This is to certify that the

dissertation entitled

A COMPREHENSIVE TREE
IMPROVEMENT PLAN FOR TAIWAN

presented by

Nathan Yung-nai Yao

has been accepted towards fulfillment
of the requirements for

Doctor of Philosophy degree in Forestry

Major professor

Date July 28, 1982

A COMPREHENSIVE TREE IMPROVEMENT PLAN FOR TAIWAN

By

Nathan Yung-nai Yao

A DISSERTATION

Submitted to
Michigan State University
in partial fulfillment of the requirements
for the degree of

DOCTOR OF PHILOSOPHY

Department of Forestry

1982

ABSTRACT

A COMPREHENSIVE
TREE IMPROVEMENT PLAN
FOR TAIWAN

By

Nathan Yung-nai Yao

Tree improvement work in Taiwan was started in the 1960s. In the last 20 years, the results have emerged and shown positive aspects. Few were planned on a long-term basis. Some work plans have been tried. These were not comprehensive and never were put into action. So a comprehensive work plan is critically needed.

My work plan includes several chapters devoted to background information. Then is a review of research activities and the capacities of the research institutions and a review of past tree improvement projects. Then come individual work plans for nine groups of species: seven conifers and two hardwoods.

For each species or species group, much of the past work involves my own work. Provenance and progeny experiments are the main features of the work plan. They differ among species because of genetic natures, silvicultural factors and available experiments. Among them are five provenance tests, eight progeny tests, two clonal seed orchards and five seedling seed orchards converted from

progeny tests. Others proposed are one hybridization trial and three arboreta. In one work plan, an attempt at workload and cost analyses is made to show that all the work plans proposed are workable and reasonable.

Tree improvement work is tightly correlated with the silvicultural system in Taiwan. A chapter focusing on the gain through silviculture is provided.

ACKNOWLEDGMENTS

I would like to express my sincere thanks to my major professor, Dr. Jonathan W. Wright, for his enthusiasm, guidance, assistance, and encouragement throughout my doctoral program. Gratitude is also extended to the members of my guidance committee: Drs. James W. Hanover, Donald I. Dickmann, John H. Beaman and Wayne M. Adams. I am greatly indebted to my wife, Honlin Chen, for her full moral support, encouragement and love during these long years of my absence from home in Chushan, Taiwan, while she has taken care as a housewife, school teacher, and mother of three children. Financial support for my doctoral program was provided by the National Science Council, Republic of China for this six-month trip in 1982; and the Joint Commission on Rural Reconstruction, JCRR (now CAPD, the Council of Agricultural Planning and Development, ROC), AID PRogram in 1976-1978. Special mention should also be made of my employer, National Taiwan University (NTU) and the NTU Experimental Forest for allowing me time to complete the work. Without their permission and support, even the possibility of this research would not have been available.

TABLE OF CONTENTS

CHAPTER

CHAPTER

CHAPTER

LIST OF TABLES

TABLE

TABLE

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Tree improvement plan is the planning of tree improvement work dealing with the planting species involved. It is a package of work including two major aspects, forest genetics and tree breeding and silviculture. Also some other fields are related such as ecology, botany, meteorology, geography, etc. It is not a pure or theoretical study *per se*, but it is a plan/plans with experimental data, practical experiences within given environmental factors, and also including financial factors, manpower and space availabilities, timing, etc., to meet certain specific conditions. In other words, it should be workable with abundant and solid supporting reasons.

An improvement plan could be a simple one but now we are dealing with a comprehensive tree improvement plan; it means it is well designed and inclusive. Trees are so-called long-term growing plants. Whenever it is mentioned, the time factor always should be emphasized. As a matter of fact, it should be time-schedule oriented. The main subject of the plan is the given species. Thus, the improvement plan will be discussed by individual species. In Taiwan, more than 30 species are now generally considered as economic for planting. Only a few are planted in large areas. Only these major species will be discussed in the text. The others would be benefited by the methodologies of the discussed species or could be applied by following the pattern from the species which are under a similar situation or have close relationships.

Taiwan is an offshore island of mainland China. It is bisected by the Tropic of Cancer. It has a tropical to sub-tropical climate--warm to hot and humid in general. The forest is exceedingly luxuriant. Forestry has been important due to such natural conditions. As its silviculture goes, because of a preponderance of old, overmature timber and difficult logging accessibility, forest management in Taiwan consists mainly of clear cutting followed by artificial reforestation (replanting). Gradually, tree improvement works are involved in such planting-tree system. In recent years, the work attracted more interested people. So far, more than 44 research projects including 64 species have been studied and more works by individuals or by different forestry institutes are going on. The whole situation looks optimistic. Nevertheless, there is little gain or contribution to the whole silviculture or management system *per se*. Most of them are independent researchers, on a year-to-year basis. Some are poorly organized. For those reasons, a comprehensive tree improvement plan for Taiwan must be worked out in time. The purposes of my study can be generalized as follows:

1. To review the past work in tree improvement of Taiwan and to evaluate it.

2. To generate the comprehensive improvement plan for each species based on known information and data accumulated in the past and the needs.

3. To demonstrate a general scheme of a tree improvement plan and analyze the factors involved and discuss the alternatives and priorities when some factors vary.

4. To try to convince the forestry administrators that theoretically, it is not only feasible but also economical.

CHAPTER 2

BRIEF HISTORY OF TAIWAN FORESTRY AND PRESENT STATUS

Taiwan in Chinese literally means "terraced bay." It is also called Formosa which came from the "Ilha Formosa" means beautiful island by Portuguese mariners in 16th century when they discovered the island.

Back in 1206 A.D., it became a protectorate of the Chinese Empire. Then in 1624, the Dutch invaded and remained as colonists for 37 years, then in 1661 they were ousted by Chinese in Ming Dynasty. Almost in the same time in 1626, Spaniards occupied until 1641 but were driven out by the Dutch. In 1887, Taiwan became a province of China. A few years later, in 1895 Japanese took the island until 1945. At last, at the end of the Second World War, Taiwan is back to China again.

Taiwan's forestry started during the Japanese occupation period (1895 to 1945). They introduced logging techniques as well as silvicultural systems. In the meantime, they also brought their homeland favorite tree species "sugi" (Cryptomeria japonica, Taxodiaceae) in, with other species such as Japanese cypress (Chamaecyparis obtusa, Cupressaceae). "Sugi" was good, in some respects, even much better than in Japan. Later the "sugi" became the main planting species in the early Taiwan forest history.

Later on more species were planted. Some are natives of Taiwan but some had been introduced by early Chinese immigrants. Taiwania (*Taiwania cryptomerioides*, Taxodiaceae) and luanta-fir (*Cunninghamia konishii*, Taxodiaceae) are native conifers with excellent growth rates, tree forms and superior wood qualities. Lately, small-scale plantings of those species began. The next one is China-fir (Chinese-fir, *Cunninghamia lanceolata*). It is a mainland China species, from south-central or south-eastern parts of China including Honan, Shensi and Yunnan, Kiangsu and Hainan. Today it is a widely cultivated species in mainland China too. No literature shows when or who brought in China-fir. At any rate it was one of the earliest to be introduced and most successful species in Taiwan's forestry history.

Other species of conifers such as Taiwan red pine (*Pinus taiwanensis*), luchu pine (*P. luchuensis*), masso pine (*P. massoniana*), Taiwan red cypress (*Chamaecyparis formosensis*) are also common. In hardwoods, Taiwan acacia (*Acacia confusa*), Fabaceae), tung tree (*Aleurites fordii*, Euphorbiaceae), camphor tree (*Cinnamomum camphora*, Larraceae), Taiwan paulownia (*Paulownia fortunei*, Scrophulariaceae), Taiwan zelkova (*Zelkova formosana*, Ulmaceae), etc., are generally common. In addition, bamboos must be mentioned, the common ones including makino bamboo (*Phyllos-*

tachys makinoi), mengtsungchu (P. edulis), machu (Sinocalamus latiflorus) and green bamboo (Leleba oldhami), etc.

Today, those species are still planted. However, there is much interest in fast growing species such as exotic subtropical and tropical pines, eucalypts, Laucaena spp., Kadam (Anthocephalus chinenses, Rubiaceae). Those are already in adaptability trials. It is easy to understand that the introduction of exotic species has played a key role in Taiwan's forestry.

Reforestation is one of the main activities of Taiwan forestry. Based on Taiwan Forestry Bureau recent report (TFB, 1981), 30,571 ha (75,540 acres) of land were planted per year for the period 1971-1980.

