains 150 students a year. The technical course lasts one year, and the students spend time in the classroom and in the field. The students return to their respective communes or brigade research units after the course. A total of 932 students have graduated from the school, of which 20 are party branch secretaries or brigade leaders, more than 200 are responsible persons in the four-level research systems, and more than 600 are researchers or technicians working on plant protection and the selection of seed.

The institute has good laboratory facilities for soil and plant analysis. It also operates a small plant for manufacturing *chinkon mycin*, an antibiotic used in controlling sheath blight. It produces about 100 tons of antibiotics, which is adequate for 100,000 mou (6,700 ha) of rice.

San Hua Brigade of the Syin Hwa People's Commune

The San Hua Brigade is the third level of agricultural research in Hua County, 40 km northwest of Canton. There are 153 research workers in the research sections of the brigade, most of them at the team level. The brigade has 18 production teams and 138 mou (9.2 ha) of experimental land. The main work of the brigade is to purify seed – select, breed, and multiply. They select single panicles and multiply from that. For the introduction and testing of a new rice variety in the brigade, a decision is first made as to whether to multiply the variety. Teams of cadres, technicians, and peasants get together to make that decision.

Table 1. *Azolla* **treatment and rice yields. Taken from a chart at the San Hua Brigade, Syin Hwa People's Commune, the People's Republic of China, October 1976.**

Treatment	1973		1974	
	Yield (kg/ha)	% area control	Yield (kg/ha)	% area control
Azolla	5,074	5.5	6,330	5.4
Azolla as topdressing			6,578	9.5
Azolla after wheat			6,158	2.5
No *Azolla*	4,845		6,008	

The IRRI group visited experimental fields and the brigade headquarters, which has many charts on the wall showing production, yield trends, and results of experiments. For example, one chart reported the results obtained for different treatments using *Azolla* as green manure, which the commune emphasizes (Table 1).

The 18th Production Team, San Hua Brigade

The 18th Production Team of the San Hua Brigade represented the fourth level of agricultural research visited by the IRRI group. The 18th Production Team included 20 people, with 9 technicians and cadres working on agricultural sciences. The Team had 15 mou (1 ha) of experimental land with the main objective of seed multiplication and research on higher yield through plant protection, irrigation water management, and fertilizer use.

RICE TECHNOLOGY IN CHINA

RICE VARIETY IMPROVEMENT

The Chinese policy on crop improvement is set forth in the simple statement of Chairman Mao Tse Tung, "When you have good seeds, even if the labor and fertilizer are inadequate, you will still get better yield."

Consequently, major emphasis in the Chinese research system is on crop improvement. The IRRI team talked with many rice breeders in each region visited, and the senior plant breeder of the Academy of Agricultural and Forestry Sciences, Peking, traveled with the team throughout its visit. China has a large number of plant breeders in rice improvement work at all levels. Breeders serve in the research groups of the production teams, brigades, and communes and are employed at county agricultural research institutes and provincial agricultural academies.

Rice breeding methods

The Chinese use three breeding methods in rice improvement work — hybridization, radiation treatment, and haploid breeding using anther culture.

HYBRIDIZATION. Hybridization is the most widely used method in China's rice breeding. A large number of crosses between different rice varieties are made each year at provincial academies, county research institutes, and at experiment stations in the communes, brigades, and production teams.

Crossing is generally between the varieties belonging to each rice group, but occasionally crosses between indica and japonica varieties

are made to transfer traits from one group to the other. For example, sources of strong resistance to blast are not available in japonica varieties, but many indica donors for blast resistance are known. Genes for blast resistance from the indica donors have been transferred to japonica varieties by backcrossing. Examples of japonica varieties utilized for the improvement of indica varieties are rare. There are no varieties of hybrid origin intermediate in traits from the two groups of rices but efforts are under way to develop such varieties.

In the future it is likely that greater emphasis will be put on developing varieties from indica-japonica hybridizations. That approach would be particularly useful for developing early maturing varieties for the second crop in central and northern China where the growing periods are short.

RADIATION BREEDING. Radiation is commonly used in rice breeding in China, but the IRRI scientists saw radiation-induced mutants at only one location. At the Kiangsu Academy of Agricultural Science, a radiation-induced mutant of Nong Hu 6, which was 10 days earlier in maturity than the parent variety, was being multiplied.

At the Institute of Plant Physiology, Shanghai, irradiation of cells and tissues in vitro was observed. Generally, the dry seeds of the

Rice seedlings grown from pollen culture at the Institute of Plant Physiology in Shanghai.

crop species are irradiated but their radiosensitivity is low, and radiation of the tissues and plant cells in vitro may increase the mutation frequency. To test that hypothesis, tobacco callus was irradiated with different doses of gamma radiation (1–120 kr) and subsequently cultured for 28 days. Callus irradiated with 3 kr showed significant retardation of growth. The growth of the callus that received more than 10 kr treatment turned black and died. However, seeds that received 40 kr of gamma radiation germinated and grew normally.

Callus that received radiation treatment within the range of 0.5 to 8 kr maintained its ability to differentiate. Several morphological variants, including albinos, were present among the plants regenerated from callus after radiation doses as low as 3 kr.

HAPLOID BREEDING THROUGH ANTHER CULTURE. Many of the provincial academies, county research institutes, and communes employ haploid breeding in rice improvement. Six of the 10 counties of Shanghai municipality, for example, used the method. The IRRI team saw extensive work on anther culture of rice at the Academy of Agricultural Sciences, Shanghai, and at Chung Shan University, Kwangchow.

The Shing Sho variety (japonica) was bred by the haploid technique using anther culture. The variety has large panicles and cold tolerance; it is nitrogen responsive, and is planted extensively as a second crop in the Shanghai area. Several newer lines bred by haploid-anther culture are early maturing and have high yield potential.

The advantage of the haploid method over conventional hybridization is that homozygosity is reached in one generation instead of after several generations of selfing and selection, thus saving tremendous amounts of labor and land. The Chinese, however, pointed out another advantage for rice. When crosses between indica and japonica are handled in the conventional manner the progeny show varying degrees of sterility. The diploid lines obtained through anther culture of indica-japonica F_1 hybrids rarely show sterility.

At the Academy of Agricultural Sciences, Shanghai, the IRRI group saw breeding lines developed by anther culture from an F_1 of the japonica variety Shing Sho and a dwarf indica parent. Those lines (2025 and 2057) were clearly intermediate and combined the desirable traits of the indica and japonica parents. They inherited a shorter growth duration (135 days vs 150 days), short sturdy straw for lodging resistance, high tillering, and an erect leaf angle from

At a Kwangtung area commune, Dr. G. S. Khush, IRRI plant breeder, with two local rice breeders, inspects rice breeding lines.

the indica parent. The desirable traits of the japonica parent, such as nonshattering, desirable panicle and grain characteristics, and cold tolerance, were also incorporated in the lines.

The cold tolerance of the new lines was not as good, however, as that of the japonica parent. The two lines were seen in yield tests in the Shanghai area and it appeared that they would outyield their japonica parent.

Coordination of rice trials

Two organizations exist for the planning and implementation of rice variety trials in China — one in the north and one in the south.

The Academy of Sciences for Agriculture and Forestry originally organized the variety trial cooperators and continues to call important meetings. Representatives participate from experiment stations, research institutes, and provincial academies of agricultural science. The meeting place rotates among the provinces with the host institution identifying the time and place for the meeting and issuing the invitations. Meetings are held every other year and, presumably, the same trials are run for 2 years.

Each cooperating unit nominates one or more varieties for each of six trial types, which are based primarily on latitude and cropping system. At the meeting decisions are made regarding the specific entries to be included in each trial, including one check entry, and each cooperating unit may add one or two local checks. The results from all trials are summarized and made available to all cooperators but no general report is published.

The same general procedure is followed below the provincial level where seeds are exchanged among experiment stations of the province, county, commune, brigade, and production team. These trials appear to be the same as IRRI replicated yield trials. Some special-purpose trials are organized on problems such as blast and cold tolerance.

Coordinated yield trials

Coordinated yield trials for rice are conducted throughout China to identify promising cultivars. In Kwangtung province, for example, the promising lines developed at the agricultural academy and county-level research institutes are distributed to research groups of the communes, brigades, and production teams for testing purposes. Breeding materials developed by the research staff of the communes, brigades, and production teams are included in the trials.

During the IRRI team's visit to Hwa county a four-level network of agricultural research was seen. The research groups of the communes, brigades, and production teams purify the selections, multiply the seeds, and conduct preliminary yield trials. County-level meetings are held twice a year for county, commune, brigade, and production team researchers. The meetings are sponsored at the provincial level and outstanding farmers, extension workers, and cadres attend.

Prefecture-level meetings attended by county research representatives are also held twice a year, as are province-level meetings attended by province-level university staff, staff of the provincial agricultural academy and representatives of various counties. During the province meetings, results of province-wide trials are reviewed and the exchange of improved germ plasm between countries is facilitated. Several varieties are approved by the provincial meetings but each county or commune decides which variety to recommend.

Regional trials are organized by the agricultural academy of each province and facilitate the exchange of seed materials of promising lines between provinces. The variety Kuang Lu Ai No. 4, developed in Kwangtung province, was introduced to Kiangsu province through

the regional trials and became popular in that province. Similarly, Nanking 11 was developed in Kiangsu province and introduced into southern China.

Rice breeding in Kwangtung province

When the rice breeding program in Kwangtung province was organized after liberation there were numerous local, tall varieties and mixtures being grown. A hybridization program was started and two varieties, Kuang Cheng 13 and Hua Nan 15, were developed and released in the province in the early 1950's. The two varieties were tall, lodging susceptible, and did not respond to nitrogen fertilization.

In 1956, after looking over many germ plasm entries being maintained at the Academy of Agricultural Sciences, breeders identified a dwarf variety called Ai Tze Chang. That variety, originally from Kuangsi province, was crossed with a locally adapted variety, Kuang Cheng 13, and from that cross the first dwarf variety of hybrid origin was released in 1961 as Cheng Chu Ai.

Another source of dwarfing was identified in 1956. Two peasant brothers, Hung Chun Li and Hing Chun Yin, Kwangtung province, selected a short-statured rice plant that was probably a spontaneous mutant of a tall variety. The brothers' entire field had been badly lodged by a typhoon but the short plant did not lodge and stood out in the field. The short-statured *selection* was rapidly multiplied and released as the variety Ai Chiao Nan-teh in 1957. It was also used in the hybridization program but proved to be a poor combiner. A few Chinese dwarf strains, such as Tie Ku Ai, were selected with Ai Chiao Nan-teh as a source of dwarfism.

The dwarf varieties were widely accepted and by 1965 most of the first crop in Kwangtung province was planted to them. Before introduction of the dwarf rices, the first crop accounted for 40% of the total rice production; after widespread acceptance of the dwarfs, the first crop accounted for 60% of the production. Cheng Chu Ai is the main variety for the first crop. Kung Lu Ai No. 4, released in 1969, is becoming popular for the first crop in the two-rice-crop system, or for the first and second crop in the three-rice-crop system. Kung Lu Ai No. 4 matures 2 weeks earlier than Cheng Chu Ai.

The first dwarf variety (Kuang Er Ai) for the second crop of the two-rice-crop system was released in 1963. That variety inherited wide leaves and sensitivity to cold temperature from its dwarf parent. It was further crossed with locally adapted second-crop varieties and an improved dwarf variety, Kuang Hwa Ai, was released for the

second crop. It has narrow leaves, is photoperiod sensitive, and has adaptation for the second-crop conditions.

The mountain areas of the north of Kwangtung province grow only one crop of rice. In keeping with the *open door* research policy, the provincial agricultural academy sent scientists to the mountain regions to integrate with the research workers of the communes, brigades, and production teams. As a result, the varieties Chu Ba Tsao and Chu Go Ai were developed for the mountain area. The new varieties give 20–25% more yield than the local varieties.

Blast is a serious problem in the mountains and an indica variety with blast resistance (Chai Ye Ching) was selected for the area. That variety is also resistant to bacterial blight and has a large number of panicles. It is somewhat taller than Cheng Chu Ai and is not as lodging resistant. Chai Ye Ching was crossed with another locally adapted variety and two promising lines, Hwang Cheng No. 1 and Hwang Cheng No. 2, were developed from that cross. They have high-yield potential, early maturity, good grain quality, and resistance to blast and bacterial blight.

Agronomic characteristics

Most of the rice improvement work in China has been to improve agronomic characteristics. High yield and short growth duration were emphasized. Short growth duration has become a major breeding objective because early maturing varieties are essential for the multiple cropping systems developing in China.

To develop early maturing varieties, conventional hybridization between locally adapted varieties and early maturing cultivars of Chinese origin was emphasized. Many early maturing indica varieties, such as Kuang Lu Ai No. 4, which is grown widely in central and southern China, were developed. The IRRI team also saw early maturing japonica lines at the experiment station of the Academy of Agricultural and Forestry Sciences, Peking. Those had been developed through conventional hybridization.

Most of the japonica varieties in the northern region and the second-crop japonica varieties in the central region mature in 150 days. Any reduction in growth duration of those varieties without sacrificing yield would be extremely beneficial. The Chinese say they have early maturing lines that have been selected through radiation treatment of well-adapted japonica varieties. At the Academy of Agricultural Sciences, Kiangsu province, they have a radiation-induced, early maturing mutant (Line 73-3252) that matures 10 days

earlier than the variety from which it originated.

China has abundant germ plasm resources for early maturity. However, it could be desirable to introduce early maturity germ plasm from IRRI and the national rice improvement programs in Asia. The national rice breeding programs of Asia would also benefit if the Chinese early maturity germ plasm were available to them.

For increasing the yield potential of rice the Chinese put major emphasis on decreased lodging through height reduction. The japonica varieties of north and central China were progressively selected for shorter height during several decades and most are now between 80 and 110 cm in height. They are highly responsive to nitrogen and have good lodging resistance.