Finally, to understand the forestry background of Taiwan, some basic data and information must be briefly presented. The total area of Taiwan island is 35,980 square kilometers (13,892 square miles), which supports a population of 17,456,000 people. A central mountain range forms the backbone of the island. The eastern half is very steep and craggy, the western slope is flat, fertile and well-cultivated. Approximately 52% (1,870,000 ha) of the island is covered by forests. Of that forest land in the mountains, 75% is in national forests administered for the Taiwan Provincial Government by TFB, 10% is in other public and private forests, and 15% is also national forest land but supervised by various other government institutes such as universities or research institutions. TFB is responsible for the large planting programs. In the last ten years the TFB planted about 12,741 ha (31,448 acres) per year in average. The hsien (county) map of Taiwan is shown in Figure 1.

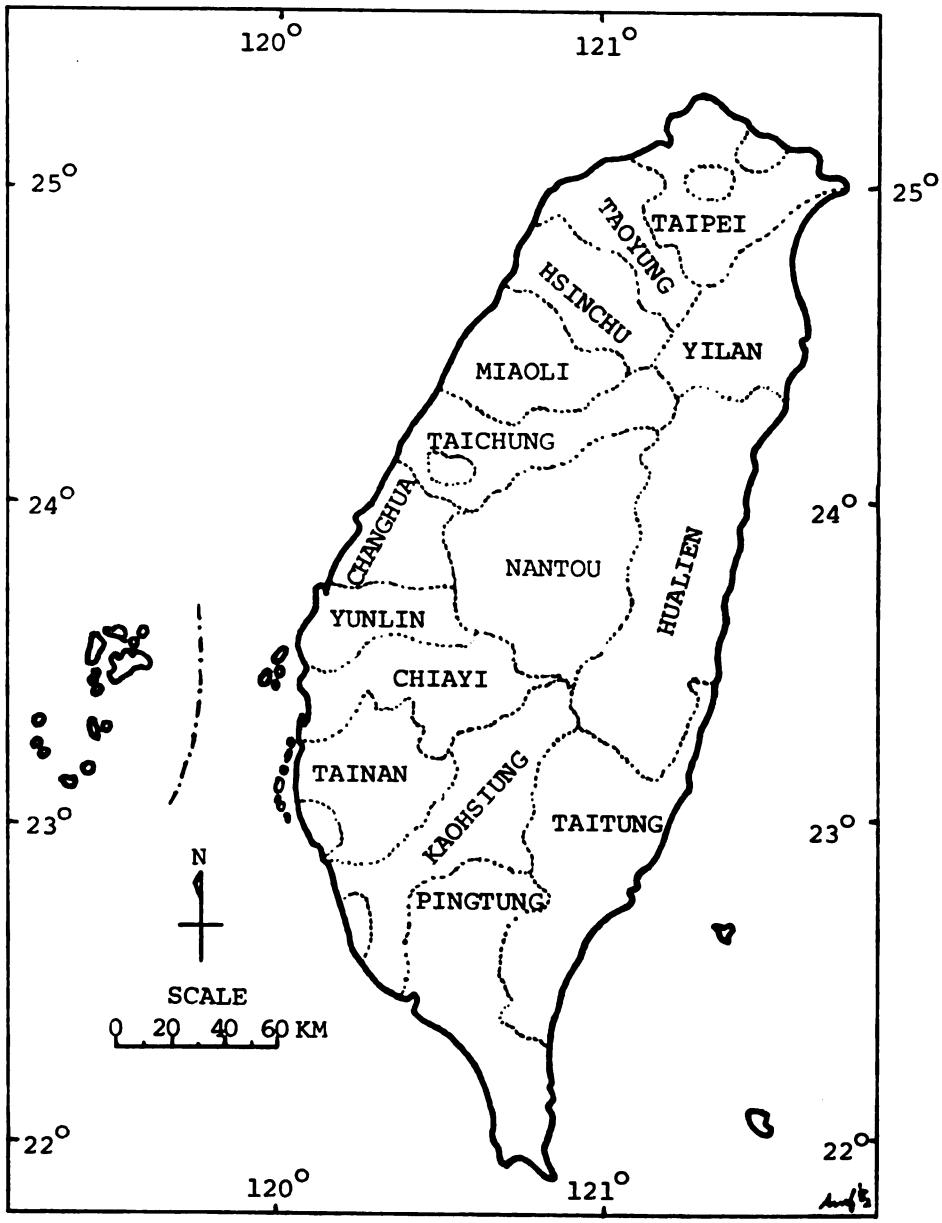

Figure 1. Hsien (county) map of Taiwan.

CHAPTER 3

ADMINISTRATION, EDUCATION, RESEARCH AND TRAINING IN FORESTRY

For improvements in the quality of tree breeding research, the administrative system, manpower resources, education and training in Taiwan are all closely related. The following are the brief facts about them.

Taiwan is a province of Republic of China, but also serves as a nation as well. So the forestry institutions sometimes overlap, some being national and some provincial. Generally, they can be separated into three categories: (1) forestry administrations, (2) universities and colleges, and (3) others.

Forestry Administrations

Taiwan Forestry Bureau (TFB) and Taiwan Forestry Research Institute (TFRI) are included here. They are both provincial, mainly dealing with Taiwan's forestry in different aspects. As for tree improvement is concerned, the department of silviculture of TFRI and Reforestation Branch of TFB both are responsible for it. So far, in TFRI about 3 to 5 senior specialists are involved in the work. On the other hand, TFB has only 2 to 3 personnel in charge of the program. Generally TFB is an execution unit, not supposed to do research except on its own problems. However, it often subsidizes universities, TFRI, etc.

Universities and Colleges

There are three universities and two junior colleges offering forestry courses. They are National Taiwan University (NTU), National Chunghsing University (NCHU), University of Chinese Culture (UCC), and Chiayi Agricultural Junior College (CYAJC). In addition some agriculture vocational schools have forestry. Tree improvement (including forest genetics and tree breeding) is a course required for silviculture major students in all universities and colleges. Both NTU and NCHU offer graduate courses at the masters and doctoral levels.

Each year researchers in universities or colleges may get financial aids from supporting agencies. Both NTU and NCHU have experimental forests which are active and productive in doing research and management. Both have land and available research personnel. The personnel are willing to work jointly with professors in universities. Each university has two persons interested in tree improvement work. NTU experimental forest has four capable senior specialists working on such studies.

Others

The first one to be mentioned here is National Science Council (NSC) which is the top agency on science

and research administration and management. The majority of research funds and subsidies come from NSC.

Next is the Council for Agriculture Planning and Development (CAPD, formerly JCRR--Joint Commission on Rural Reconstruction). Within it, forestry is a branch. The majority of employees in CAPD are specialists. So they serve as advisors in specific fields of agriculture. There are four silviculturists who are related to tree improvement programs.

Third is Academia Sinica (AS). For pure research *per se*, it is the top-ranking agency in Taiwan. Unfortunately, forestry is excluded, but still one or two biologists are doing basic researches related to forest genetics and tree breeding.

Besides the main categories mentioned above, local governments of some hsiens (=counties) do tree improvement works. This is especially true for hsiens which have forests and wild lands, such as Nantou, Hwalian, Pingtung, Yilan. Those hsiens are actively involved and work closely in cooperation with TFB and CAPD people. Generally extension is their main job.

Advanced Training

Taiwan forestry authorities since 1960 recognized the importance of advanced training of their own foresters abroad in order to meet the need of expanding tree improvement programs. The training programs are sponsored by separate individual institutions.

From NTU Experimental Forest, F. S. Kung studied a year (1963) at Oregon State University with Dr. K. K. Ching; C. H. Chiang (1967), C. F. Shih (1968), and B. J. Yen (1974) studied at University of Idaho with Dr. C. W. Wang (1974), and Mr. Chiang and Mr. Shih gained M.S. there; Y. N. Yao studied at Michigan State University with Dr. J. W. Wright and gained M.S. in 1971 and later (1976-77, 1982) he was back for his doctoral degree.

TFB offered shorter termed training programs, generally less than a year and emphasized in practical aspects. C. F. Chen (1975) studied at North Carolina State University with Dr. B. J. Zobel, T. S. Lin (1966) at the University of Minnesota with Dr. Scott Pauley, E. K. Tsou (1967) at Michigan State University with Dr. J. W. Wright (1967). Other one-or-two month tours were offered for Japan, New Zealand and Australia for special projects.

Of the TFRI staff, T. W. Hu studied at the University of Idaho with Dr. C. W. Wang and gained an M.S. in 1966, B. Y. Yang (1965) worked with USDA in the southern United States for a year.

Among others, P. C. Kuo of NTU studied a year at MSU in 1970 with Dr. J. W. Wright, Y. K. Fang of NCHU worked with Dr. H. Miyajima at Kyushu University in Japan in 1966.

Such training programs are still going on. Today young foresters in Taiwan have more chances for advanced training either in graduate schools in Taiwan or in foreign countries. Generally speaking, high-school level foresters in TFB, TFRI and NTU Experimental Forest are sent to NTU or NCHU for 6-12 months training on a non-degree policy. Those trainees follow programs individually designed for each student. Generally the graduates of colleges seek advanced training in other countries.

CHAPTER 4

REVIEW OF FOREST GENETICS AND TREE IMPROVEMENT WORK IN TAIWAN

Early Period

Forest genetics and tree improvement works were started early in Taiwan forestry history. The works are cumulative along with the forestry development and the activities. Since the 1900s, there were activities related to tree improvement. Some events had significant influences on later tree improvement practice. When interest in forest genetics increased in the 1960s, tree improvement work became active. Inevitably some mistakes and controversies existed in that period of time. In the 1970s, more intensive programs were started. Then some data and results became available. The important events related to this research will be discussed in detail, the contribution or flaws of them also will be the main concerns in this chapter.

Forestry practice and cryptomeria (*C. japonica*) introduction in Taiwan began in the 1900s, when Japanese occupied the island. When clear cutting became common, Japanese tried replanting with their familiar species. Then they took cryptomeria along. In 1903, the Experimental Forest of Tokyo University, Japan, was established in Nantou Hsien, Taiwan. In 1911, cryptomeria was introduced and planted at Chitou, Nantou Hsien. It grew very well so the Japanese tested its adaptability by planting many small plantations on different sites and elevations. There were also larger experiments with different spacings to study the effects of spacing on growth rate. Some of these plantations are in Chitou today and NTU Experimental Forest keeps them for permanent growth studies.

Another Japanese experiment at Chitou is also interesting. That is the cryptomeria race trial. Cryptomeria is a widely distributed native species of Japan, the geographic variations exist. It has been cultivated for hundreds of years and the Japanese have recognized different races. Different areas have been planted with different races. The race trial was established in 1941. It includes one 20-tree row of each of the most widely planted races. There was no replication. This was the only cryptomeria race trial they left in Taiwan. The Japanese apparently took the record of this experiment with them.

American Visitors and Their Contributions

In the 1960s, when forest genetics began booming in Taiwan, many activities gradually happened here and there. There must be some persons who made the progress possible, one of the key persons was Mr. K. Y. Tai. In the late 1950s, he worked for NTU Experimental Forest. Later he transferred to JCRR as a specialist in charge of forestry research. Most of the tree improvement events mentioned in this chapter relate to him. He always supported the programs, and offered opportunities for young foresters for advanced training. He also recommended distinguished foreign scientists to visit Taiwan. Most important, he was unselfish in dealing the business. Now he is still an active person in forestry in Taiwan.

In 1964, Dr. Kim K. Ching and his wife Dr. T. M. Ching (both of Oregon State University) came to Taiwan for a one-month stay. Their main purpose was to give an intensive training course in forest genetics and tree breeding for Taiwan foresters. The sponsors were JCRR, TFB, and NTU. Two main subjects were covered in the training program.

Dr. K. K. Ching gave introduction to forest genetics and demonstrations of practical techniques. Dr. T. M. Ching conducted a course in cytogenetics and related subjects including seed and pollen handling and storage techniques (Ching and Kung, 1965a, 1965b). That was the first time American forest geneticists were invited to Taiwan. The lectures were interesting and fresh. Dr. K. K. Ching especially had suggestions for research works. It was a long list which almost covered every aspect of forest genetics and general silviculture. It was true because tree breeding was just at beginning. The Chings' visit has opened a new era of tree breeding in Taiwan forestry history.

In 1965, Dr. Chi-wu Wang (University of Idaho) visited Taiwan for a month, sponsored by JCRR, TFB, NTU, TFRI and Chunghsing Paper Company. There was a training program, the trainees (about 60) were from all over the different agencies in Taiwan and Dr. Wang was the sole instructor. The program included lectures and field practices. In the final week, a general report was made. In the report, there were tree breeding plan outlines for Taiwan. He placed emphasis on execution of tree breeding work and suggested establishment of a permanent agency on tree breeding. The main benefit to Taiwan forestry of this workshop was the involvement in tree breeding of a great number of interested foresters as well as various forestry agencies. The workshop was very successful and stimulated Taiwan's interest in tree breeding.

Dr. Wang returned to Taiwan for his second visit in 1968-69. This time he worked on a Taiwan red pine progeny-provenance test of 24 seedlots. Later three test plantations were established and 1-year results were published (Wang et al., 1972). In 1972, Dr. Wang spent most of the year in Taiwan. His involvements were as follows: (1) He participated as a representative of the Republic of China in U.S.-China Cooperative Science Program, Seminar on Forest Ecology and Genetics. (2) He arranged for seed from 86 stands of cryptomeria from Japan. With those seeds, a provenance test with eight test plantations was established in 1974 by NTU Experimental Forest. (3) He organized another workshop, this time with other Chinese specialists. After the meeting, 19 short articles related to tree breeding were published as a proceedings (TFB, 1972b).

Dr. Wang is now retired. He gave his personal enthusiasm for Taiwan's tree breeding work and trained several outstanding Chinese tree breeders from the University of Idaho. Now, they are playing the main roles in Taiwan tree breeding field.

Another visitor to Taiwan was Dr. Jonathan W. Wright of Michigan State University, U.S.A. He gave direct assistance to the work during his two visits to Taiwan and tried to set up long-term tree improvement plans for Taiwan.

In January and March, 1969, Dr. Wright was invited as visiting professor of National Taiwan University for a two-month visit. He taught a course in forest genetics at the university, gave some training classes for forestry people, and worked with forestry staffs of NTU and the planning and research people of TFB, JCRR, TFRI, and NCHU for a number of consultations. During his stay, several field trips, about two weeks in total, were arranged to let him see and understand the forestry of Taiwan. He ended the visit with a report on Taiwan tree breeding (Wright, 1970a). Some points made in that report are as follows: (1) Acacia confusa is a common low altitude planting species, but with poor trunk form. Improvement is possible, either by silvicultural techniques or selection of other promising species for replacing it. (2) The coordination of forestry and other programs should be strengthened. (3) Cooperation with foreign countries should be emphasized for the exchange of information. (4) In forestry research, there are deficiencies in orientation toward Taiwan's needs and the small size of most experiments. (5) For better professional training, "forest genetics" should be developed at the graduate level. (6) The potential in tree breeding research for Taiwan forestry is very optimistic. (7) Research planning should be improved. A good work plan must consist of justification, objectives, literature review, methods, costs, time schedule and review. Suggested new projects include introduction and testing subtropical and tropical pines, introduction and testing *Eucalyptus* species, improvement of the *Pinus taiwanensis*-*luchuensis*-*massoniana* complex, combined provenance-progeny tests of *Cryptomeria*, *Pinus elliottii*, *Cunninghamia konishii*, *C. lanceolata*, *Alnus formosana*, *Taiwania*, *Acacia confusa* and *Taiwania* seed orchard.

In July, 1972, he was back again and stayed for one month. The purpose of his second visit was to assist and review the execution of the tree breeding projects. During his stay, he went and saw the test plantations in the field and discussed with the people in charge. Also, he gave some seminars.

After he left, he published three articles in Taiwan with some Chinese co-authors. One was "Plan for the genetic improvement of Taiwan red pine" (Wright *et al.*, 1972), a plan to accomplish genetic research and establish profitable plantations at the same time.

UNDP/FAO Project, 1966-1969

During the late 1960s, an important project dealing in part with forest genetics worked in Taiwan for 30 months. It is important because we learned good lessons.

The project "Forest and Forest Industry Development Project" was sponsored jointly by the Chinese government and United Nations (UNDP/FAO Project). There was a team in charge of forest genetics and silviculture, consisting of E. H. Hinkle, B. Y. Yang, F. S. Kung, J. H. Hsu and C. F. Chen. The purpose was to demonstrate activities in forest genetics and tree breeding as the basis for an improved reforestation and planting program. They worked on *Chamaecyparis formosensis*, *C. taiwanensis*, *Cunninghamia konishii*, *Taiwania cryptomerioides*, *Pinus taiwanensis*, *P. luchuensis*, and *P. elliottii*. The main techniques for genetic improvement were phenotypic selection and clonal seed orchard establishment. The team established *Cunninghamia konishii*, *P. luchuensis* and *P. taiwanensis* clonal seed orchards. At the same time, a *Taiwania* seed orchard was established by NTU Experimental Forest, JCRR and TFRI joint efforts. Unfortunately, there was no progeny testing. The seed orchards continue to be maintained and they produce seed which is harvested for commercial planting.

With slash pine (_P_. _elliottii_), they applied the same pattern as mentioned above. Slash pine is native to the southern United States. Scions from 67+ trees were imported directly from Florida. A total of 2,518 grafts were made in March, 1969. Only 2% survived, and there was no further work on this species.