High tillering ability was not identified as an objective in China's rice breeding program. Apparently, the large number of seedlings per hill (more than 10) used in the Chinese production system offsets any disadvantage their low-tillering varieties may have.

The Chinese consider photoperiod sensitivity an important trait for the second crop of rice in the two-rice-crop system in the south. The second crop must flower by the end of October and be harvested before the end of November to prevent cold temperature effect on yield. However, photoperiod sensitivity does not appear to be an essential trait because photoperiod-insensitive varieties with appropriate growth duration are available for use as the second crop. For example, IR24, a photoperiod-insensitive variety, does extremely well as the first as well as the second crop.

Threshability is a trait considered necessary for the areas affected by cold weather. Indica varieties shatter badly when they mature in low temperatures and therefore are less adapted as the second crop in the central region. Japonicas as a group, however, have been selected for the regions where temperatures are low during the maturity stage.

Temperature tolerance

With increased intensity of cropping, tolerance for extreme temperatures in rice has become an essential feature in breeding work.

COLD-TEMPERATURE RESISTANCE. In the north the single crop matures in late September or early October when temperatures are low. In the central region, the second crop flowers and matures during a cool period. The second crop of rice in the high elevations of the southern and southwestern regions is also affected by cold

temperatures. The most important characteristic of the varieties grown in those regions is tolerance to cold temperature. Varieties grown in the north, the second crop varieties in the central region, and the varieties grown above a 1,800-m elevation in the southwest region are all japonicas.

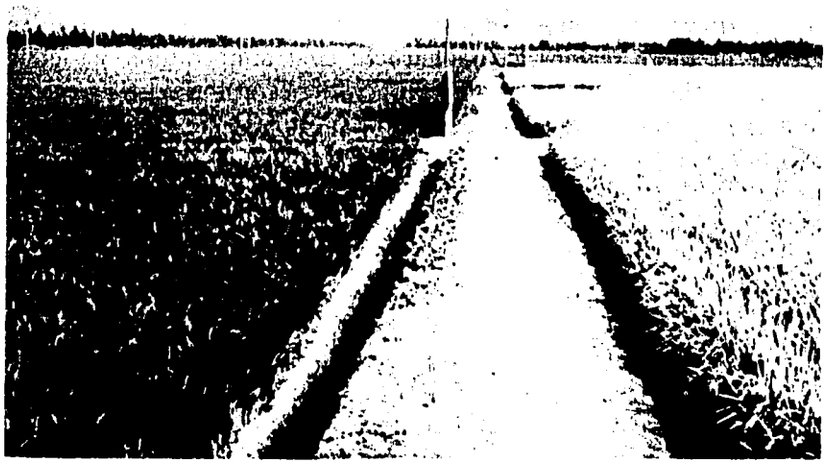
In the varietal improvement programs in the cold areas special attention is paid to selection for tolerance for cold temperatures, but early maturity for cold weather avoidance is also emphasized. The IRRI team saw cold-tolerant early-maturing breeding lines of japonica rice in the experimental fields of the Academy of Agricultural and Forestry Sciences, Peking. At the Academy of Agricultural Sciences, Kiangsu province, multiplication fields of a japonica variety (Nong Hu 6) had 15 to 20% floret sterility caused by an early cold wave. However, a radiation-induced progeny of Nong Hu 6, Line 73-3252, with 10 days earlier maturity, had escaped cold temperature injury.

In southern China cold-tolerant indicas are grown as the second crop in high-elevation areas where they must mature before the end of November to avoid cold weather. Photoperiod-sensitive varieties are grown that flower during the short day-length period of October and mature by the end of November.

At the Institute of Plant Physiology, Shanghai, considerable work is being done on the fundamental aspects of cold resistance in rice. Specifically, the studies investigate the unfavorable effect of low temperature, devise means to prevent the effect of low temperature, and identify cold-temperature resistant varieties for breeding programs. The Institute has found that the period when the plant is most cold-temperature sensitive is from 1 day before flowering until 1 day after flowering. Meiotic processes also seem to be affected by cold temperature. Screening for cold resistance is done at 17.5°C for 5 days. About 70 varieties had been screened at the time of the IRRI visit.

HIGH-TEMPERATURE RESISTANCE. High-temperature resistance is required in the varieties grown as the first rice crop, especially in the central region. The first crop there flowers the first week of July when temperatures are extremely high. Only indica rices are grown as the central region's first crop because they have good resistance to high temperature, but there is considerable variation of high-temperature resistance in the indica germ plasm.

The japonica varieties are highly sensitive to high temperature, which is the reason they are not planted as the first crop even



Two types of rices growing in adjacent fields — indica (lighter color leaves) and japonica.

though there is a distinct preference for japonica rice in the central region's market.

Grain quality and protein content

The japonica rices have been grown from a time immemorial in northern and central China and the consumer has a distinct preference for japonica rice. Japonica rices sold for US$0.28/kg compared to US$0.25/kg for indica rices during the time the IRRI group was in Shanghai.

The indica rices introduced as the first crop in central China are characterized by short, round grains similar to those of japonica varieties. However, those indica rices are harder to cook and presumably have a high amylose content. Because the grain shape of the two types of rices is almost similar, it is possible that some proportion of indica rices is mixed with japonica rice.

In southern China several long-grain indica varieties are grown but varieties with medium-long and medium-bold grain seem to predominate. The IRRI team members were repeatedly told that the primary emphasis in selection work is on yield, and that grain quality is of secondary importance.

Selection work for grain quality is mainly carried out by visual classification. Other traits being equal, lines with less chalkiness are saved first. Chemical tests for amylose content or gelatinization temperature are not conducted. No attention has been given to protein content of rice.

Following their *open-door research* policy, the *three-in-one* and the principle *three-togetherness concept,* plant protection work is carried out by Chinese workers at all levels of the government. The organizational structure is extensive and coordination of pest survey, forecasting, and control-operation systems appears efficient. A typical organizational structure follows the national-level to production-team flow outlined in the chapter on research and educational institutions.

At the provincial level, a department of an academy of agricultural sciences has 10—30 persons involved, and in a county a plant protection institute has 4—5 persons involved. At the commune level, there is a plant protection station with 3—4 persons. The brigade level has a plant protection team of 2—3 persons, and in a production team there are one or two members assigned to the technical group. (At commune, brigade, and production-team levels, there are three groups of technical personnel — seed, water and fertilizer, and plant protection.)

The Chinese pest control program integrates cultural methods with use of chemicals and varietal resistance. Most emphasis is placed on cultural methods and host-plant resistance is used where available. Biological control of insects and use of antibiotics for disease control are intensively studied. The academies at national and provincial levels are mainly responsible for developing original methodology such as the screening and development of chemicals (including antibiotics) and screening for varietal resistance, while the county, commune, and lower levels manufacture chemicals, test methods, study life cycles, etc.

The insect and disease forecasting system appears well organized. The number of forecasting stations varies considerably among provinces but includes scientific research institutes, professional forecasting teams, agricultural communes, and farm-level forecasting teams. The provincial forecasting center is located at the provincial academy and gets reports from all forecasting stations. The center analyzes and interprets the information on occurrence and abundance of a pest, population trends, and suggested control methods and sends it to all pertinent organizations. The pest information also

includes trends for the year, and shifts in pest populations in a given period.

Pest forecast information is also published and provides an important base of information for future predicting and related studies. Forecast information collected over many years from many points is used to relate pest populations to meteorological conditions, taking into account the impact of natural enemies.

A handbook (in Chinese) on rice diseases and insects and their control was published by the Agricultural Publishing Society in 1975 as the first volume of a *Plant Protection Handbook* series. The handbook covers 36 rice diseases and 28 rice insects. The book has 51 color pictures, 82 illustrations or black and white pictures, a section on basic knowledge of insects and diseases, and a section on how to record the intensity of each pest attack and determine the economic threshold for each major insect and disease.

The Chinese have strict quarantine regulations that cover movement of seed from locality to locality. Rice seed is inspected for contamination by disease organisms and if any contamination is detected the seed cannot be used for planting.

Rice diseases

The major rice diseases in China are sheath blight, bacterial blight, and blast. Other known diseases include five virus diseases (black-streaked dwarf, stripe, dwarf, yellow dwarf, and yellow stunt), brown spot, *Cercospora* leaf spot, white tip, stem rot, Bakanae disease, leaf scald, and a heart-rot disease.

During the China visit the IRRI team saw very few disease problems. Only bacterial blight and sheath blight were observed, but blast was reported to be severe in Liao-ning province and the northern highland of Kwangtung province. Bacterial blight and sheath blight were common in the Yangtze and Pearl river valleys.

DISEASE RESISTANCE. The IRRI scientists were told that disease resistance is a breeding objective but the group did not see any of that work. It appears that disease resistance has not yet received much attention and that the major effort is on management and control of rice diseases. From conversations, the indication was that some disease resistance work is done at national, provincial, or municipal academies or institutes. Resistant selections are primarily made in disease endemic fields. No special disease nurseries are planted and no artificial inoculations are made except for occasional spraying

of spore suspensions to induce blast.

At the Kiangsu Academy of Agricultural Science the variety Nang-ken 15 was reported moderately resistant to bacterial blight, and at the Kwangtung Academy of Agricultural Science the variety Tsou-yi-ching was reported resistant to blast. Tsou-yi-ching was developed through the multiple crosses:

Zu Zuan/Indo-ie-jo → Zu-yi No. 2
Zu-yi No. 2/Tan-pu-ai → Tan-zu
Tan-zu/Fa-lung-zu-tiangao (F4//Gi-dei-lun///Zhei-ching No. 8)
→ Tsou-ye-ching.

Tsou-ye-ching was reported as moderately resistant to bacterial blight and sheath blight. The Chinese have other varieties that are resistant or moderately resistant to blast.

FUNGICIDES DEVELOPMENT AND USE. Chinese research on antibiotics for disease control is active and somewhat similar to that of Japan a decade ago. The IRRI team visited many laboratories engaged in development of antibiotics as fungicides.

• *Microbiology Institute, Academy of Sciences.* One of the objectives of the Microbiology Institute is the survey of useful microorganisms for industry and agriculture, and that includes collection and screening of *Streptomyces, Micromonospora, Actinomyces,* and *Thermo-actinomyces* for antibiotics production. Two antibiotics, *blasticidin* and *kasugamycin,* have been developed and are widely used. The antibiotics work at the Institute, and elsewhere, also includes methods of antibiotics production that use simple local materials as culture media so that production can be at the county, commune, or brigade level.

• *Plant Physiology Institute, Shanghai Academy of Agricultural Sciences.* The Agricultural Antibiotics Laboratory of the Plant Physiology Institute developed an antibiotic substance called *chengfungmycin* from a *Streptomyces* from Chekiang province. *Chengfungmycin* has a control efficiency of 60–80% against rice blast, and 70–90% against powdery mildew of wheat. The Laboratory has also isolated several antibiotics from *Streptomyces* that gave promising results for wheat scab control in pot experiments. Rice or wheat brans were the major ingredients of the medium. The products were filtrates from the fermentation and not specially purified. They have been produced and used by communes and brigades.

• *Agricultural Research Institute, Hwa County, Kwangtung.* The Hwa County Institute manufactures *chinkonmycin* with a culture of

Actinomyces from the Kwangtung Academy of Agricultural Sciences. Corn meal is the major ingredient of the culture medium. After 40 hours of fermentation, the medium is filtered and the filtrate used directly without purification. The filtrate is packed in 20-kg jars and preservatives are added. The filtrate is sprayed at 15 kg/ha to control sheath blight.

CULTURAL CONTROL OF RICE DISEASES. The main emphasis in China is on the control of the three major rice diseases — sheath blight, bacterial blight, and blast.

• *Sheath blight.* In Nanking, the IRRI team was told that the principal measure for control of sheath blight was management of irrigation water and fertilizer. In Wu-Shi, workers explained that they drain the irrigation water around the time of maximum tillering to reduce the number of tillers and to delay filling in of the rice leaves. The drainage should be such that a person walking in the paddy will not sink into the soil. Proper planting density, and fertilization — determined by growth and color of seedlings — are emphasized. Chemicals such as *chinkomycin* or *tochunlin* are used. When fields are prepared, the sclerotia of the sheath blight fungus are floated on water, collected, and removed.

In Shanghai, workers explained that drainage after maximum tillering would make the stems of the rice plant thicker, the leaves more erect, and the modified microclimate would make the plants more resistant to sheath blight. In Shanghai, a chemical, zinc methylarsenate (or the like), was used at a rate of 75–100 g (in 100–150 kg of water)/ha.

In Kwangtung, ferric methylarsenate and lime-sulfur were used in addition to water control.

• *Bacterial blight.* Extensive studies of bacterial blight have been made at the Kiangsu Academy of Agricultural Science. They found that the causal organism is carried by seeds and diseased straw, and that irrigation water is the primary disseminating agent. Control measures emphasize avoidance of contamination and strict control of irrigation water movement.

In Nanking, bacterial blight preventive measures included separate irrigation and drainage channels, and avoidance of water running across the field, deep-water irrigation, and flooding of seedbeds. Nanking specialists also encourage a two-crop system to avoid a peak disease period, and the selection of resistant varieties at the commune and brigade levels.

In Kwangtung, bacterial blight control measures included the use of phenazine in seedbeds, raising of seedlings under upland conditions, and the use of a mixture of antibio-fungicide, lime and plant-ash. Kwangtung workers also disinfect seeds, use organic and potassium fertilizer, practice early drainage, and change seeds when necessary.

• *Blast.* Cultural methods for blast control include the use of resistant or moderately resistant varieties, proper fertilization and the use of organic fertilizer, shallow and frequent irrigation, avoidance of cold water for irrigation, and disposal of diseased straw to avoid contamination. Chemical blast control measures are seed disinfection with lime water (1%), formalin (1:50), or other disinfectants; and field spray with *kitazin* (1:600), *blasticidin*, tea-seed cake extract, etc.

Rice insects

The insects mentioned as pests of common occurrence and of major significance during the IRRI team visit in different parts of China were:

- striped borer *(Chilo suppressalis)*,
- yellow borer *(Tryporyza incertulas)*,
- green leafhopper *(Nephotettix virescens)*,
- brown planthopper *(Nilaparvata lugens)*,
- white-backed planthopper *(Sogatella furcifera)*,
- zigzag leafhopper *(Recilia dorsalis)*,
- smaller brown planthopper *(Laodelphax striatellus)*,
- rice gall midge *(Pachydiplosis oryzae)*,
- leaf folder *(Cnaphalocrosis medinalis)*,
- rice thrips *(Echnocremus bipunctatus)*, and
- armyworms

The incidence of various insect pests is low in northern China. The rice crop during the time of the IRRI visit was almost ready for harvest, or was being harvested, and one had to look carefully to see evidence of insect damage. Rice fields visited in the Peking and Nanking areas appeared to be virtually insect free. Occasionally a few whiteheads caused by stem borers were noticed. Although a regular program for the control of stem borers is still followed in most rice areas of China the IRRI team was told that the damage caused by stem borers is now less than 1%.

However, as the IRRI team went into the two-rice-crop areas near Shanghai, and the three-rice-crop areas in Kwangtung province, the incidence of insect damage became more obvious. Insects appeared

Dr. Pu Chih Lung, professor of biology, describes entomological research at the Sun Yet Sen University to members of the IRRI team.

particularly abundant in Kwangtung. There was generally a low incidence of stem borers as evidenced by whiteheads, but a few fields had patches of hopperburn caused by the brown planthopper. One rice field seen between Kwangtung and Chung-hwa was heavily infested (60%) by gall midge. However, a low (< 1%) incidence of galled tillers was noted in most of the fields visited in Kwangtung province, which suggested that either the insect was being effectively controlled or that its population was just beginning to spread in the province.

Insect control

The current practices for rice insect control in China have evolved under a system that embodies excellent organization for various crop production practices, and has enthusiastic workers and adequate availability of labor. However, it has limitations in terms of availability of insecticides. Furthermore, there has been a general consciousness of the adverse effects of insecticides on nonpest organisms, and emphasis has been on the use of pesticides as the last resort. This is evident in the common Chinese practice of applying insecticides only to infested areas of the fields for the control of certain insects.

In a broad sense, every possible effort is made to minimize the development of insect populations but if they reach a level of economic significance, pesticides are used. Thus, the practice of rice insect control in China can be considered a good example of *Integrated insect control.*

LIFE-CYCLE INVESTIGATION OF INSECT PESTS. One of the first aspects that the Chinese workers thoroughly investigate whenever a pest problem is noticed is the basic bionomics of the insect — life history, host range, life cycle, and population buildup — under natural conditions. The data are gathered by monitoring insect populations in the fields. Parasites and predators are also monitored in these field observations.

Data collected from production teams, brigades, and communes are transmitted to the provincial level where they are compiled and interpreted by entomologists. The field observations are helpful in determining the timing of insecticide application. For example, in Kwangtung province Chinese workers observed that there were four generations of the brown planthopper. The insects in generations one to three were usually not numerous enough to cause economic losses but the fourth generation often caused serious crop damage. The observation led to the concept that if the fourth generation was predicted as potentially damaging, wide-area treatments should be made to control the insect during the third generation. If in spite of that treatment a large number of fourth-generation brown planthoppers were recorded in certain areas, then each field was examined carefully and the fields where the number of insects exceeded economic levels (about 5 to 10 adult planthoppers per hill) received insecticide treatments, which were repeated as necessary.

Manual removal of insects and insect eggs (e.g., yellow borer) from the rice fields is a cultural control practice that is generally recommended.

In many areas visited, light traps were being intensively used as a means of reducing insect populations. Some light traps had arrangements for electrocuting insects; others had poisoning devices.

BIOLOGICAL CONTROL. There appears to be heavy emphasis on biological control of rice insects in China. Mass rearing and field release of *Trichogramma* sp., particularly *Trichogramma australicum,* are widely practiced. This parasite is considered effective against the leaf folder and provides some control of stem borers. *T. australicum* is often mass reared at commune and brigade levels and scientists at the

National Institute of Zoology, Peking, were working on synthetic diets and artificial host eggs for mass rearing. The IRRI group was told that in certain areas mass release of *Trichogramma* adults has parasitized as many as 70 to 85% of the eggs of the leaf folder.

Another biological control organism receiving major attention in China is *Bacillus thuringiensis.* It was also being mass produced at various communes and production brigades and used for control of yellow borers, rice skipper, rice leaf folder, and armyworm. More than 50 strains of the bacteria have been isolated in China. They have been compared morphologically, biochemically, and serologically with 13 introduced strains.

An interesting and practical approach to biological control seen at Chung-san University was the use of ducks in rice fields to control rice insects. A predetermined number of ducks of appropriate size was herded in the fields to feed on the brown planthopper and other insects. The Chinese claimed fairly satisfactory control of several insect species by ducks.

INSECTICIDES. The use of insecticides constitutes an important aspect of insect control and a large amount of insecticide is used on rice in China. Usually, treatments are based on insect population data and may be confined to individual fields or even to infested spots within a field. However, in a few cases large-area treatments are also made.

Great emphasis is placed on selecting only low mammalian-toxicity insecticides for use in rice fields. Thus, carbofuran, which has become popular in many countries was not tested in China because of its high toxicity. BHC and DDT are still widely used although the general trend is away from the persistent-residue pesticides. A BHC-DDT mixture is often used on rice and is popularly known as insecticide 889.

Chinese scientists are evaluating insecticides developed outside China as well as synthesizing their own compounds. Among the insecticides commonly used on rice are malathion, methyl parathion, sumithion, chlordimeform, dichlorphos, trichlorfon, dimethoate, and phoxin. Many of those insecticides are manufactured by communes.

BHC is generally used against striped borer, brown planthopper, rice leaf folder, rice skipper *(Parnara* sp.*)*, and rice thrips *(Thrips oryzae).* Dimethoate is popularly used against the brown planthopper, green leafhopper, leaf folder, and rice thrips. A dimethoate seedling-dip is used for systemic protection against the yellow borer.

Sumithion is considered much safer for general use than methyl parathion, which is used only by trained personnel. Phoxin is effective against a wide variety of rice insects but has short residual effects. Metamidophos is effective against green leafhopper, and cyanox is effective against the striped borer.

The insecticide C9140 has been found effective against yellow borer, striped borer, rice leaf folder, and brown planthopper. It has an antifeeding effect against those insects and is not toxic to hymenopterous parasites — *Trichogramma* sp., *Telenomus* sp., and *Tetrastica* sp.

Most of the rice fields the IRRI group visited had little apparent insect damage, and it was explained that insect damage had been minimized to nonsignificant levels. However, in almost all areas visited most of the rice fields had received at least one insecticidal spray. The group frequently saw mechanical sprayers and mechanical dusters suitable for large-area treatments.

Development of resistance of insecticides

The Chinese reported that several insect species have developed resistance to such insecticides as DDT, malathion, and parathion. Resistance of the paddy borer to DDT had been observed in certain areas and several leafhopper and planthopper species had developed resistance to malathion. Chinese scientists reported that mixing *kitazin* with malathion gave effective control of the brown planthopper even though malathion alone did not give control.

Breeding for insect resistance

The IRRI team did not visit any project in which concerted efforts were made to identify sources of insect resistance in rice varieties for use in a breeding program. Even though work in this field elsewhere has started only in recent years, based on the experiences at IRRI and in many other rice growing areas, it appears that varieties can be developed that are resistant to several of the important insect pests in China.

Cultural practices for insect control

Several kinds of cultural practices are being used in China to suppress the development of insect populations. China has been very successful in minimizing pest damage wherever large-area treatments at one time or communal efforts were important. Excellent examples of that are the organization of large-area campaigns for the control of

rats and locusts.

Clean cultivation is constantly emphasized as a means of eliminating the insects' alternate hosts. Wherever information is available that important insect pests are on the weeds in rice fields, along levees, or in unplanted areas, those areas are meticulously cleaned of weeds.

Chinese publications recommend that a small section of a field be planted early with susceptible varieties to trap insects, which are then sprayed with insecticides before the rest of the field is planted. The IRRI group did not observe that practice. The Chinese reported early planting of rice in several areas to evade the second generation of the yellow borer.

Integrated insect control

As mentioned earlier the Chinese emphasis in pest control is to use insecticides judiciously and only when they are urgently needed. This has evolved into an integrated method of insect control.

The various aspects of cultural control constitute the backbone of the integrated method. There has been great emphasis on the use of parasites, predators, and microorganisms in the biological control of insects. Research on the biological control of rice insects has not been intensively pursued in most of the world and what may be the best work in that field is being done in China. At the Chung-san University, Kwangtung, the IRRI team saw some basic work on the biology and ecology of some rice parasites and predators.

In general the following components constitute the various aspects of China's integrated pest control approach for rice:

- forecasting of pest infestation and population buildup;
- intensive study of the biology of the rice insects to find weak spots in their life cycle that can be attacked with relative ease;
- use of insecticides, when found to be necessary, based on the forecasting network and actual count in different fields;
- use of cultural practices such as flooding of rice fields at the end of the winter when the larvae begin to pupate, so as to kill the larvae hibernating in the stubble;
- use of light traps to attract insects; the crop surrounding the light traps is frequently sprayed to prevent a population buildup of insects attracted to the light traps;
- use of ducks in rice fields to eat leafhoppers, planthoppers, leaf folders, and yellow borers; use of frogs in rice fields as predators of insect pests;

- release of *Trichogramma* wasps for control of leaf folder; and
- use of *Bacillus thuringiensis* and low concentration of dimethoate for the control of paddy borer, leaf roller, and other lepidopterous pests.

A major missing link in the integrated control program in China is the availability of insect-resistant varieties. Such varieties would be valuable, particularly for the southern parts of China where the climate is pest-favorable and two to three rice crops are generally grown per year.

SOILS AND CROP MANAGEMENT

Many factors contributed to the recent record grain production in China. Since the People's Revolution soil and water conservation have greatly improved and with those improvements the hazards of natural disasters, such as drought and floods, were greatly reduced. The cropping systems in China were modernized, and in most areas double cropping has substituted for single cropping; intercropped and multiple-cropped hectarage has expanded in major rice-growing areas. The improvement of cropping systems in general, and of rice production in particular, was possible because of better irrigation facilities.

China has adhered to food grains as the key link to an all-round development. As a result of persistent efforts to improve soil and crop management, the Chinese were able to harvest a record grain crop of 280 million tons in 1975 (including soybeans). Rice accounts for slightly less than half of China's total grain production.

Organic manures

Farm manure is the main rice fertilizer in China. Other organic fertilizer sources include green-manure crops of various kinds, compost, mud manure, and night soil. No other country in the world does as thorough a job of recycling organic waste as China.

HUMAN WASTE AND COMPOST. Near the cities with their huge supplies of night soil, the Chinese have developed a tremendous capability for recycling organic waste. Human wastes are collected in Shanghai, for

example, by a special city department. There is a collection station in every city district from where human wastes are hauled to nearby communes. Those wastes are collected from each household, or in some cases, from common collection tanks.

Large amounts of organic manure are applied to rice. For example, in the Shanghai and Wu-Shi areas, 75 tons compost/ha are used as a basal treatment. The nitrogen content of that compost ranges from 0.1 to 0.4%. Inorganic sources of nitrogen are also applied, which makes the total amount of nitrogen applied extremely high.

COMROST MAKING. in many places piles of compost are visible in the rice paddy, on the levees of a paddy, or on an adjacent road. Sometimes, those piles are covered by mud. The components used to make compost vary among locations, but the basic steps are similar. In the Wu-Shi area, for example, the manure of pigs, sheep, and rabbits are used for compost. The manure is mixed with silt and the mixture is allowed to decompose.

In the Hsu-Hang People's Commune, Ja Din county, Shanghai, compost is made from a mixture of 70–80% silt from the bottom of fishponds, 15% straw, and 9% night soil. Dead leaves are also added to the mixture, which is placed in a pit and covered with mud. Sometimes the mixture is stored above ground and mud covered. The mixtures are stirred from time to time and the compost is ready for use after 3 months.

The plant nutrients in compost vary according to the major constituents used. For example, if silt from a fishpond or river bottom is used, the nitrogen and phosphorus (P_2O_5) contents vary from 0.1 to 0.2%. On the other hand, if the main ingredient is straw, the nitrogen content can be as high as 0.3% and phosphorus will exceed 0.2%.

The composting and recycling of waste are not only ecologically sound, but they also appear to be economically efficient under Chinese conditions. On the basis of information made available to the IRRI group, 75 t of compost/ha is applied, and it requires one man-day of labor to produce and apply 1 t of compost. That ton may contain about 1 kg of nitrogen. The value of 1 kg of nitrogen in China in the form of ammonium bicarbonate is about US$0.73. By producing a ton of compost the commune uses one man-day of labor and reduces the cash cost for chemical fertilizer by $0.73. This imputed daily wage rate is comparable with that in other developing countries of Asia. The labor requirement for compost alone is about

China does a better job of recycling organic wastes as farm fertilizers than any other country in the world. Mud-plastered compost piles such as the one shown here are common sights at China's communes. Materials such as fishpond silt, rice straw, and farmyard manure or night soil are mixed and allowed to decompose in the piles, or in pits. The compost is spread on the fields between crops, often at a rate of 75 tons of compost per hectare.

equal to the total labor for all preharvest activities in many other parts of Asia.