The next project was the _Eucalyptus_ introduction work, done by owning the UNDP/FAO Project with advice from L. D. Pryor, a eucalypt expert from Australian National University, Canberra, Australia. The eight species introduced were _E_. _citriodora_, _E_. _grandis_, _E_. _saligna_, _E_. _robusta_, _E_. _tereticornis_, _E_. _decepta_, _E_. _globulus_, and _E_. _fastigiata_. Before the introduction, Dr. Pryor visited Taiwan twice in 1967 in order to understand the local environmental conditions and choose species with the best chances for success. In the spring of 1969, four low-elevation, private-lands, unreplicated plantations of 2.5 to 5.0 ha were planted. In 1970, TFB planted 250 ha in different places and on different elevations. Except for a brief 1972 visit to one plantation at Yangmei, there has been no follow-up.

U.S.-China Seminar on Forestry, 1972, Taipei

In 1972, the U.S.-China Cooperative Science Program "Seminar on Forest Ecology and Genetics" (March 31 to April 8) was held in Taipei, Taiwan. U.S. participants included ten American forestry scientists: C. F. Cooper (San Diego College, Ecology), R. F. Fisher (University of Illinois, Ecology), G. Frankie (Texas A & M University, Genetics), J. F. Franklin (Forestry Science Laboratory, USDA, Oregon, Ecology), J. Hett (Division of Ecological Sciences, Oak Ridge National Laboratory, Tennessee, Ecology), W. J. Libby, Jr. (University of California, Genetics), D. Mueller-Dombois (University of Hawaii, Ecology), G. Schneider (Michigan State University, Ecology), T. L. Sharik (Oberlin College, Genetics), D. B. Zobel (Oregon State University, Genetics). The Chinese delegates with forest genetics interests included C. W. Wang (University of Idaho), P. C. Kuo (NTU), C. W. Yang and T. Kiang (JCRR), E. D. Tsou and C. F. Chen (TFB), S. C. Woo (Academia Sinica); F. S. Kung, T. W. Hu, B. Y. Yang, C. M. Lu (TFRI); Y. K. Fong (NCHU); C. M. Kung, C. F. Shi, Y. N. Yao, C. H. Chiang (NTU Experimental Forest).

In the meeting, some suggestions were made (NSC, 1972) as follows: (1) Recommendations were made for research in Chamaecyparis, Juniperus squamata, and wide-ranging deciduous angiosperms common to both countries. (2) The exchange of scientific information materials and techniques was suggested. (3) The establishment of an official agency in charge of forest genetics and tree improvement activities in Taiwan was suggested. (4) The establishment of a committee to work out plans for the establishment of seed orchards, clonal banks and seed production areas. (5) Research in the ecology and improvement of native hardwoods should be emphasized.

All the American scientists were young, in their 30s to 40s. It was hoped that all would take an interest in and continue to cooperate with Taiwan, but that has not happened. The suggested new agencies were not established.

TFB Activities

In 1979, TFB senior specialist E. K. Tsou (1979) reported current activities in tree improvement work of TFB. The main items are as follows: (1) A total of 6,231 ha of natural stands of 31 species were designated as seed production areas. Also, 23,138 phenotypically superior individual plus trees were located in Table 1. (2) Clonal banks of luchu pine (7 ha), Taiwan red pine (10 ha), *Sassafras* and *Cinnamomum microarthum* (1 ha), Taiwania (15 ha), luanta-fir (10 ha), Taiwan cedar (10 ha) were established. Taiwan red pine and those of luanta-fir have already produced seed.

Forest Genetics Symposium, 1981, Taichung

In December, 1981, a symposium of forest genetics and breeding was held at Taichung, sponsored by NCHU. Six speakers presented papers. They were Y. N. Yao, C. H.

TABLE 1

AREAS OF SEED PRODUCTION AREAS OF THE MOST IMPORTANT SPECIES ESTABLISHED BY TFB FROM 1971 TO 1978 (from Tsou, 1979)

Species	Area (hectares) by forest district							
	Lanyang Wenshan	Chu-tung	Puli	Luanta	Tachia	Tahsue-shan	Yushan Nannung Hengchun	Kwanshan Mukua Yuli
Cryptomeria japonica	--	--	--	--	--	--	15	--
Taiwania cryptomerioides	--	205	--	176	128	21	--	523
Pinus luchuensis	126	6	--	37	--	--	35	5
Cunninghamia konishii	--	167	--	176	132	8	--	300
Keteleeria davidiana	38	--	--	--	--	--	--	3
Chamaecyparis formosensis	30	221	104	166	20	--	437	223
C. obtusa var. _formosensis_	49	221	104	142	6	32	218	40
Other conifers: _Taxus celebica_, _Tsuga chinensis_, _Pinus armandii_, _P. taiwanensis_, _P. massoniana_, _Pseudotsuga wilsoniana_	--	--	--	1	2	21	--	--
Cinnamomum micranthum	30	82	--	10	--	8	108	23
Sassafras randalense	21	30	--	--	--	5	31	3
Schima superba	--	82	10	10	--	5	58	--
Alnus formosana	--	--	13	--	--	--	--	2
Zelkova serrata	--	9	--	--	--	5	58	1
Michelia formosana	3	--	1	1	--	5	199	14
Other hardwoods: _Acacia confusa_, _Fraxinus griffithii_, _Aleurites fortunei_, _Liquidambar formosana_, _Juglans cathayensis_, _Paulownia fortunei_, _Cinnamomum camphora_, _Castanea mollissima_, _Diospyros discolor_	--	--	22	6	1	--	43	2

Chiang (NTU Experimental Forest), P. J. Wang (Academia Sinica), F. H. Huang (NCHU), J. C. Yang, T. W. Hu (TFRI). The scope of the research in the meeting included genetic engineering, isozyme implicatins tissue culture, tree species introduction and current improvement work.

Hu, T. W., of TFRI reported current activities on tree breeding in Taiwan (Hu et al., 1981). The paper 44 research projects, 64 species have been worked on since 1967. Details of the activities are in Table 2. The report gave no results except for a species introduction trial of leucaena (Leucaena leucocephala). On a good site at Tulan, the annual volume growth of a fast growing type from El Salvador was 40.3 m^3 per ha per year at age 3.

NTU Experimental Forest Activities and My Background and Experience

My thesis is "A Comprehensive Tree Improvement Plan for Taiwan." In large part, it is based on a review of the literature. However, I have had personal experience with many of the experiments cited. Therefore, in this section, I give a brief account of the NTU Experimental Forest, where I work, and its relationship to Taiwan tree improvement activities, and of my personal participation in tree improvement studies.

The experimental forest of National Taiwan University (NTU Experimental Forest) was established in 1949. It is managed under the supervision of College of Agricul-

TABLE 2

CURRENT TREE BREEDING TESTS IN TAIWAN
(from Hu *et al.*, 1981)

Species	No. Seedlots	No. Planta-tions	Planting Date	Sponsor
Provenance Tests:				
Araucaria cunninghamii	9	3	1969	TFRI
Chamaecyparis (7 spp.)	18	1	1975	TFRI
Cryptomeria japonica	86	9	1973,74	TFRI,NTU
Cunninghamia lanceolata	4	1	1970	TFRI
Dendrocalamus giganteus	4	3	1974	TFRI
Pseudotsuga menziesii	14	2	1977	TFRI
Taiwania cryptomerioides	6	2	1972	TFRI
Progeny Test:				
Alnus formosana	11	2	1970	NTU
Camellia oleifera	100	2	1980	TFRI
Cinnamomum osmophloeum	147	1	1980	TFRI
Cunninghamia konishii	56	2	1977	TFRI
Daemonorops margaritae	80	3	1981	TFRI
Melia azedarach	130	3	1981	TFRI
Sapium sebiferum	120	3	1981	TFRI
Schima superba	12	1	1977	NTU
Pinus luchuensis	214	2	1970,72	TFRI
Acacia confusa	156	3	1972	TFRI
Broussonetia papyrifera	108	3	1977	TFRI
Calocedrus formosana	104	2	1973	TFRI
Chamaecyparis formosensis	224	3	1975,76	TFRI
Cunninghamia lanceolata	97	3	1972,73	TFRI
Pinus taiwanensis	225	4	1971	TFRI
Taiwania cryptomerioides	90	2	1980	TFRI

ture of NTU. NTU Experimental Forest is located in the center part of Taiwan. It is 33,522 ha in size, which is about one-hundredth of Taiwan land area. Of the total area, 6,380 ha (19%) is operable forest land including 5,280 ha of manmade forest (1978 data). The rest is natural forest, protection forest, bamboo forest or non-forest land, etc. The objectives of the forest management are as follows: (1) To provide facilities and field practice for University students, (2) To undertake forestry research, and (3) To demonstrate advanced forest management techniques. There are about 100 members on the staff. Of them, 39% are college graduates and one-third have masters degrees.