WATER HYACINTH. In most countries in South and Southeast Asia, the water hyacinth *(Echiornia crassipes)* is a noxious weed in canals, ponds, irrigation ditches, and flood plains. In China, the water hyacinth is extensively used as a pig feed as well as for making compost. *Cover your water surface with green* is a common saying in China that calls for use of idle water surfaces to grow plants that can be used in agriculture.

PIG MANURE. "One pig per mou (0.15 ha) is like having one little fertilizer factory per mou" said Chairman Mao, thereby encouraging pig production not just for meat but for manure. In 1972, China produced 250 to 260 million pigs, which was four-fold greater than the pig production in the United States that year.

In many animal sheds urine and solid wastes are collected in a fully covered pit and kept several months before they are applied to

the field. In Hwa county, Kwangtung province, pig production has increased to 80,000 pigs, providing almost one pig per mou as suggested by Chairman Mao.

The composition of pig manure varies. The Academy of Agricultural Sciences, Kwangchow, reported that in pig manure the nitrogen content ranged from 0.5 to 0.6%; the phosphorus (P_2O_5) content varied from 0.1 to 0.2%, and the potassium (K_2O) content was 0.5%.

GREEN MANURE. In many areas of China, green-manure crops such as *Sesbania* sp. and *Crotelaris* sp. are grown to improve soil fertility. In areas where lowland rice is to be followed by an upland crop, the green-manure crop is grown before the upland crop to improve soil structure. In Hwa county vetch is grown during winter primarily for green manure.

AZOLLA. In many tropical Asian countries *Azolla* (small water fern) is found in the rice paddies, but no systematic use of *Azolla* is practiced to improve soil fertility. In China, however, *Azolla* is commonly raised in small ponds and is used to inoculate the main rice fields. In many areas of Kwangtung province, *Azolla* is grown extensively to improve soil fertility. In the Syi-Tang Production Brigade near Wu-Shi *Azolla imbricatus* is grown for application to the main rice fields. *Azolla* is a basic manure in the seedbed and superphosphate is applied at a rate of about 75 kg/ha in a split (three) application.

In Hwa county *Azolla* is grown during the summer and a small amount of complete fertilizer is applied to increase *Azolla* yields.

Fertilizers and fertilizer management

In most areas visited by the IRRI team people talked about inorganic fertilizers only as a supplement to organic manures, particularly as a supplement to compost.

FERTILIZER PRODUCTION. The production of chemical fertilizers in China falls short of the requirement. The Chinese fertilizer industry had two plants producing 27,000 t/year in 1949. By 1974 there was almost a thousand-fold increase with at least 40 large plants and hundreds of small plants producing 25,000,000 t of fertilizer in that year.

- *Nitrogen.* Small fertilizer plants play a major role in nitrogen fertilizer output using local raw materials to produce aqueous ammonia and ammonium bicarbonate. In 1973, China contracted for

13 urea plants. Those complexes are expected to produce 5,000,000 t of urea/year by 1978. The IRRI team inquired frequently about the 13 urea complexes but few knew about them. Apparently, no consideration is being given to changing the amount of fertilizer applied wher. additional supplies of fertilizers become available. One official reported that one large urea plant was located near Shanghai but furnished no details. Discussions with scientists and technicians gave no evidence that they were aware of the probability of a good supply of urea in the near future.

• *Phosphate.* Phosphate fertilizer production is largely from small plants using domestic rock. The few large superphosphate plants use imported rock. Between July 1973 and June 1974, China produced 725,000 t (nutrient basis) and imported about 428,000 t of phosphorus.

• *Potassium.* Production of potassium fertilizer is low, despite large natural salt deposits in western China.

SMALL FERTILIZER PLANTS. Small-plant ammonia production began in 1958 with a production capacity of 800 t/year per unit. The small-plant program gained momentum with the development of the ability to produce complete sets of fertilizer plants and equipment in China.

The IRRI team visited the Nan Hai chemical fertilizer plant at the Ta Li People's Commune, Nan Hai county. The plant is a state-owned enterprise under the direction of the county. It has a staff of 1,360 and is divided into three smaller plants — two chemical fertilizer plants (one for nitrogen and one for phosphorus) and a machinery production unit for fertilizer plants. The main fertilizer products are ammonium bicarbonate (the major product), superphosphate, sulfuric acid, and aqueous ammonia.

The Nan Hai plant was originally a matchbox factory and was converted to a fertilizer factory in 1958. In 1964, because of increased demand for fertilizers, the capacity was increased by 3,000 t aqueous ammonia/year and in 1975 that capacity was increased to a total of 15,000 t/year. By 1975, the capacity to produce 16 to 18% superphosphate was 30,000 t/year plus 15,000 t sulfuric acid/year. Superphosphate is produced from a local fluorapatite rock; sulfur is obtained from iron pyrites.

The plant produces 7,000 t ammonium bicarbonate/year from coal at a cost of about US$95/ton. The ammonium bicarbonate is sold at about US$124/t to communes and production brigades. Two

problems encountered by the plant are unstable production of nitrogen fertilizers and pollution in their waste water.

PRICE INCENTIVES FOR FERTILIZER USE. The price of fertilizer is largely determined by the cost of production. As indicated in the previous section, in the plant visited a ton of ammonium bicarbonate is sold for about US$124. With 17% active ingredient, the value of nitrogen in ammonium bicarbonate is US$0.73/kg as previously noted. This compares with today's world market price of $0.33/kg of nitrogen in the form of urea, and explains the Chinese decision to invest in urea plants. However, given China's poor transportation system, it can be argued that, at least in the short run, ammonium bicarbonate plants located near the source of demand were a practical investment.

The fertilizer price to the Chinese producer is high compared with other Asian countries and the price of paddy is low (US$0.10/kg) compared with a world market price of almost US$0.20/kg. Despite this unfavorable input:output price ratio chemical fertilizer was used in fairly large amounts in the areas visited. The dependable irrigation and extension systems of China lead to stable yield and insure that profits from fertilizer investment can be realized every year.

Fertilizer management

Although organic sources of nitrogen fertilizer are used extensively in all the rice-growing areas of China visited, some inorganic sources of nitrogen are always used. The most common inorganic fertilizer used is ammonium bicarbonate. Ammonium sulfate, urea, and liquid ammonia are also used for rice. For phosphorus, single superphosphate is commonly used. Potassium is not generally applied in inorganic form; compost provides most of the potassium required for rice.

Compost and other organic sources are generally applied as a basal dressing. In the two-crop culture in the Peking area compost is applied prior to the wheat crop. In the three-crop areas compost and other organic sources are applied for each crop. Nitrogen is generally applied to each crop in split applications — as basal and at tillering and panicle initiation. Table 1 gives some typical rates and times of application of fertilizers materials in the rice areas visited.

TYPICAL FERTILIZER APPLICATION. In the Kwangchow area of Kwangtung province, the schedules for fertilizer application include sufficient basal fertilizer, such as 22.5 t of compost/ha plus 11.25 t of pig manure/ha. Inorganic nitrogen is topdressed two times within

Table 1. Typical fertilizer application rates used in some rice-growing areas in China.

Place	Organic (kg/ha)			Inorganic (kg/ha)			
	Compost	Pig	*Azolla*	NH_4HCO_3 (17% N)	$(NH_4)_2SO_4$ (20% N)	Liquid NH (17% N)	Superphosphate (16–18% P_2O_5)
Double Bridge Commune	(for wheat)				75		150
Peking area	22,500			750			375
Kiangsu province (near Shanghai)		37,500		525	375		150
Wu-Shi area	75,000				375		
Shanghai area	60,000			750			
Hsu-Hang People's Commune, near Shanghai	57,600–75,000 or	26,250		600 600			some some
Hwa county (Kwangchow) (3 crops/year system)	6,000		30,000	225 B[a] 135 T 90 PI		375 B 528 T	

[a]B = basal, T = tillering, PI = panicle initiation.

Professor Hsuing Yen, Deputy Director of the Soils Institute of the Chinese Academy of Sciences, accepts a book on soils from Dr. N. C. Brady, IRRI Director General.

10 days after transplanting using ammonium sulfate at the rate of 187–225 kg/ha.

In Nan Hai county, Kwangtung province, for two crops of rice, the nitrogen fertilizer schedule is 30 t of pig manure/ha, 30 t of *Azolla*/ha, and 22.5–30 t of decomposed night soil/ha. Inorganic fertilizer which is added is 600 kg of ammonium sulfate/ha per two crops, used as 150 kg/ha per two crops at 5 days after transplanting, 300 kg/ha per two crops at the tillering stage, and 150 kg/ha per two crops at the late growth stage, depending on growth duration.

Application methods consist of basal incorporation or topdressing into mud or water. To avoid burning of foliage, Hwa county used two methods of application for ammonium bicarbonate – as a solution or placement in the soil in mudballs. Hwa county was the only area visited where mudballs and liquid band placement were used extensively. Basal dressing is common for phosphate fertilizer.

At the Double Bridge People's Commune, phosphorus and potassium fertilizers for rice were applied as foliar sprays at flowering. In Hwa county, liquid ammonia is applied with a long-handled dipper-spreader.

Research on soils and fertilizers

Chairman Mao set the stage for the priority of research in soils and fertilizers when he said, "Scientific experimentation must be aimed exclusively at production."

RESEARCH PROGRAMS OF INSTITUTES. At the Soil Research Institute, Nanking, research programs are geared to soil classification, soil mineralogy, soil fertility, plant nutrition, and soil microbiology. The Chinese point out that the soil classification and production of crops should be integrated. For example, soil structure is changed (destroyed) upon puddling, which should be considered in classifying paddy soils. In China, 25% of the arable land is classified as paddy soils.

Soils are classified into five regions:

- rice-growing region in south China – lateritic paddy soils, also alluvial soils;
- central parts of China – red earths, also alluvial soils;
- middle and lower ridges of the Yangtze River – yellow-brown earth, swamps;

Chinese scientist describing the functions of a soil testing kit at the Soils Institute, Chinese Academy of Sciences in Nanking.

• rice-growing areas of southwest China (Wen Lang, and the Kwechow plateau) — mainly red and yellow soils; and

• rice-growing areas in north China — caicareous paddy soils and saline soils.

At the Academy of Agricultural Sciences, Shanghai, the soil fertility research laboratories are involved in research on soils and fertilizers, and plant protection. In one laboratory a research program involved nitrogen ^{15}-labeled fertilizer to trace nitrogen absorption at various stages of rice growth. In the soil testing laboratory, soils are classified and analyzed to characterize high-yielding and low-yielding rice soils. The Chinese scientists believe the characteristics of high-yielding rice soils are:

- good soil structure throughout the profile,
- deep surface soil (15–20 cm deep top soil),
- granular structure of surface soil,
- organic matter content of 2.5%,
- total nitrogen of 0.15–0.18% (similar to the IRRI soil),
- total phosphorus of 0.1–0.15%,
- total of potassium of 2–3.1%,
- friable subsoil structure, and
- good permeability.

Soils are classified according to their productivity and area, and described as:

• Wang Yi To, a brownish-yellow upland rice soil. It is considered a high-yielding soil with an annual production capacity of 15 t/ha (total of 3 crops);

• Chin-Chi-Ni, a grayish-blue lowland rice soil. Yields on this soil are low and the annual production capacity ranges from 9 to 11.25 t/ha (total for 3 crops); and

• Go-Go-Ni, a grayish-brown upland rice soil.

The Hwa County Institute of Agricultural Sciences' fertilizer and soil group covers soil fertility research. In their soil and fertilizer research laboratory the principal functions are soil and plant analysis. Their equipment includes a spectrophotometer, a flame photometer, a pH meter, and a muffle furnace. Research problems cover plant nutritional problems of the cropping systems.

For commune-level work, research personnel and technicians from the county institute are responsible for all aspects of research, and for advising the commune on how to increase production. Plant nutrition and fertilizer management are important areas at the commune-level of research. Research work is also done on the

optimum timing of topdressings.

The IRRI team saw field experiments comparing broadcasting of ammonium bicarbonate with mudball placement. Such studies had been going on at the production-brigade level for 2 years. The IRRI group also saw a deep-placement device for applying nitrogen solution that was similar to the one developed at IRRI. The Chinese machine was simple, made of wood, and made a single-row application at a specified soil-depth.

DEEP PLACEMENT OF NITROGEN FERTILIZER. The Chinese experience with fertilizer placement illustrates their ability to borrow or transfer technology. In the mid-1960's a team of Japanese specialists, familiar with techniques of fertilizer placement developed in Japan during World War II, were invited to China. That visit apparently marked the beginning of the introduction of fertilizer placement technology. Placement is extremely important in the case of ammonium bicarbonate and liquid ammonia, which are both high-cost and unstable.

In China only the mudball technique was initially used for deep placement of fertilizer, but by the end of the 1960's from 50 to 60% of the rice area in Hunan province used deep placement by basal broadcast and incorporation. Other techniques included use of mudballs, placement of ammonium bicarbonate as granules or pellets, liquid band placement of ammonia, and trampling of powdered fertilizers into the soil.

Depths of application of fertilizer vary with climate. In southern Kiangsu province the application depth is 5 to 7 cm. In southern parts of China the application depth for nitrogen is 10 cm. In Kwangtung province ammonium bicarbonate was broadcast before 1973 but since then deep placement has been practiced. As a result 225 to 375 kg/ha more rice is produced with the same amount of ammonium bicarbonate. It appears that deep placement is of vital importance in China to conserve nitrogen fertilizer.

RATOONING OF RICE. The Hwa county institute had greenhouse studies on the ratooning ability of rice varieties. Research on ratooning has important implications in Kwangtung province which already grows three crops, and in some cases, four crops, a year (three rice crops plus a wheat crop) are being grown. By ratooning one of the three rice crops, they could possibly reduce the field duration of three rice crops and thereby increase productivity.