NTU Experimental Forest research activities are basically the responsibility of the Department of Forest of the University. However, some research is undertaken by the Experimental Forest staff. Due to the heavy loads of administrative work, most staff members only work part-time in research.

Research funding comes from several sources. The forest itself has a small regular appropriation for research. Individuals often apply for research funds to NSC (National Science Council) or CAPD (Council for Agricultural Planning and Development). The forest publishes its own research publication, "NTU Experimental Forest Bulletin." Both faculty and forest staff members can publish in it. Twice a year, both the faculty and forest staff members gather to review and discuss the research projects and related matters.

The most common species in the NTU Forest are cryptomeria, China-fir, luanta-fir and taiwania. Those four species constitute 80% of the plantations. There are also plantations of hardwoods (paulownia, tung tree, zelkova). Bamboo, cultivated by bamboo farmers, occupies large areas.

NTU Experimental Forest contains 93 test plantations or research stands, totally 115 ha in size. Among them are some cryptomeria growth study test plantations established in 1921 which are the oldest record-kept test plantations in Taiwan forestry history. The test plantations related to tree breeding are listed in Table 3.

Following are the research works in which I am personally involved. They are discussed species by species, and trial by trial.

A. 1941 cryptomeria provenance trial. This 9-seedlot experiment was in Chitou and was established by the Japanese. In 1966, I was in charge as a forest ranger there and was responsible for this experiment. Later, I found that record file of this experiment was missing, so I managed it as a common plantation. When Dr. Sakaguchi of Japan visited Chitou in 1972, we asked him for help if he could find the information of this experiment in Japan. He published in 1973 in Japan some growth data. In 1979, when I returned to measure the growth, I found the planta-

TABLE 3

SUMMARY OF TEST PLANTATIONS IN TREE BREEDING OF NTU EXPERIMENTAL FOREST (from NTU, 1981)

Title	Area (ha)	Established	No. Seed-lots
Alnus formosana progeny test	1.0	1970	11
Alnus formosana progeny test	.3	1974	1
Schima superba progeny test	1.0	1970	12
Kadam introduction trial	1.2	1974	5
Kadam introduction trial	1.8	1980	5
Cryptomeria provenance test	15.1	1974	83
Luanta-fir seed production area	4.0	1971	1
Luanta-fir x China-fir full-sib progeny test	.2	1978	6
Luanta-fir provenance test	.5	1980	1
China-fir provenance test	.5	1980	1
Taiwania provenance test	3.0	1973	12
Taiwania progeny test	3.0	1973	26
Taiwan red pine progeny test	1.5	1972	24
Taiwania and Luanta-fir clone banks	1.2	1966	20
Exotic pine introduction trial	4.0	1973	25
Sequoia sempervirens and *Sequoiadendron giganteum* introduction trial	.1	1975	2

tion was gone, except for a few trees.

B. 1967, 1968 cryptomeria provenance trials. These 13-seedlot experiments were started by a rice breeder, Prof. Dr. C. J. Yu of the NTU Department of Botany, who obtained seeds in 1968 and 1969. As Division Chief of Silviculture of NTU Experimental Forest, I became involved in 1969. In 1972, when the plantations were 4 and 5 years old, I made the record files, supervised maintenance of the plantations. I measured them five times from 1972 to 1982. There has been no publication.

C. 1973 cryptomeria provenance trial. A team was assigned responsibility for this 86-seedlot experiment establishment. I was a member of this team. The seeds were obtained by Dr. C. W. Wang from Japan. The team wrote a work plan for a nursery test in Chitou in 1972, and started a project funded by JCRR (Joint Commission on Rural Reconstruction) and established seven test plantations in 1973.

Before outplanting, the seedlings were measured in Chitou in 1974. During planting season, I was in charge of the Chitou nursery, and establishment of the Salishien plantations, including the mapping and labeling. In February, 1976, I and three others measured the plantations. And in 1979, we jointly published the first report on this trial (Chiang et al., 1979). In addition to helping on the measurements, I did the ANOVAs.

D. 1972 Taiwania provenance and progeny trials.

The seeds from TFRI, the 12-seedlot provenance test and 26-seedlot progeny trials were started as separate experiments. I am totally involved. I started the nursery test and supervised establishment of the test plantations in Chitou and Sanpin in 1972 and 1973. I measured the growth at age 1, 2, 4, 5, and 7. A complete report of the growth analyses was published in 1981.

E. 1966 Taiwania density study. I established the test plantation in 1966 in Chitou of NTU Experimental Forest. The total area was 2.0 ha. In 1972, the first preliminary results were published (Yao, 1972). In 1979, I measured again including diameter, height, crown size and mortality: This is the first spacing study in Taiwania. I include detailed data in my thesis.

F. Taiwan pines nursery growth studies. In the past several years, I compared the growth in nurseries of Taiwan red pine, masso pine and luchu pine. The growth of them was uneven within the same species, sometime even strongly contrasted in the same nursery beds. Such phenomena have never been found in cryptomeria or China-fir or Taiwania. It is suspected to be due to mycorrhizae effects in microsite differences. A further study is underway.

G. 1973 TFRI Taiwan red pine progeny trial. This was established by TFRI. I became involved when it was tested in nursery since 1972. I worked with TFRI members to collect the growth data in the nursery of this 200-

seedlot trial. In 1979, I worked on the calculation of ANOVA of the measurements including nineteen traits in cone, seed, nursery and test plantation growth. In 1979, we wrote a paper "Geographic variation in Taiwan red pine," and now it is in review.

H. 1971 TFB luchu pine trial. Mrs. E. K. Tsou of TFB established the 214-seedlot progeny test. From 1979 to 1981, I had a grant from TFB to work with Mrs. Tsou on this trial. My major work is to assist in the measurements, the report writing.

I. 1973 NTU Experimental Forest exotic pine trial. In 1972, P. C. Kuo and I jointly published a study on "Selection of exotic pine species for testing in Taiwan" (1972). In the meantime, I contacted IUFRO (International Union of Forestry Research Organization), and asked for seed from Dr. J. Burley of Oxford, Great Britain. Then a 25-seedlot trial was started in 1974 in Chitou and Chushan and outplanted in four test plantations in 1975. I measured the seed characteristics and year-old seedling height. I also measured the test plantations at ages 1, 5 and 7. The results have been reported (Yao, 1974, 1979a, and 1981).

J. 1975 NTU Experimental Forest Kadam trial. I cooperated with my associate Mr. B. J. Yen to establish test plantations at Hoshe and Hsueli. The seed was from the Philippines. It was supplied by Dr. S. C. Wu of NTU when he had a trip there in 1974. We measured the test plantations in 1978, and thinned the Hsueli plantation.

In 1981, we made the second measurement, in order to make second thinning in 1983. Now NTU Experimental Forest is cooperating with TFRI on kadam wood property studies and further adaptability testing.

K. 1970 Taiwan alder and guger trial. NTU Experimental Forest started hardwood studies quite early. Mr. C. M. Kung established the alder (*Alnus formosana*) and guger (*Schima superba*) progeny trials in 1970. Two years later he died without record files. I then became involved. First I labeled the trees and established the record system, including the plantation maps. Then I measured and supervised the test plantations. And I also distributed the location maps to those who might be interested. In 1975 and 1977, two research papers of these two trials were published in NTU Experimental Forest technique bulletin.

CHAPTER 5

CRYPTOMERIA AND ITS IMPROVEMENT

Introduction

Cryptomeria japonica D. Don of Taxodiaceae, also called cryptomeria or sugi, is one of the major economic coniferous species in Taiwan. It is not native, but was introduced from Japan in the 1900s. Because of its good timber qualities, fast growth, ease of planting, and high survival, it used to be commonly planted. At the end of 1965, it had been planted on 21,820 ha. Between 1966 and 1975, an average of 1,487 ha per year (TFB, 1976) were planted. In recent years, due to heavy loss by squirrel damage, the planting has been reduced. But as it is a traditional species, it cannot stop being planted like this. If the damage would be under control, a high planting rate would be back very soon.

Cryptomeria has been planted on most parts of the island. It is especially abundant and excellent in growth in Chitou, Alishan, Chutung, Puli, and Chilanshan. It grows best where it is warm and humid with fertile and deep soils. When it is planted on a good site, it can reach 50 to 60 m in height. The optimum elevational range is from 1,200 to 2,400 m in elevation, but sometimes it can grow as low as 900m. The optimum climate condition is about 10 to

$17^{o}C$ in average temperature, 300+ mm rainfall per year. The humidity is often over 80%. The growth rate generally is 33% faster than in Japan. It cannot grow well on dry sites, or in a windward slope facing west or southwest.

The wood is mainly used for construction, bridges, shipbuilding, poles, wooden ware and barrels. The wood is light and soft, but stiff. The specific gravity is 0.30 to 0.33. The heartwood varies from russet brown to dull brown in color. This character is said to relate to variety seed source and the lighter color trees are the best for furniture or panels.

Cryptomeria is a native in Japan. It occurs in almost all the main islands except Hokkaido. It covers a wide geographic range from $30^{o}15'$ to $40^{o}42'$ N in latitude and $129^{o}50'$ to $142^{o}03'$ E in longitude. Cryptomeria grows from sea level to 2,800 m elevation in the high mountains.

Cryptomeria is also a common native species in the southern part of mainland China, being especially abundant in the southeastern provinces of Kiangsi, Anhwei, Chekiang, and Fukien.

Species Description, Silviculture and Growth

Cryptomeria is a large tree, to 60 m in height. The bark is reddish brown, peeling off in long strips. Leaves are spirally arranged in 5 vertical ranks, green, awl-shaped, 1 to 2 cm long, incurved, tapering or obtuse.

Staminate strobili are in cylindrical clusters. The pollen sacs are 3-5. Cones are brown, subglobose, 1 to 1.5 cm long with 20-30 scales. Each scale has 2 to 5 seeds with narrow wings. There are about 93,000 to 118,000 seeds per liter (110,000 to 136,000 seeds per pound). Cryptomeria in Taiwan does not bear as much seed or seed with as good germination as in Japan. Therefore, Taiwanese foresters have relied completely on Japanese seed supplies. Taiwan formerly imported 2,000 liters per year, but in recent years has imported only half as much. The cones mature in October and November. If the seed is collected and stored at room temperature, it lasts about 8 months. When sown in soil, it takes 2 to 3 weeks for germination. The juvenile growth is much faster than luanta-fir and China-fir, and also than taiwania. One-year-old seedlings are good for outplanting.

Cryptomeria is rather a selective species as to site. The height growth on different site classes and different parts of Taiwan and Japan are shown in Table 4 (Liu *et al*., 1955) and Table 5 (Liu *et al*., 1978).

The expected rotation is 20-30 years. The estimated mean annual increment is 10 to 12 m^3 per ha per year, with a maximum of 19 m^3 per ha per year.

The pests and diseases of cryptomeria are usually not serious except for squirrel damage. In the nursery, needle blight (Fungi, *Imperfecti*) used to cause serious

TABLE 4

HEIGHT GROWTH OF CRYPTOMERIA ON THREE SITE CLASSES IN TAIWAN (from Liu *et al.*, 1955)

Age (years)	Height on Site Class (meters)		
	I	II	III
10	11.1	8.9	6.8
15	13.9	11.2	8.1
20	16.3	13.2	10.0
25	18.5	14.9	11.4
30	21.4	18.1	13.8
40	24.2	19.6	14.9

TABLE 5

HEIGHT GROWTH OF CRYPTOMERIA AT THREE TO FIVE LOCATIONS IN TAIWAN AND JAPAN (from Liu *et al.*, 1978)

Age (Years)	Height (meters)				
	Taiwan			Japan	
	Chitou	Alishan	Wulai	Akita	Kyushu
10	8.5	7.1	8.6		5.2
15	12.7	10.8	12.0	6.3	7.2
20	16.0	14.1	14.5	8.7	9.0
25	18.5	16.9	16.2	11.1	10.8
30	20.7	19.3	17.6	13.4	12.4
35	22.5	21.2	18.6	15.5	13.9
40	24.1	22.5	19.8	17.4	15.3
45	25.5	23.4	21.2	19.1	16.7

damage. Now, however, chemical controls have already been put into nursery management systems, and have been very effective.

The other nursery disease is damping off caused by *Pythium*, *Pellicularia*, *Fusarium*, and other fungi, and it is also common. It happens during the lignifications stage of young seedlings. Infected seedlings rot at the bottom. Sterilization of seed and soil generally results in good control.

Squirrel damage on cryptomeria is serious. After age 10 the damage happens. The squirrels bite the tree bark and tear it off in long strips. Sometimes they peel the bark and girdle the trunk. The damage causes growth stagnation. At the beginning, the tree crown becomes brown and dried out, then the wounded tree may survive a while without the tip, but the growth would never be recovered. In Luikuei, 55% of cryptomeria trees of age 45 were damaged (Hwang *et al.*, 1979). Wang and Kuo (1980) surveyed the damage island-wide. Between 52 and 66% in different stands were damaged. Sometimes, Taiwan foresters are so discouraged that the disaster seems out of control. Therefore, many have stopped planting these species. As guns are not legal, the only other control method is poisoning, as is practiced on the NTU Experimental Forest.

Past Work on Genetics

Many research works on cryptomeria have been done in Taiwan and Japan. In Taiwan, most are growth and management. In recent years, NTU Forest especially has been interested in provenance tests, and four different trials have already been conducted. A brief summary of each trial is given as follows.

1941 Trial at Chitou

In May 1941, a 9-seedlot provenance test was established at Chitou by the Tokyo Imperial University of Japan. This trial, which covered 3.47 ha, was unreplicated. The nine seedlots were from three different parts of Japan (Table 6).

TABLE 6

RELATIVE GROWTH AT AGE 13 OF NINE SEEDLOTS OF CRYPTOMERIA PLANTED AT CHITOU IN 1941

Seedlot	Location, Island and Locality	Height (% of mean)	Diameter (% of mean)
3	Nor. Honshu, Akida	120	110
1	Cent. Honshu, Yoshino	122	120
2	Cent. Honshu, Chito	144	119
4	Kyushu, Etaya A	89	100
5	Kyushu, Obi	100	104
6	Kyushu, Etaya B	86	102
7	Kyushu, Aya	72	77
8	Kyushu, Yakutoshi	88	93
9	Kyushu, Satzema	73	74
Actual Mean		10.0 m	15.5 cm

This experiment was measured in 1946 by Japanese foresters, who returned to Japan with the data and the plantation map. In 1973, these data were published in Japan by Sakaguchi.

The experiment was re-measured in 1954 by Young and Chiao, who published their report in Taiwan in 1955. At that time, they did not have maps or any written data on the experiment, and so they relied on the memories of the foremen who had planted and cared for the experiment.

I calculated the correlations between age 5 (1946) and age 13 (1954) height, using seedlot means as items. This correlation was r = .92. This indicated two things: (a) the age-age correlation was high, and (b) the foremen's memories were probably correct.

The results are summarized in Table 6. The three seedlots from Honshu grew much faster than the six from Kyushu. There was a very strong correlation (r = .97) between height and diameter. This plantation was cut in 1975.

<u>1967, 1968 Trials</u>

In 1967, a 13-seedlot provenance test was established in Chitou. The seed, except one seedlot from Alishan, Taiwan, were given by Dr. K. Sakaguchi, Government Forest Experiment Station of Japan, and with the help of the late Prof. C. J. Yu, Dept. of Botany, NTU.

The test plantation is at 1,300 m in elevation, with 10-tree row plots and 10 replications. The spacing is 2 x 2 m. In 1977, I measured the height at age 10 and analyzed the data. The growth was good, and competition had begun. Thinning is needed. The average height of the test plantation was 8.38 m. The results are as in Table 7. The differences were significant. The Alishan seedlot grew well but those from Shikoku grew best.

In 1968, the second test plantation with 8 seed-

TABLE 7

RELATIVE GROWTH AT AGE 10 OF 13 SEEDLOTS OF CRYPTOMERIA PLANTED IN CHITOU IN 1967

Seedlot	Location	Height (% of mean)
1	Nor. Honshu, Ajigasawa	83
2	East Honshu, Fukushima	106
11	East Honshu, Tomioka	98
12	East Honshu, Daishi	109
8	East Honshu, Takuhagi	98
3	East Honshu, Jiyama	90
4	South Honshu, Miyama	77
9	Shikoku, None	110
10	Shikoku, Uwajima	109
7	Shikoku, Ehima	105
6	Kyushu, Fukuyama	103
5	Taiwan, Alishan	106
Actual mean		8.38 m

lots were established in the same area. With same experimental design, the test plantation was measured in 1977 at age 9. The difference was significant. The growth is better than in the 1967 trial and the average height was 9.06 m. The results are as in Table 8.

1972 Trials

In 1972, a provenance trial of 86 seedlots was established by NTU Experimental Forest. There are seven test plantations located all over Taiwan (Table 9). Each test plantation consists of 2-tree plots and 10 replications. Spacing was 2 x 3 m. Due to uneven germination, the total seedlots per test plantations vary. In 1977 at age 3, the height, diameter, branch length, and branch angle were measured. The height data are summarized in Table 10 (Chiang et al., 1979).