MECHANIZATION AND LABOR USE

Chinese policy regarding agricultural mechanization is set forth in the simple statement, "The way out of agriculture is through mechanization." To many that might mean that the way to reduce the labor requirement for agricultural production and to increase the productivity of labor is to mechanize. But given China's resource endowment — a shortage of land and a surplus of labor — the meaning of the statement is, *the way out of agriculture is to create an agricultural surplus.*

The role of agricultural mechanization in China is to help increase the productivity of land. Thus, mechanization is focused on those activities that save both time and labor, and the time and labor saved go to increase cropping intensity and the output per hectare per year. In the Chinese operation, labor is saved only to be used elsewhere in the production process.

The first commune visit by the IRRI group illustrated the relationship between mechanization and labor input. The visit was between the harvest of the rice crop and the sowing of winter wheat, a peak period of demand for labor. Land preparation was done almost entirely by tractor — in some cases by large tractors — but primarily by small 12-hp tillers. Labor was mainly occupied by rice straw removal and the transport and spreading of compost. By mechanizing only the burdensome and time-consuming jobs, the period between the harvest of one crop and planting of another was reduced to 2 days for an individual field and 2 weeks for most of the commune. The labor requirement had not, however, been reduced; instead it increased because two crops a year were being grown where only one had been grown before. Furthermore, the straw was recycled through the composting process, which alone was an extremely labor-consuming task.

This picture stands in sharp contrast to what is normally observed in South and Southeast Asia. There, land preparation activities are also being mechanized in the more advanced regions, but even on the mechanized farms it frequently requires 3 weeks between the harvest of one crop and the planting of a second. On an area the size of a commune (2,000–4,000 ha), the turnaround time is normally

The People's campaign approach is used to speed operations between crops and to grow more crops per year in a commune's fields. Workers, as a team, haul compost onto a field of the Double Bridge People's Commune near Peking. Work teams include men and women. Simple machinery, like the one-wheeled wooden cart, is usually fabricated in the commune.

2 months — compared with the Chinese commune's 2 weeks.

What accounts for the difference? There are perhaps three factors — water control, power and labor availability, and the organization of labor. The ability not only to deliver water but to irrigate and also to drain the field, when needed, enhances the efficiency in timing and use of machinery and labor. For example, it was pointed out that draining the rice field at the right time made the task of hand-applying compost by wheelbarrows much easier. (In many Asian irrigation systems, land preparation is delayed by inadequate management in the scheduling and delivery of water.)

The approximate manpower and horsepower available per cultivated hectare for the six communes visited are summarized in Table 1. There are some parts of Asia with comparable manpower (Java, Indonesia) and other parts of Asia with comparable horsepower (Punjab, India), but even in East Asia where farms are small and the population is dense, mechanization during the past decade has been largely to displace labor. Thus, the *high-and-stable-yield area* in China appears to present a unique combination of manpower and machinery available per hectare of cultivated land.

The IRRI team witnessed a *campaign* to apply compost on a commune field. Two persons to a wheelbarrow — a production team clearly in good physical condition — worked at a fast pace (for the

Table 1. Approximate number of laborers and tractor-horsepower per cultivated hectare in six communes, China, 1976.

	Commune					
	1	2	3	4	5	6
Laborers (no./ha)	5.0	6.6	6.2	5.7	7.4	6.2
Tractors (hp/ha)	1.0	1.0	1.0	1.4	0.9	1.0

benefit of the visitors, perhaps, but the visitors thought not). While there is concern in many developing countries that mechanization will displace labor, no such concern exists in China where surplus labor is an asset rather than a liability.

Sequence of mechanization

The time sequence of mechanization of agriculture in China over the past two decades further illustrates the functional relationship between mechanization and labor utilization.

The first step in the mechanization process was to expand the supply of available labor for productive use. The concept was that with everyone fully employed it would be possible to increase the agricultural surplus. Every able-bodied person, 16 years of age or older, became a part of the labor force. Those tasks for which labor was extremely inefficient were the first to be mechanized. Table 2 shows a list of machinery for a commune near Wu-Shi. Note that the machinery prior to 1966 included rice processing equipment and water pumps. Labor released from those tasks could be used for composting and for capital investment activities such as constructing canals, leveling and terracing land, and planting trees. That is to say, labor was used to help improve the physical environment and to control water.

After they had achieved control of water, it was possible to turn attention to activities designed to raise yield and increase the cropping intensity. The list of equipment purchased by the Chien Chan Commune between 1966 and 1976 includes many items related to the mechanization of land preparation, transplanting, and harvesting, and to transportation. The commune area is served by canals. Boats — made from locally produced concrete — and power tillers with carts attached are important modes of transportation.

Threshing, hand spraying, and land preparation in the communes visited had been almost fully mechanized during the past decade.

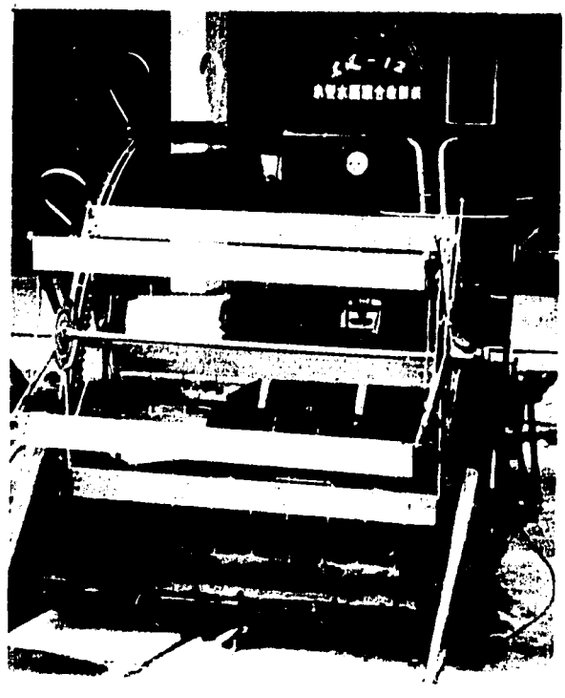
Table 2. Inventory of agricultural machinery in Chien Chan Commune, Kiangsu, China, 1976.

	Units (no.)	
	1966	1976
Diesel engine* (12 hp)	–	243
Diesel engine (25 hp)	–	11
Diesel engine (4 hp for transplanter)	–	37
Gasoline engine (4 hp for transplanter)	–	30
Hand tractor (12 hp)	2	171
Large 4-wheel tractor	–	1
Seedling puller*	–	4
Transplanter*	–	25
Mower for grain*	–	18
Electric motor	288	1,112
Thresher (electric)	231	368
Thresher/cleaner (electric)	–	54
Power sprayer	–	54
Hand sprayer	312	802
Duster	3	177
Boat engine	–	65
Grain cleaner	–	285
Pump with motor	61	224
Crusher for water plants	–	5
Flour grinder	12	40
Rice miller, 5 fhp	24	38
1-ton trailer	–	14
Rice huller	2	2
Huller-crusher for wheat	1	2
Hand cart for 2-wheel tractor	–	124

*Indicates the machines in great demand.

About 70 to 80% of the land is now prepared by tractor with the small 12-hp tiller as the most common source of power. The mechanization of transplanting and harvesting is still in the early stages, with about 20% of the rice-crop area now transplanted by machine in at least one area (Shanghai).

Seedling pullers, transplanters, and grain mowers are high on the machine *wanted* list (Table 2), but the return to the investment in those machines is not likely to be large. In fact, the return on investment of both labor and capital appears to have declined rapidly over time. It now appears that the opportunity for more productive investment lies in the poorer communes or in industry, but in the *spirit of self-reliance* China has not emphasized strong linkages between different sectors of agriculture, or between agriculture and industry. Thus capital and labor cannot be easily reallocated to areas of more productive investment. China soon may need to reform its



Machines such as this Chinese rice mower-bundler have high priority on the list of China's needs for mechanization of rice production. Mechanization of rice harvesting will further reduce turnaround time between crops.

institutions and strengthen the links between various segments of the economy in order to promote more rapid employment.

Labor requirement for specific tasks

The Chinese report that the process of mechanization over the past decade has reduced the labor requirement per crop of rice from about 400 to about 200 man-days/ha. Because of the shift to double- and triple-cropping, however, total labor per hectare per year has remained about the same.

Two operations rather unfamiliar to the IRRI scientists were composting and transplanting with a transplanting machine. The amount of compost applied varied, among communes, from 35 to 75 t/ha. Estimates of the labor required for composting, including the making of compost piles and application in the field, ranged from 30 to 75 man-days/ha.

Transplanting is normally done by hand and requires 20 or more

man-days/ha with close spacing. A large transplanter with five operators can transplant 2 to 3 ha/day. A small hand-operated transplanter can transplant 0.5 ha/day.

The turnaround time from harvesting of one crop from a field to the transplanting of the next crop was most frequently quoted as 2 days. Two rotovations with a 12-hp tractor requires 1 to 1.5 days. With one 12-hp tractor available for every 12 ha (see Table 1), it is reasonable to expect that the total commune (2,000–4,000 ha) can harvest one crop and transplant a second in 2 to 3 weeks.

Appropriate technology

Concern is frequently expressed that the mechanization technology designed in the developed countries does not suit the needs of the developing countries because the developing countries have a more abundant supply of labor and a shortage of capital and land. Thus, an intermediate technology is required that is more appropriate for developing country conditions.

The organization of agriculture and industry at the commune level in China facilitates the development of an appropriate technology. Each of the brigades has its own capacity for developing simple tools and repairing the more complex tools. The commune normally has the capacity for fabricating more complex equipment, or components of equipment. However, the commune does not have the capacity for developing large-scale machines. In the spirit of *self reliance* there seems to be little danger that the output of the commune will not match the needs of the workers. The close proximity of manufacture to final use solves the distribution problem.

In every commune visited there was a keen interest in mechanization and a strong demand for certain pieces of equipment, such as transplanters, that are not yet available in adequate quantities. That demand is generated by the funds allocated from the commune's public fund for reinvestment in machinery and equipment. The level of reinvestment appears high, and has resulted in demand for machinery running ahead of supply.

There has been recent talk of Chinese agriculture being fully mechanized by 1985 and for the advanced communes visited, that appears to be a possibility. However, one must be clear on the meaning of *full mechanization* in the current Chinese context. Full mechanization means, first and foremost, the mechanization needed to reduce the turnaround time from harvesting to planting (or transplanting) to a minimum and make it possible to maximize cropping

Table 3. Industrial growth in the Chien Chou Commune, Wu-Shi, China, from 1970 to 1975.

Factor	1970	1975
	Commune	
Commune factories (no.)	8	13
Factory workers (no.)	380	1,207
Value of industrial product (10,000 yuan[a])	58.6	582.8
Fixed capital (10,000 yuan[a])	6.5	127.1
	Brigade	
Factories (no.)	42	59
Factory workers (no.)	893	1,856
Total value of output (10,000 yuan[a])	95	430
Fixed capital (10,000 yuan[a])	13	104

[a]US$1.00 = about 1.85 yuan.

intensity and yield per hectare per year.

A gradual transformation of the Chinese economy is occurring, with small-scale industries in the advanced communes absorbing more of the labor force, and non-agricultural earnings growing rapidly (Tables 3 and 4). The communes visited were selected in part because they were undergoing a rapid transformation. Eighty percent of the labor still remains on the land, even in those communes. One would expect a continuing reduction in labor in the years ahead, and a continuing move toward mechanization, but China's agriculture will remain highly labor-intensive for some time to come.

China's emphasis on small-scale industry is not without its costs. As the transportation system develops and the linkages between

Table 4. Labor force and value of output for agriculture and industry, 3 communes, high and stable yield area, China, 1975.

Labor force, output value	Commune		
	Mei Chung (Wu-Shi)	Sui Hang (Shanghai)	Dali (Canton)
Population	31,300	21,000	68,000
Total work force	15,000	12,700	35,000
Factory and sideline	1,400	3,000	5,850
Agriculture	13,600	9,700	29,150
Value of output (million yuan)[a]	10.7	20.3	22.0
Factory and sideline (million yuan)[a]	4.7	15.0	10.5
Agriculture (million yuan)[a]	6.0	5.3	11.5

[a]US$1.00 = 1.85 yuan.

agriculture and industry become more fully developed, the small-scale plants will become high-cost and inefficient. Eventually many may have to be abandoned and labor and capital resources reallocated, a process that has created serious adjustment problems in a number of industrial economies in the past. China's fertilizer industry is a typical example. With a poorly developed transportation system and a shortage of foreign exchange for capital investment, the small-scale ammonium bicarbonate plants were the best answer for the domestic supply of nitrogen fertilizer. But the development of large-scale urea plants, now under way, will gradually render the ammonium bicarbonate plants obsolete.

CROPPING SYSTEMS

A major effort in all parts of China is making the land as productive as possible. Because most of China's major rice-growing areas have full water control, droughts and floods are no longer common constraints to high, stable rice yield. Multiple cropping is practiced extensively in all of China. Generally, cropping systems are determined by the length of the growing season and the availability of water. Great attention is given to the development and growth of early maturing crops.

Considerable variation existed among the communes visited by the IRRI team as to both varieties used and the cropping patterns followed. Rice is universally transplanted and in some cases, double transplanting is practiced to save time. All rice crops are started in the seedbed. In some instances, if rice is harvested in the morning, the land is prepared during the daytime, and the next crop is transplanted in the evening. Mechanization has top priority in land preparation, pulling of seedlings, transplanting, and harvesting — operations where machines replace slow, manual operations.

Cropping systems in the Peking area

In most of the Peking area, wheat is grown after rice, and rice varieties are extremely early to medium in maturity. Rice is mostly transplanted but it is occasionally direct seeded in water or in dry soil. The main cropping systems — particularly the rice-based cropping systems — are outlined in Table 1.

Table 1. Crop calendar for cropping systems, Peking area in China.