TABLE 8

RELATIVE GROWTH AT AGE 9 OF 8 SEEDLOTS OF CRYPTOMERIA PLANTED IN CHITOU IN 1968

Seedlot	Location	Height (% of mean)
4	East Honshu, Takahagi	98
5	East Honshu, Tomiaka	96
8	East Honshu, Daishi	97
9	East Honshu, Nikko	99
10	East Honshu, Nakatokawa	104
12	South Honshu, Shingo	102
7	Shidoku, Ehima	97
13	Kyushu, Obi	106
Actual mean		9.06 m

TABLE 9

LOCATION, SIZE, AND SURVIVAL OF 7 TEST PLANTATIONS IN CRYPTOMERIA PROVENANCE TEST IN 1972 (from Chiang et al., 1979)

Test Plantation	Location in Hsien	Elevation (m)	Seedlots	Survival (%)
Chitou	Nantou	820	86	93
Salishien	Nantou	1980	86	95
Chilanshan A	Ilan	1800	81	60
Chilanshan B	Ilan	1100	82	77
Yuli	Hualien	950	71	82
Alishan	Chiayi	2160	79	95
Kuanshan	Taitung	1700	82	91

In each plantation there were significant differences among seedlots. Also, there was consistency from

TABLE 10

RELATIVE GROWTH AT AGE 3 OF 86 SEEDLOTS OF CRYPTOMERIA PLANTED IN 7 TEST PLANTATIONS IN 1972 (from Chiang et al., 1979)

Seedsource in Region	Chi tou	Sali shien	Chilanshan A	Chilanshan B	Yuli	Ali shan	Kuan shan	Mean
Toho, Honshu	85	93	89	91	83	87	88	88
Chubu, Honshu	97	96	95	95	92	92	91	94
Kanto, Honshu	99	104	102	103	102	102	110	103
Chyukoku, Honshu	105	103	102	102	113	112	99	105
Shikoku	111	103	114	107	113	102	109	108
Kyushu	102	100	97	102	96	101	102	100
Actual mean	1.99	1.28	0.80	1.62	1.26	1.02	0.81	--
F value**	3.0	3.3	3.9	3.5	4.5	3.5	2.7	--

**All F values are significant at 1% level.

plantation to plantation. As each of the seven test plantations, seedlots from Shikoku and southern Honshu grew fastest and those from northern Honshu grew slowest. One seedlot, No. 49 from Kyushu, grew 17 to 32% faster than average in each of the seven test plantations, averaging 22% faster than average at all places.

In this test, except for 9 seedlots, most are from manmade stands. So the results are not good to study geographic variations. But it gives help for Taiwan cryptomeria reforestation program, because we learned where is the right site for the right seed source.

The results of these 4 tests, some general conclusions, can be summarized as follows:

(a) Northern Honshu seed sources are slow growing.

(b) Seed sources from Kyushu and Shikoku are better than average.

(c) Variation among seedlots and among test plantations is large.

Other Genetic Studies in Taiwan

Other studies in Taiwan can be mentioned as follows. Kung (1970b) studied the flowering induction in conifers by hormones. He applied gibberellin to 8 conifers including cryptomeria. It was effective on producing flowers on 2-year-old cryptomeria seedlings, but not on other species.

Ku (1967) described the silviculture practice of cryptomeria in Taiwan, including its races, introduction history, proposed seed production areas, total planting areas, and some suggestions on seed procurement and its production improvement strategy. Chang (1969) compiled annotated bibliography on Taiwan cryptomeria. Yao (1977) (unpublished) finished a special problem study on the silvicultural system of cryptomeria in Taiwan.

Now, some interesting reports will be cited. These reports do give some fine ideas or insights into cryptomeria improvement. Rin (1972) and Lee (1972) reported the visit of Dr. K. Sakaguchi to Taiwan in June and July 1972. Dr. Sakaguchi made several points concerning the seed source and its adaptability: (1) The growth of individual trees differs within stands. (2) Poor stem form is either genetic reason or due to weed control. (3) Light or dark heartwood color is genetic or due to water stress in the environment. Rin (1973) also reported the visit of Dr. H. Miyajima, Professor of Kyushu University, in July and August 1973. Dr. Miyajima responded to questions with almost the same answers that Dr. Sakaguchi had given a year before. They both agreed that the provenance trial would clean the seed source complication and give the better seed source for Taiwan's planting. Wright (1970b) wrote a report on Japanese tree breeding experiments for Taiwan foresters when he visited Japan in 1969. He stressed the need for provenance trials.

In Japan, the publications on cryptomeria are numerous. Here I will cite only those relating to its genetics. Hashizume (1973) conducted an intensive study on flowering control in cryptomeria. Toda (1980) studied the karyotype of 3 cultivars in Kyushu. Some differences were found on length of certain chromosomes, but not in the arm ratio. Miyazaki and Sakai (1969) studied the application of zymography for identification of clones. They concluded the technique is useful for clone identification. Goo (1971) studied flowering of cuttings. Year-old cuttings produced more flowers than twigs on parent trees. Ohba _et al_. (1971) studied controlled pollination in greenhouse with year-old seedlings induced to flower by gibberellin. They successfully made F_1 and backcross F_2 generation within 3 years, and studied a lethal recessive gene. Ohba and Marai (1971) continue studying some recessive albino gene by controlled pollination. I found no references to provenance tests on progeny tests.

Work Plan

Follow-up of 1972 Provenance Trials

1. Maintain all seven plantations.

2. At age 10-15, thin to 1 tree per plot (to a 3 x 4 m spacing) and at age 15-20 remove the 50% slowest growing seedlots (to give 4 x 6 m spacing).

3. Measure height, diameter, height-diameter ratio, and squirrel damage per tree, flowering and fruiting at 5-year intervals.

4. Perform ANOVA for each plantation and for all plantations combined. Compute variousness among and between parental regions. Complete age-age correlations.

5. Publish after each set of measurements, making each publication 5-6 pages long.

Follow-up of 1967, 1968 Provenance Trials

1. Proceed as in "A" above.

Management of AliShan Seed Production Area

The AliShan Seed Production Area is a 30+ year-old plantation on AliShan from which seed has been collected for the last 15 years. It covers an area of 15 ha and has been thinned to 100 trees per ha, or 1,500 trees total: the trees that are 25+ m tall and 50+ cm in diameter.

This area produces 1,200 to 1,500 liters of seed per year, which is sufficient for current needs. The genetic quality of the seed is good (see Table 7), but not so good as some stands in Japan. The seed is collected by climbing.

This area will be maintained as at present.

Improving Seed for Immediate Use

Contact Japanese foresters to determine if it is possible to bring seed from stand no. 49 and the other stands producing the best offspring in the 1972 provenance trial. If it is possible, arrange for the purchase of seed from such stands. This may require 1-3 man-months of effort.

200 Parent Half-Sib Progeny Test, Start 1990

1. The AliShan seed production area produces seedlings capable of growing 6% faster than average (Table 7). Presumably, stand no. 49 and some other Japanese stands in Kyushu and Shikoka produce seedlings capable of growing 22% faster than average. Therefore, a major new improvement program should be based on those stands.

2. In 1988, remeasure 1973 NTU Experimental Forest provenance test. Determine the 15 stands giving the fastest growing progeny.

3. Go to Japan with a 4-man team, locate those 15 stands, mostly in Kyushu and Shikoku, in fall of 1988.

4. Select best (tallest) 20 parents in each stand,

label the trees, collect 50 cones per tree, and keep cones separate by tree. Return in 1989 to re-collect from each tree. As controls, collect seed from 3 average trees per stand.

5. For each stand, record numbers of trees, average height and diameter, age, site characteristics. For each selected tree, record height, diameter, crown size.

6. Store the seeds in a freezer and sow seeds in the nursery in spring of 1990.

7. In 1991, establish five test plantations, each to include 4-tree plots and eight replications. Plant experimental trees on 3 x 4 m spacing, filling every other row with non-experimental cryptomeria. That is, actual spacing at planting time will be 3 x 2 m. Remove the fuller ones as soon as they are merchantable for small poles (probably at age 10-15).

8. Manage all five plantations as potential seed orchards. To do this, remove the two poorest trees per plot at age 10-15 and thin by removing the poorest families starting at age 15. Plan on spacing of 6 x 4 m at age 20 and 6 x 8 m at age 25. Wide spacing is essential for heavy seed production.

<u>Clonal Seed Orchard and Accompanying Progeny Test to be Established in 1986</u>

1. In 1983 (age 10), re-measure 1973 NTU Experimental Forest provenance test.

2. Determine the 10 families having the best growth and the least squirrel damage. Within each family, select the five best parents. Select the same number (50) of parents from the best commercial stands in Taiwan.

3. Collect scions from the 100 selected parents and establish two clonal seed orchards, one at the AliShan and one at Kuanwu. Each orchard should contain 100 clones x 25 ramets = 2,500 ramets. Spacing should be 3 x 4 m. The space required will be 2,500 x 12 m = 30,000 m^2 = 3.0 ha per orchard.