Item	Single crop of rice	Double-crop system (rice and wheat)			
		Early-maturing rice varieties	Late-maturing rice varieties	Wheat	Spring barley
Variety	Chin Yu 1 Chin Ye 1, etc.	Ching Ying 47, etc.	Chin Ye 1	–	–
Plant seedbed (date)	15–30 April	end May to beginning June	1–20 May	–	–
Seed in field (date)	–	–	–	Immediately after harvesting of rice	In mid-March
Transplant (date)	End May to 10 June	End June to beginning July	End June to beginning July	–	–
Flowering (date)	August	Beginning Sept.	Before 5 Sept.	10–15 May	20 May
Harvest (date)	10–20 October	10–20 October	15–25 October	15–20 June	25 June
Yield (av., t/ha)	6–7.5	4.5–5.25	5.25–6	3–3.75	3

DOUBLE BRIDGE COMMUNE (NEAR PEKING). The Double Bridge Commune grows rice in combinations that include wheat, vegetables, and forage or green-manure crops. A small experiment station at one of the commune's production brigades used three transplanting dates and rice maturity combinations:

- 170 days from seeding to harvest for early transplanting (15–20 May). The plants are kept in the seedbed for up to 45 days before transplanting. The rice crop follows green-manure crops or vegetables.
- 155 days from seeding to harvest for medium transplanting (date not specified). The rice crop follows forage crops and rape.
- 140–150 days from seeding to harvest for late transplanting. This system is used following wheat and requires the use of older seedlings (40–45 days) of long-duration varieties, or short-season varieties.

Cropping systems in central China

In central China the multiple cropping index is comparatively higher. In that region the main cropping system is wheat-rice-green manure-rape. In some areas, rice-wheat-cotton-green manure-rape are grown in rotation and in some areas, corn is substituted for rice. Occasionally, barley is substituted for wheat because the growth duration of barley is shorter.

North of the Yangtze River the rotation generally includes only one crop of rice because the growing season is too short for two rice crops in addition to wheat, rape, or a green-manure crop. Where only a single crop of rice is grown in the summer, indica varieties are used most because of their greater resistance to blast and bacterial leaf blight. Some IRRI varieties with bacterial leaf blight resistance were tried — with some success — but their growth duration is generally too long.

South of the Yangtze River the leading communes are trying for a three-crop system — two crops of rice followed by wheat, barley, rape, or a green-manure crop. The first rice crop is mostly indica varieties and the second crop is almost always japonica. Low temperatures and the tendency of the grain to shatter limit the use of indica varieties for the second crop.

In the Tai Hu Lake area, 80% of the area grows two crops of rice plus a winter crop, of which 70% is wheat and barley, 25% is green manure, and 5% is rape.

DOUBLE TRANSPLANTING OF RICE SEEDLINGS. A double-transplanting system is used with the second crop of rice in the Yangtze basin. Seedlings are taken from the seedbed after about 35 days and transplanted in a field at double the density of normal transplanting. After about 15 days, one half of the plants are uprooted and transplanted in a second field. The latter yield about as much as those transplanted only once at 35 days, but maturity is delayed a few days.

The double-transplant technique shortens the time rice occupies the land for the second crop. In Kiangsu, rices requiring 140 to 150 days were occupying the land for only about 100 days when the 50-day-old seedlings were transplanted.

TURNAROUND TIME. At the Shi Tang Brigade near Wu-Shi the turnaround time between rice crops in a wheat-rice-rice system was essentially nil. The rice for the next crop was transplanted the day

The Chinese mobilize large amounts of labor to get the speed needed for their *three-colors-in-a-day* approach to rice growing. The ripe grain (yellow) is harvested in the morning, the field is fertilized and plowed (black) in the afternoon, and the next crop is transplanted (green) in the evening of the same day. Workers from the cities may be sent to the communes to work at harvest time.

after the preceding crop (wheat or rice) was harvested. In one case rice (second crop) was transplanted in the afternoon of the day the first rice crop was harvested.

Cropping systems, Shanghai area

Table 2 shows details on a crop calendar of rice-based cropping systems in the Shanghai area. The Chinese began to experiment with triple cropping on a small scale in 1964, and after 1969 there was a rapid increase in the area triple cropped. In 1976 at least 86% of the area in southern Kiangsu province was triple cropped, particularly the area south of the Yangtze. If the area north of the Yangtze, as far north as the Hwai river, is included then the area triple cropped becomes about 50% of the total crop area.

In the upland arid zone in the western Kiangsu province, barley is normally sown with an intercropping of corn — four rows of barley and two rows of corn or green-manure crop.

Cropping systems, Kwangtung province

Kwangtung province is tropical and subtropical and its climate makes it possible to grow three crops a year, particularly south of the 24°N latitude. An objective of the cropping systems work in the Kwangtung area is to increase annual rice yields by 2.25 to 3 t/ha

Table 2. Crop calendar for cropping systems, Shanghai area in China.

Item	First rice crop	Second rice crop	Wheat	Barley	Rape	Green manure
Variety	–	–	–	–	–	–
Plant seedbed (date)	From 2nd 10 days to last 10 days April	From 2nd 10 days to last 10 days June	–	–	–	–
Seed in field (date)	–	–	2nd 10 days Nov.	From last 10 days Oct. to 2nd 10 days Nov.	From last 10 days Sept. to early Oct.	From last 10 days Oct. to 2nd 10 days Oct.
Transplant (date)	From last 10 days May to 1st 10 days June	From last 10 days July to 1st 10 days August	–	–	–	
Harvest (date)	From last 10 days July to 1st 10 days August	From last 10 days Oct. to 1st 10 days Nov.	1st 10 days June	Last 10 days May	Last 10 days May to 1st 10 days June	
Yield (av., t/ha)	6	5.3	–	4.5	–	

Table 3. Crop calendar for cropping systems in Kwangchow area of China.

Item	First rice crop	Second rice crop	Third rice crop	Wheat
Variety	Kuan Luai-4	Kuang Luai-4	Kuang Hua-Ai	Early maturing spring wheat-mexican dwarf
Plant seedbed (date)	From 1st 10 days to 2nd 10 days February	From 3rd 10 days May to 1st 10 days June	3rd 10 days June	Middle November
Transplant (date)	From 1st 10 days to 2nd 10 days March	From 2nd 10 days to 3rd 10 days June	Last 10 days August	
Flowering (date)	From 2nd 10 days to last 10 days May	From 3rd 10 days to 1st 10 days July	10–17 October	
Harvest (date)	10–20 June	15–25 August	15–25 December	2nd 10 days March
Yield (av., t/ha)	6.75	6.0	5.25	3.75
Agronomic and other characteristics of three-rice crops				
Total duration (days)	120	85	145	
Field duration (days)	95–100	60–70	85	
Seedling age (days)	20–25	15–20	60	
Photoperiod sensitivity	Insensitive	Insensitive	Sensitive	
Seedlings (no./hill)	5–6	10	10	
Hills (no./ha)	450,000	450,000	450,000	
Panicle (no.) (1,000/ha)	4,500–5,250	4,500–3,250	4,500–3,250	
Total grains (no./panicle)	75–80	55–60	55–60	
Filled grains (no./panicle)	55–60	45–50	45–50	
1,000 grain weight (g)	25–26	24–25	22–23	
Milling (%)	70	70	70	

by increasing cropping intensity from two crops a year to three crops a year.

Table 3 describes the detailed crop calendar for the four-crop system being tried in Kwangchow area. Rape or soybeans may be grown in place of wheat. The reasons for early maturity of the second rice crop (85 days total duration) and maintenance of high yields (more than 6 t/ha) (Table 3) are:

- Early-maturing rice is grown between two late-maturing crops. The second crop grows under favorable conditions. Average temperatures are 28.3°C for July and 28.2°C for August. For the first crop, the mean temperature is 21.8°C for April and 25.7°C for May.
- Total day length for the second crop is 232 hours in July and 220 hours in August.
- Total solar energy is highest for the second crop – July, 12,000 calories/sq cm per month and August 11,500 calories/sq cm per month. Solar energy received is high every day in July and August.

Table 4. Crop calendar for cropping systems in Kwangtung province, Hwa county, China (three crops per year).

Item	First rice crop	Second rice crop	Wheat
Variety	Chai Ye-Chin (narrow green leaf) Chun-Chu-Ai (Pearl dwarf)	Kwan Er Ai Chai Ye Chin (Cantonese No. 2)	Fang Sui (square panicle)
Plant seedbed (date)	From last 10 days January to 1st 10 days February under plastic cover	1st 10 days June	
Seed in field (date)	–	–	From 1st 10 days to 2nd 10 days November
Transplant (date)	From last 10 days March to 1st 10 days April	From last 10 days July to 1st 10 days August	–
Flowering (date)	From 1st 10 days to 2nd 10 days June	From 1st 10 days to 2nd 10 days October	From last 10 days January to 1st 10 days February
Harvest (date)	From 1st 10 days to 2nd 10 days July	From 1st 10 days to 2nd 10 days December	From 2nd 10 days to last 10 days March
Yield (av., t/ha)	4.5	4.35	1.5

• Difference in environment from place to place is low.

Although three crops of rice has an 80-year history on the Hainan Islands, it started in the Kwangchow area in 1973–74. At present, about 53,000 ha in the Kwangchow area grow three rice crops a year (four crops a year total). That means that 2.7% of the rice area in Kwangtung province grows three rice crops plus another crop annually. It is believed that by 1980 the area growing three crops of rice a year will increase to 670,000 ha.

The reasons the system of three rice crops per year has not spread faster are:

• it takes time for the farmers to adopt any new system,

• seed for new varieties are not available for rapid dissemination,

• fertilizers and agricultural supplies are not available for faster spread, and

• there are about 250 safe days to grow three crops of rice and 270 days are generally needed.

HWA COUNTY. In Hwa county, yields reported for both rice and wheat are somewhat lower (Table 4) than those reported in Table 3. That is because yields reported in Table 3 were from experimental fields. The yields reported for Hwa county are more typical of what is generally reported by the communes.

APPENDICES

1. MEMBERS OF IRRI TEAM

DR. N. C. BRADY, Director General. Ph.D., Soil Scientist. Dr. Brady's main interest is overall research and development to increase the world's rice production. This includes improved yield per crop as well as total productivity of land. Dr. Brady has been Director General of IRRI since 1973. Before joining IRRI, he had 28 years of experience at Cornell University where he was Head of the Agronomy Department, Director of Research, and Associate Dean.

DR. M. D. PATHAK, Director — Research Coordination. Ph.D., Entomologist. Dr. Pathak was head of IRRI's Entomology Department for 12 years and has been Research Coordinator for the past 3 years. He is interested in general research and development for rice. His subject matter interest is all aspects of control of insect pests, including development of insect resistant varieties, and pesticidal and integrated methods of insect control.

DR. S. H. OU, Head, Plant Pathology Department. Ph.D., Plant Pathologist. Dr. Ou has been Head of IRRI's Plant Pathology Department for 15 years. He has made outstanding contributions on the control of rice blast and sheath blight diseases, and pioneered the study of rice viruses in the tropics. He is interested in varietal resistance and the epidemiology, surveillance, and control of rice diseases.

DR. G. S. KHUSH, Head, Plant Breeding Department. Ph.D., Plant Breeder. Dr. Khush has been a rice breeder at IRRI for 8 years. His main interests are all aspects of rice breeding and genetics of insect and disease resistance of the rice plant. He is also working on interspecies hybridization and chromosomal aberrations to increase rice yields.

DR. S. YOSHIDA, Head, Plant Physiology Department. Ph.D., Plant Physiologist. Dr. Yoshida has been head of the IRRI's Plant Physiology Department for 9 years. His main interests in rice research are factors influencing photosynthesis

in rice, influence of climatic variables on rice growth and yields, and relationships between root development and drought resistance.

DR. S. K. DE DATTA, Head, Agronomy Department. Ph.D. in Soil Science, Agronomist. Dr. De Datta has been an IRRI Agronomist for 10 years and Head of the Agronomy Department since 1969. His main research interests are fertilizer efficiency, control and management of rice weeds, and drought and flood tolerance of rice.

DR. R. BARKER, Head, Agricultural Economics Department. Ph.D., Agricultural Economist. Dr. Barker has been an IRRI economist for 9 years and Head of the Agricultural Economics Department since 1970. His main interests are constraints to rice production in farmers' fields and means by which those constraints may be removed. He is also working on the effects of government policies on rice production, marketing of rice, and the economic and social consequences of the use of high yielding varieties and associated technology.

2. ITINERARY AND SCHEDULE OF VISIT

PEKING

October 7	Hongkong to Peking
8	Palace Museum Double Bridge People's Commune
9	Institute of Microbiology, Chinese Academy of Sciences Institute of Zoology, Chinese Academy of Sciences
10	Ming Tombs and Great Wall Banquet by Chinese Agricultural Association
11	Chinese Academy of Agricultural Sciences Lunch by Vice Minister Yang Agricultural exhibit Banquet by IRRI
12	Discussion – IRRI report Peking to Nanking

NANKING

13	General briefing Yangtze River bridge, Yuan Wu Lake, Purple Gold Mountain Cultural activity – children's show

14 Soils Institute, Chinese Academy of Sciences
Kiangsu Provincial Academy of Agricultural Sciences
Banquet by China Agricultural Association, Nanking Branch

15 General discussion by IRRI team
Sun-yet-shan Tomb

WU-SHI, KIANGSU

16 Nanking to Wu-Shi
Chien-Chow People's Commune
Syi-Tang Brigade
Banquet by Agricultural bureau of Wu-Shi

17 Mai-Tsien People's Commune
Sightseeing, Tai Lake
Chinese movie

18 Shi-Wei Park, doll factory
To Shanghai

SHANGHAI

18 Agricultural exhibit

19 Shu-Yen People's Commune
Industrial exhibit

20 Shanghai Academy of Agricultural Sciences
Discussion
Banquet by China Agricultural Association, Shanghai Branch

21 Plant Physiology Institute
Shanghai Academy of Agricultural Sciences
Entomology Institute, Shanghai Academy of Agricultural Sciences
Shanghai to Kwang Chow
Banquet by China Agricultural Association, Kwangtung Branch

KWANGTUNG

22 Cereal (food) Crops Institute, Kwangtung Provincial Academy of Agricultural Sciences
Chung-Shan University, Biology Department
Chung-hwa hot spring

23 Lew-che River Dam and Power Plant
Chung-hwa County – Botanical Garden
Peking Opera

24 Ta-Lie People's Commune of Nan-Hai County
Fertilizer Plant

	Lunch at the commune
	Commodity exhibit
	Banquet by IRRI
25	Hwa County Agricultural Research Institute
	Agricultural experiment stations — commune, brigade and production team levels
	Lunch at the commune
26	Discussion
	White Cloud Mountain
27	Departure

3. PLACES AND PEOPLE VISITED

Places visited	Chinese hosts
	PEKING AREA
Chinese Association of Agriculture	Ma, Ling, deputy secretary-general Huang, Yung-ning, secretary Lin, Shu-chen, rice breeder Hsu, Chin, member Chen, Tien-lin, worker
Double Bridge People's Commune	Chuang, Ho-shan, deputy chairman, revolution committee Kung, Ta-yean, Hi-chong-Wu Brigade, deputy chairman of the revolution committee
Institute of Microbiology, Chinese Academy of Sciences	Mao, Chen-Kwei, head, planning section, production division Wang, Yuan-chang, noted member Chou, Chia-tze, noted member
Institute of Zoology, Chinese Academy of Sciences	Chien, Yen-wen, head, operations division Chu, Li-chung Kung, Quen-yuan Tsai, Shue-yu Ken, Kai-sing Ho, Chung Chen, Yung-lin

Places visited	Chinese hosts
Chinese Academy of Agricultural Sciences	King, Shen-pao, president, also vice-president of Chinese Agricultural Association Hsieh, Chin-Kwei, vice-president Lin, Shu-chen, rice breeder Chiu, Shi-ponn, entomology
	KIANGSU AREA
Chinese Academy of Agricultural Sciences, Nanking Branch	Fon, Sheon, president Hsiung, Yen, deputy director, Soils Institute Lu, Liang-shu, member Chui, Shu-fang, member Yang, Li-chun, rice agronomist Shao, Pai-yen, member Ma, Yung-tang, member
Kiangsu Academy of Agricultural Sciences	Chui, Shu-fang, deputy director Chen, Yuang-kong, deputy director, farmer-breeder Lu, Pei-wen, entomology Ku, Chong-chien, plant pathology Tsui, Che-lin, plant physiology Chen, Yu-lin, plant pathology Shen, Tze-Pei, soil and fertilizer Ling, Yu, entomologist
Soils Institute, Chinese Academy of Sciences	Hsiung, Yen, deputy director Kung, Tze-tung, soil classification Yao, Yen-lian, organic fertilizer Leao, Shein-lin, agricultural chemistry Ma, Yen-tsu, rice soil Tsao, Tze-hong, agricultural chemistry
Wu-Shi Agricultural Bureau	Hwa, Ting-yuan, responsible person
Chien-chew People's Commune	Lo, Pin, deputy chairman, revolution committee Shih, Huon-chen, member, revolution committee
Mai-Tsien People's Commune	Chien, Pein-chang, revolution committee Yu, Tie-tsien
	SHANGHAI AREA
Chinese Agricultural Association,	Tung, Chia-pon, responsible person Ku, Tsu-teh, member

Places visited	Chinese hosts
Shanghai Branch	Yang, Yu-chun, member Hsu, Tien-teh, member Tang, She-hwa, professor of plant physiology institute Lew, Teh-yuan, plant protection and quarantine chief
Shu-yen People's Commune, Chia-lien County	Chie, Teh-chang, deputy chairman, revolution committee Hsu, Hen-chung, deputy chairman, revolution committee Leu, Chi-tson
Shanghai Academy of Agricultural Sciences	Tang, Chie-yan, deputy chairman, revolution committee Lew, Shi-hsin, crop institute, responsible person Shu, Hsin, production section head, crop institute Wang, Yen-hu, soils, fertilizer, and plant protection institute Hu, Chion-poun, soils, fertilizer, and plant protection institute Pan, Yuan-chang, soils, fertilizer, and plant protection institute
Plant Physiology Institute, Shanghai Academy of Agricultural Sciences	Wang, Wei-nan, revolution committee chairman Shen, Yuen-kong, responsible person, photosynthesis section Thang, Shi-Hwa, responsible person, phytotron Chen, Tze-chin, plant hormone Kwai, Yuen-chin, weed control Wang, Ming-yang, worker
	KWANGTUNG AREA
Chinese Agricultural Association, Kwangtung Province Branch	Wu, Tung-chiang, chairman Tsai, Tsao-pu, Kwangtung Academy of Agricultural Sciences, deputy director Huang, Chao-wu, professor, Kwangtung College of Agriculture and Forestry Hsieh, Youon-sun, member Lao, Yuen-hai, member Lo, Yuen-mo, member Hu, Shao-ho, member

Places visited	Chinese hosts
Kwangtung Academy of Agricultural Sciences	Tsai, Tsao-pu, deputy director Wen, Lin, deputy director, Cereal Institute Lao, Yuen-hai, agronomist, Cereal Institute Chen, Yao-hwa, rice breeder Yang, Yuen-Hsiun, deputy director, plant protection
Chun-shan University	Huang, You-mai, vice-president Wei, Tsong-kwei, professor Chee, Yu-tsio, deputy director, biology department Pu, Tze-long, professor, entomologist Lee, Pao-chien
Ta-lie People's Commune, Nan-hai County	Lin, Wei-chen, deputy chairman, revolution committee
Hwa County Agricultural Research Institute	Wang, Yu-lin, deputy director Cheng, Tson-ken, Hsiu-Hwa Commune Pan, Shi-nin, Hwa County Agricultural Bureau Chao, Ye-pin, deputy director
Kwangtung College Agriculture and Forestry	Chao, Shen-hwan, deputy dean Faan, Wei-chung, professor, plant pathology

4. VISIT TO INSTITUTE OF ZOOLOGY

Mr. Yen-wen Chien, head, Operations Division of the Institute, received the members of the IRRI team. He briefed them about the institute's major research programs and accompanied them to different laboratories.

The Institute of Zoology was founded in 1962 by the merger of the former institutes of Zoology and Entomology. At present it has 300 scientific workers and 200 supportive, administrative, and other staff. Named below are its 10 departments and their respective main functions or areas of emphasis.

1. Insect Taxonomy
2. Invertebrate Taxonomy

} surveys, collections, and identification

3. Insect Ecology
4. Vertebrate Ecology

} integrated control of insects and rodents.

5. Insect Physiology	biological control agents such as *Trichogramma*, ladybird beetles, and others.
6. Insecticide & Toxicology	
7. Cell Biology	origin of cell, cell genetics.
8. Endocrinology	reproductive physiology, mechanisms of insulin reaction, and acupuncture effectiveness.
9. Technology	instrument maintenance and design of simple instruments.
10. Sex Pheromones	agricultural and forest pests.

Most of the work is of the basic-applied nature, it is decidedly oriented to practical use, and is done in cooperation with communes and Department of Health personnel. For example, field work on cotton pests is done in cotton-growing areas.

The IRRI team visited the laboratories engaged in activities associated with agricultural pest-related problems.

INSECT PHYSIOLOGY DEPARTMENT

The physiology laboratory, organized in 1958, works primarily on viral and bacterial pathogens of agricultural and forest pests. The laboratory has isolated several viruses from armyworms, cutworms, and the cotton leafworms. A polynuclear virus from *Agrotis* was specially mentioned.

Insect pathology

Work on *Bacillus thuringiensis* is receiving special emphasis. The laboratory holds six collections of the 17 known varieties of this bacterium. Some of those varieties have been found highly effective against cabbage butterfly, rice skipper, and pine caterpillar, but not against the rice stem borer.

A combination of *B. thuringiensis* and insecticides is used against the rice stem borer. The treatment is made before the larvae bore inside the stem. Several of the bacteria are commercially produced, some in production plants at the commune level. Much of the production of *B. thuringiensis* is carried out in Kwangtung and Hunan provinces.

The present research on *B. thuringiensis* is oriented toward the selection of more efficient strains, the biochemistry of its mode of action, and techniques for mass production of the bacteria.

Biological control

The main emphasis in the biological control program of the Institute of Zoology is on the mass rearing of *Trichogramma* and the ladybird beetle. *Trichogramma*

has been widely accepted by farmers in many communes as an efficient agent of reducing insect populations. (It is an egg parasite, but several workers elsewhere have reported it as often having limited value). The eggs are reared on Tusser and Indian silk moth eggs, but the supply of these eggs could be a limiting factor.

Experiments are under way to develop artificial eggs, which the Institute workers termed "intermediate host." The artificial egg should have suitable material for an egg shell and suitable nutrients for larval development of *Trichogramma.* Thus, the insect can oviposit inside the artificial egg, the emerging larvae will develop normally, and the parasite that develops inside the egg should be able to emerge through the egg shell. Detailed basic work on the structure of the insect's oviposition, including electron microscope scanning, has been done. Polyvinyl was found to be suitable for making artificial eggs; chicken egg yolk contained inside such eggs allows completion of larval development, but the parasite reared via this method generally fails to pupate. Work is continuing to resolve this and other problems regarding the emergence of the adult insect.

Also, the ladybird beetle has been found to effectively reduce the population of aphids on wheat and to prevent their mass migration to the cotton crop. Farmers are interested in the use of the ladybird beetle. They frequently organize its collection from wheat fields and its release in cotton fields. However, this release does not often coincide with the occurrence of the aphid on the cotton crop.

Efforts are under way to devise a standardized mass rearing of ladybird beetles using synthetic or semisynthetic media. Pork viscera have been found to be a suitable diet and certain juvenile hormone analogs have been recorded to affect its chemotaxis and food intake. The beetle larvae prefer sweetened fresh meat and do not feed on vegetables. Efforts are being made to identify the different biotypes of the ladybird beetle, which may differ in their feeding habits. Hibernating ladybird beetles that have an adequate food reserve, when treated with certain hormones, can be induced to lay eggs.

Insect Physiology: compound eyes of night-flying insects

The reason certain insects are attracted to lights is being investigated, and light traps that may be highly effective against certain insects are being developed for use both as a survey tool and as a control method. Adequate knowledge of the subject may also be helpful in developing light sources that repel insects.

Cotton bollworm eyes are being used in the studies. Their compound eyes are mounted on a slide, light is reflected through the mounted eyes from the light-piece mirror to the eye-piece lens of a compound microscope and the measurements are made in a special recorder. The eyes of moths exposed to darkness for 2.5 hours reflected 70 times more light than those of moths not exposed to darkness. This ability to reflect light disappears if the eyes are exposed to blue or purple light, but red and yellow lights do not alter it. At present a single beam of lights has been tested; light of different wavelengths will be tested later.

Electron microscope

A local company fabricated the Institute's electron microscope, which has a 250,000X magnification. It was the first-generation electron microscope made by the company, which has now developed more recent models.

INSECTICIDE AND TOXICOLOGY DEPARTMENT

Half of the 32 members in the Insect and Toxicology Department are working on the synthesis of organic compounds including insecticides; the other half, on the toxicology of insecticides. The emphasis is on organophosphate and carbamate insecticides, and on juvenile and sex attractant hormones.

Insect hormones

A juvenile hormone for silkworm has been identified. Treatment of the fifth instar larvae with the hormone increases the size of the cocoon with no deleterious effect upon the insect or the quality of the silk produced. About 1 ml is adequate for treating about 40,000 silkworm larvae. The hormone helps to induce molting.

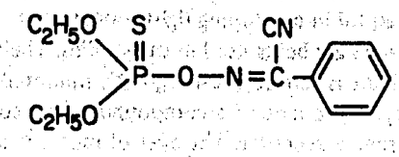
Since 1975, several sex attractant hormones have been synthesized for the oriental fruit moth, a serious orchard pest in China, which is particularly severe in pears, peaches, and apples. The hormones can be used for trapping insects for control or for survey. A simple cardboard trap has been devised and the hormones remain effective for 1 to 2 months. The hormones can be used in conjunction with insecticides for insect control.

The occurrence of a male sex attractant hormone has been demonstrated in female pine caterpillar moths. The hormone has been extracted from field-collected female moths. Work is under way to purify and to identify this attractant.

Toxicology studies

Work in the toxicology section is focusing on the development of effective insecticides with a low mammalian toxicity and low residues. An organothio insecticide, Phostoxin,

Phostoxin



came from this program. It is now being used widely throughout China for the control of grain, orchard, and vegetable insect pests. Phostoxin persists long in darkness but is decomposed in sunlight in 4 to 6 days. It is effective against the rice stem borer but has not been tested against the brown planthopper. When used as seed treatment, it even controls several species of soil insects. Further-

more, it is a safe insecticide, with an oral LD_{50} value of more than 1 g/kg body weight of mammals.

INSECT TAXONOMY DEPARTMENT

The Insect Taxonomy Department has a nationwide insect collection and identification center staffed by 50 scientists and holds about 1.5 to 2.0 million insect specimens. It does not send any specimens for identification abroad, but may consider the possibility of identifying specimens from abroad.

OVERALL IMPRESSION

In general, the work being conducted at the Institute of Zoology was impressive and the various workers appeared knowledgeable in their respective fields. The scientist working on insect attraction by light of different wavelengths was a high school graduate, who lived for 2 years in a commune and had worked at the Institute for 2 years. He appeared well versed in his field.

The research projects at the Institute are of a basic nature, but are oriented toward the solution of practical problems. The research facilities appeared adequate. Collaboration between the Institute of Zoology and IRRI in the areas of biological control could benefit not only both institutes but also many nations of the rice-growing world.

5. A CHINESE UNIVERSITY

The only Chinese university visited by the IRRI team was Chung Shan University in Kwangtung Province. Mr. Hwang, vice chairman of the Revolutionary Committee, explained the general organization of the university.

Chung Shan University was founded by Dr. Sun Yat Sen more than 50 years ago. It once included a College of Agriculture, but the college was moved in 1950 to a town about 100 km from Kwang Chou. Chung Shan University concentrates on literature, arts, and natural sciences. The literature and arts include Chinese literature, history, philosophy, economics, and foreign languages. The sciences include physics, chemistry, biology, geography, and metal sciences. The University has 1,000 teachers for more than 3,000 students who are in a 3-year program plus another 10,000 students whose duration of university education varies from a few weeks to a year.

Before China's cultural revolution, university education required 4 to 5 years. The required period now is 3 years, with greater emphasis on the short courses. There are fewer courses, and teaching materials are based on China rather than on foreign texts. Lecture materials are prepared jointly by teachers and students. During the final year, all students have a half-year practical thesis topic.

Dr. Pu, a professor of biology, briefed the IRRI team on entomological research in his department. The professor said that the department had 110

students. The basic policies followed in teaching were:

- Teach in the *open-door policy* — as much as possible do the research and teaching in the field.
- Teach theory related to practical problems.
- Teach with all indigenous teaching materials (text books, specimens, equipment, and others).
- Reduce courses to the minimum and teach only those absolutely essential.
- Prepare lectures collectively, involving the students.
- Devote the last 6 months of the curriculum to thesis research, mostly on practical problems, but also on theoretical topics.
- Follow the 3-in-1 method of teaching, i.e., teaching, practical work, and production. Teachers and students live in communes and, besides doing research, also participate in physical labor.

Professor Pu indicated that he and his students had been conducting commune research on biological control. They were working on viruses to control the pine caterpillar and a vegetable noctuid, *Prodenia litura.* They were also raising and mass releasing parasites to control the leechi stink bug. This has been done since 1970 and the need for insecticidal treatments has been drastically reduced. Professor Pu also gave some indication that there was a strong move to reduce the amount of chemicals being used on vegetables.

In the case of brown planthopper, it was pointed out that ducks turned into the paddy at the right time will eat the brown planthopper nymphs without bothering the rice. Gall midge was another insect problem in the area. Chemical insecticides had reduced the predator population, which may explain the increase in the incidence of gall midge in the area.

6. A CHINESE PROVINCIAL EXPERIMENT STATION

The IRRI team visited the Kiangsu Academy of Agricultural Sciences. The Academy has 600 staff members and 67 ha of experimental fields. Named below are the eight departments and their main objectives:

1. *Grain Crops* — to develop better varieties of wheat, paddy, rice, and corn.
2. *Soils and Fertilizer* — to improve low-yield soils and study methods to improve soil fertility.
3. *Plant Protection* — to control diseases and insects.
4. *Industrial and Cash Crops* — improve cotton and oil crops.
5. *Agro-chemistry* — to select food varieties by physical or chemical methods, including use of isotopes.
6. *Animal Husbandry and Veterinary medicine* — to study diseases of animals, and produce good pigs.
7. *Horticulture* — develop new varieties of fruits and vegetables.
8. *Water products* — to improve fresh-water fish production.

The Academy's research is based on the *open-door* policy and is done at specific or integrated research centers. The integrated research center remains at one location. The specific research center moves from place to place, and operates on the following principles of *four links between research workers and masses.*

- About two-thirds of the scientists are in the field and only one-third in the laboratory.
- The center provides technical training to workers from the communes.
- Work is in cooperation with other research institutes, e.g., agricultural universities.
- Research in communes is in cooperation with the masses.

The Academy runs a 1- to 2-year general training program in agricultural technology for people from communes. The trainees receive work points from their commune but no salary from the state. About 200 students are trained at the Academy at one time. More specialized training is given by the provincial colleges, which replaced the old university system. Nanking University agricultural college, for example, was moved to northern Kiangsu province.

The team visited the Academy's museum, plant protection laboratory, and field plots. In the laboratory, rearing of brown planthopper was by a technique similar to that used at IRRI, although the number of insects in the cages was small. Also seen was the section that evaluates insecticides for the common rice insects — green leafhopper, brown planthopper, and stem borers. The insecticides Kalthene, Bassa, Ofunak, Padan, Isofate, C-9140, and chlordimeform have shown promising results. The low mammalian toxicity of the compounds (both oral as well as dermal) is one of the primary considerations in selecting an insecticide.

Both *indica* and *japonica* breeding lines were growing in the Academy plots. Some fields were being harvested. There was low visible incidence of pests or diseases. The crop in general looked good and should have yielded 6 to 7 t/ha.

In a 0.25-ha plot, a three-crop rotation system — two rice and one wheat — was being followed. Details were:

Crop	Yield (t/ha)	Planting date	Growth duration
Wheat	6.7	early Nov.	—
Rice (*indica*)	8.3	20 May	100 days
Rice (*japonica*)	7.5 (lest)	July	140 days

The fertilizer used for both the rice crops were as follows:

- 37.5 t pig manure/ha
- 375 kg super phosphate/ha
- 580 kg ammonium sulfate/ha
- 212 kg potash/ha

The cultural practices for both rice crops were generally identical except that the age of the seedlings of the second crop *(japonica)* at transplanting was 35 days instead of the usual 20 days for the *indica* crop.

One crop the team saw had been double transplanted, the first transplanting was at 20 days and the second, 11 days later. This method is used to reduce the field time of the second crop to about 100 days.

7. A CHINESE COMMUNE

The IRRI team visited the Shu Yen People's Commune, about 20 km from Shanghai, and were received by Vice-Chairman Comrade Chu, Comrade Che Hong Chow, Comrade Lui Chi Chung, and Comrade Fan (Technical Agricultural Research Station of the commune). Vice-Chairman Chu gave a general briefing.

The commune was founded 23 September 1958. It has 11 brigades, 123 production teams, 5,583 households, and a population of 21,000 people, of which 12,700 constitute the labor force. Rice, wheat, and cotton are the main crops grown on the 1,724 ha of arable land.

Animal husbandry and seven small factories (farm machinery, integrated food processing, chemicals, metal works, electric bulbs, plastic tubs and bleaching powder) are the main noncrop occupations of the commune. Factory workers constitute about 24% of the total labor force.

The commune has 24 large tractors, 123 hand tractors, and 142 motor-driven transplanters. It is experimenting with a seedling puller, a silt dredger, and a cultivator. Of the total arable land, 98% is plowed by tractors. There was a definite emphasis to intensify mechanization. Field plots are well maintained and 50% of the crop area has an underground irrigation system.

In 1965, the commune adapted a three-crop system (rice–rice–wheat or rice–rice–barley) instead of the two crops a year system (rice–wheat or rice–barley) previously practiced. A bumper harvest was reported for all of the last 14 years. In 1975, the commune's total grain production averaged 15 t/ha, which was 2.5 times greater than the harvest of the precommune era. Similarly in 1975, cotton yields averaged about 900 kg/ha, which was 6.7 times the 1949 yields.

The objective of the commune's industry is to serve agriculture and the earnings from industrial production are invested in agricultural land development and other capital programs. In 1975 the total value of the commune's industrial production was about US$7.4 million and the accumulative public fund was about US$1.6 million. The value of agricultural production was US$2.4 million.

The general standard of living of the people of the commune has improved. The per capita income in 1975 was US$105 on the basis of work points and between US$210 and US$260 per worker, including food. The commune has a hospital and each production unit has a *barefoot* doctor. Each member pays about US$1.00/year as a health service charge and is entitled to free medical treatment. The system covers invalids and elderly persons.

The commune has 17 middle and primary schools, and all children are expected to attend. There are two cinema projects and 65 television receiver sets. Construction of new apartment houses started in 1969.

Later the team visited some rice fields that were well maintained but in which the crops had a considerable percentage of unfilled grains, possibly damage caused by cold. The general farm layout included an underground irrigation system. Livestock seen included ducks, pigs, and Holstein cows. The cows produce about 15 kg milk/cow daily.

The commune workshop was well equipped and produced bicycle rims and various kinds of tools. The team also saw a display of a power tiller, a seedling puller, and a transplanter.

The team was informed that the tax levied on communes was 8% of the agricultural income; it used to be 4%. The tax is levied on a production base assigned to the production team. If the team exceeds the base, the excess is not taxed.

Profits from small industries run by the commune are kept by the commune and used for field construction and improvement. For example, irrigation projects are implemented with labor from the production units but the equipment and supplies may be furnished by the commune.

8. A FARMER SCIENTIST

The Chinese claim that farmers are good research workers.

Mr. Chen is one of those farmers. He is a native of Song-kiang county, Kiangsu province, and has grown rice since childhood. In the early 1950's he bred a rice variety called Lao-lai-ching (green when old), which yielded more than 9.5 t/ha.

Chen was selected as a national hero of labor in 1955. In 1969 he represented the farmers of China and was received by Chairman Mao Tze-tung. In the same year, the Kiangsu Academy of Agricultural Sciences invited Chen to be a special researcher and made him Deputy Director of the Institute.

Based upon his long experience with intensive cultivation of rice, Chen developed a theory of *three yellows and three blacks* for the various growth stages of rice — yellow means greenish yellow, and black means dark green. Chen became — in modern terms — a rice breeder and rice agronomist-physiologist. He advocated that crop management should be based on the growth conditions of plants in the field.

Within 5 years the average yield on 40 fields, using Chen's method, was 7.12 t/ha. Demonstrations on state farms and communes showed a yield increase of 12% or more. Using Fang-dien Commune as a center of training, Chen's methods of growing rice were extended to other localities. Many people came

to Fang-dien Commune to study. They worked with Chen in the field in the morning and held discussions in the afternoon at the various growth stages of rice (1-day discussion at 5 different growth stages). The trained people taught other people at various levels. A film was made on Chen's methods.

Chen's variety Lao-lai-ching had a growth duration of 170 days. It was useful for a single rice crop in the 1950's but did not suit the three-harvest cropping system to be adopted. His cultural methods, however, remained valuable.

Chen's methods of growing rice was reported by Liochun Yang, a senior agronomist at the Kiangsu Academy of Agricultural Sciences, who had organized a team to work with Chen.

The foundation for a good rice crop consists of:

- good seed;
- vigorous seedlings from an even and light seeding rate; every individual seedling well developed;
- careful leveling of land, not more than 2 cm difference;
- close planting and fewer seedlings: 17 X 20 cm but 20 X 20 cm if the fertility is high, each individual plant needs to receive sufficient light and must have more leaves to absorb light; the tillering ability of the variety must also be considered.
- transplanting even and shallow; and
- sowing date in mid-May and transplanting in mid-June.

The *three yellows and three blacks* management practices emphasize:

- harmony between underground (roots) and above-ground (stalks) plant parts;
- harmony between individual and group development; and
- harmony in early, middle and late stages – too vigorous growth in the early stage causes poor field aeration and increases disease and insect incidence, if growth is poor in the early stage there will be fewer panicles.

The management is determined by:

- color of the leaves,
- rate of growth, and
- plant form.

Management requirements are:

- Fertilization. Apply organic manure, 70% as basal, to upper, middle, and lower layers of the soil;
- Tillers. The tiller number at 20–25 days after transplanting should reach 4,500,000/ha (some varieties 5,250,000). That will make a yield of 7.5 t/ha possible. At this time the leaf angle is more or less horizontal and color should be *black*. This is Chen's *first black*.
- First drainage. The plants continue to produce tillers. When tiller number reaches 450,000,000 t/ha, the field should be drained and the leaf color turns *yellow*. This is Chen's *first yellow*. Before that time the soil should be flooded. Drainage has the following functions:
  – controls tillering;

– stimulates new root development because of more aeration;
– decreases nitrogen metabolism and increases carbon metabolism so that both stem and leaves become erect. Plants are more resistant to diseases;
– activate aerobic microorganisms, which indirectly increase soil fertility; and
– induce *yellow* to a degree, but not to excess.

- Second flooding and fertilization. At the proper stage of *first yellow*, the field should be flooded and fertilized again with manure and bean cake. The leaf color becomes *black* again, Chen's *second black*. Again this should not be to excess. When too *black*, the internode will be too long. If not sufficiently fertilized, the stem will be thin and the panicles will be smaller.
- Second drainage. At panicle initiation, drain the field again, and the leaf color turns *yellow*, Chen's *second yellow*. If there is no *yellow*, aeration is poor and the panicles will be poor. The leaf area index should be about six. Ten days after panicle initiation leaf closing should occur. If leaf-closing occurs too early, the internodes become too long, the stem weakens and plants may lodge.
- Third flooding and fertilization. One week after panicle initiation, irrigate and fertilize the field, use chemical fertilizers such as ammonium sulfate called *panicles fertilizer*. How much fertilizer to be used depends upon the degree of *yellow* – if not *yellow enough*, no fertilizer. This gives Chen's *third black*.
- *Third yellow*. After the *third black*, there should be a *third yellow* by gradual withdrawal of water to a degree that a person can stand without sinking into the soil. Chen's *third yellow* is important. It promotes movement of nutrients from lower to upper leaves and reduces insects and diseases.

In general, on rich soils, plants need more *yellow* and less *black* but on poor soil they need less *yellow* and more *black*. It is reported that at the time of *yellow*, no blast disease will develop, even if it is artificially inoculated.

Describing the plant form, the Chinese say that at the *first black* stage, the leaves look like the leaves of a white lily, slightly bending at the upper portion. At the *first yellow*, the leaves are erect. At the *second black* and afterwards, the leaves are erect.

Chinese scientists believe that the *three yellows and three blacks* coincides with the physiological needs of rice plant at various stages of growth, controlling proper tiller number, growth rate, and plant form to maximize the yield. A paper on the theory was presented at the 1964 International Scientific Conference in Peking.