4. At the same time, establish two half-sib progeny test plantations of the 100 selected parents, each to contain 100 families x 4-tree plots x 8 replications = 3,200 trees. At a spacing of 3 x 2 m, each plantation will occupy 3,200 x 6 = 19,200 m^2 = 1.92 ha.

5. At age 10, measure progeny test and remove from the seed orchards the 25 clones producing the slowest growing families.

6. To determine the permanent value of these seed orchards, collect the seed orchard seed in 1996 and establish small progeny test including seed orchard seed and a bulked sample of all the Japanese seed collected for the 1990 progeny test-seed orchard program.

Hybridization of Cryptomeria x Taiwania

Start to Work in 1985

To improve the squirrel damage resistance of cryptomeria, taiwania is immune from the damage in general.

1. Raise 20 cuttings collected from aged cryptomeria and plant them in Chushan in 1984. Also, select 2 taiwania aged trees in Chitou as parents.

2. Treat the cryptomeria clones with GA and expect flowering in 1985 to 1986.

3. Do controlled pollinations at Chushan with female cryptomeria x male taiwania and reciprocal. Also, make crosses within species and make unpollinated control crosses.

4. Because seed production of cryptomeria is always better at Alishan than at Chitou, repeat the experiment at Alishan.

CHAPTER 6

CHINA-FIR AND LUANTA-FIR AND THEIR IMPROVEMENT

General Description and Distribution

Cunninghamia lanceolata Hook. of Taxodiaceae is called China-fir (Taiwan) or Chinese fir (Mainland China). It was discovered by J. Cunningham in 1701 in Chowshan archipelago of Chekiang Province, Mainland China. It is distributed near the southern part of the Yangtze River, in the southwestern provinces of Kweichow, Yunnan, Szechuan, Chekiang, Fukien, and Hainan. In Taiwan, it was introduced from Fukien in early times, so commonly is called Fukien-fir.

Cunninghamia konishii Hayata of Taxodiaceae, also called luanta-fir, is native to Taiwan. It is similar to China-fir in general appearance, but different in some details. The main differences are shown in Table 11. It occurs naturally in the northern and central parts of the island at elevations of 1,300 to 2,000 m, mostly scattered in forests of Taiwan red cypress (*Chamaecyparis formosensis*). It occasionally forms pure stands. According to the UNDP/FAO project, 1969 data showed that luanta-fir is most abundant in the forest district office areas of Chutung, Tachia and Luanta.

Luanta-fir was discovered in 1907 and named in

1909. Then the argument began as to whether it should be named *C. konishii* or *C. lanceolata*. In 1912, H. G. Wells, a famous British botanist, visited Taiwan. He visited LuantaShan (the mountain of luanta-fir) where the species was discovered. After he saw the beautiful natural forests, he recommended acceptance of the name *C. konishii*.

TABLE 11

COMPARISON OF LUANTA-FIR AND CHINA-FIR

Characteristic	Luanta-fir	China-fir
Natural range	Taiwan	Mainland
Elevational range in Taiwan, m	1,300-2,000	500-1,500
Seed length, mm	3-5	4-8
Seed width, mm	2-4	3-5
Seed weight, gm/liter	214	330
Seeds per liter, no.	90,400	43,000
Leaf length, mm	8-25	24-88
Leaf width, mm	15-25	25-50
Cone size, mm	14-25x16-27	27-42x27-42
Staminate strobili per cluster, no.	14-16	16-31
Rotation, years	60	15-25
Wood specific gravity	.38-.40	.35-.36

China-fir is a very commonly planted species. It is planted all over the island in the low mountain areas from 500 to 1,500 m elevation. Thus it is planted in warm, humid regions of 17° to 22°C average temperature and 2,000-

3,500 mm annual rainfall. Each year more than 1,000 ha are planted. From 1967 to 1976, according to TFB, a total of 11,100 ha were planted (TFB, 1977).

China-fir trees are generally fast-growing. The expected rotation age is 15-25 years, but plantations are sometimes cut at age 10. The maximum size is 45 m height and 1.8 m diameter. This species generally has low wind resistance. Wind damage is common in regions subject to typhoons.

Luanta-fir is also an important species for planting in Taiwan. Before 1960, the total plantation area was less than 100 ha, but it has been increasing rapidly. From 1967 to 1976, an average of 118 ha per year were planted and the trend is still increasing. The trees are usually large, the maximum size being 50 m height and 2.5 diameter. Besides being fast-growing and pest resistant, it has high growth vigor, straight stems and beautiful crown form. It can be planted below its natural distribution, growing well as low as 700 m elevation.

The wood of China-fir is light, soft and easy to work. It has a strong, resinous odor. The specific gravity is .50 to .36. It is used for various purposes such as posts, beams, stringers, staircases, ceilings, siding, sub-floors, window sashes, doors, bridges, boat building, furniture, farm implements, coffins, boxes and crates, and slack cooperage.

The wood of luanta-fir is relatively light and low in shrinkage. It is very stiff and strong, and is of better quality than is that of China-fir. The specific gravity is .38 to .40. The uses are multiple.

China-fir is generally about 20 m tall. The trunk is straight and the bark is brownish outside, red inside. The branches are short, whorled and horizontally spreading.

China-fir cones are globose, 3-4 cm long. Seeds are three per scale, narrowly winged. Trees begin to flower at age 5. The flowers appear in April and the seeds ripen in October and November. There are about 43,000 seed (330 grams) per liter (59,000 seeds per lb.). The seed is considered of best quality when collected from trees more than 20 years old. The germination rate is usually 25-30%. Seeds require 4-5 weeks for germination. When the seed is stored at room temperature, it lasts 6 months. For planting, 1-year-old seedlings are commonly used.

Cunninghamia is one of the few conifer genera which can sprout from the base if cut. Coppice regeneration is often used after clear cutting. Propagation by cuttings is also feasible but is seldom used. The estimated mean annual increment at rotation age is 13-14 m^3 per ha per year.

Luanta-fir has reddish inner bark and brownish outer bark, fissured into scales. As in China-fir, the branches are whorled and spreading. The leaves are much shorter than those of China-fir.

Luanta-fir cones mature in November. Seed quality is best if the cones are collected from old native stands. In plantations, coning starts at age 20. The seed germination rate is 20-27%. Silvicultural practice is similar to that for China-fir.

The growth rate of China-fir on three different site classes has been summarized by Wang and Kuo (1960). Liu et al. (1976), using stem analysis, studied growth rate of luanta-fir. Results for both species are summarized in Table 12. The table shows that luanta-fir grows as well or better than China-fir. Estimated mean annual increment of luanta-fir at rotation age is 13-14 m^3 per ha per year.

Spacing requirements of luanta-fir have been studied by Hung (1977). He concluded that thinning should start by age 8 and that the first thinning should not be delayed beyond age 12 for any reason. Disease and insect damage in this species are minimal. Damping off in the nursery can be a problem, but can easily be controlled by chemicals and good nursery management. In plantations, squirrel damage is severe. According to Hwang et al. (1979), 82 and 91% of the China-fir and luanta-fir trees in a 21-year-old plantation at Liukwei were damaged. The damage does not usually cause mortality, but often permits the entry of decay organisms. For example, in NTU Experimental Forest, a China-fir plantation at Hsiengen was given a final cut. We found that only 57% of the wood was merchantable. Chemical control of squirrels is now generally used in NTU Experimental Forest. This is reported to be effective, but dead bodies are seldom recovered.

Previous Silvicultural and Genetic Work

China-fir is an important species. Considerable amount of research has been performed on it and luanta-fir. Wang and Kuo (1960) published a report on the silvics of both species. They covered many details and included a large bibliography. Liu (1968, 1971, 1973, 1974) and Liu *et al*. (1964, 1979) studied China-fir varieties, growth, and controlled pollination. They concluded that China-fir and luanta-fir should be considered varieties of a single species.

TABLE 12

GROWTH RATES OF CHINA-FIR AND LUANTA-FIR
(from Wang and Kuo, 1960; Liu *et al*., 1976)

Age	China-fir I	China-fir II	Height of on-site quality III	Luanta-fir
Years			meters	
5	7	5	4	5
10	12	10	8	13
15	16	13	10	18
20	18	14	12	20
25	21	17	13	21
30				22

Liu *et al*. also started a small provenance test, including four seedlots representing both taxa. They planted one plantation with 200-tree plots, five replications and a 1.5 x 2 m spacing. They published diameter and volume data. At age 12, after two thinnings, luanta-fir grew best.

Kung (1970a) studied pollen storage of luanta-fir. After 3 years, some pollen remained 15-26% viable.

Chiang (1975) studied controlled pollination, using four parent trees of China-fir and two of luanta-fir. The experiments were conducted at Chitou on the NTU Experimental Forest. The crosses were made in the tops of the tree crowns of trees 20-35 m tall. The seed yields and germination rates were generally high (Table 13).

Due to its wide distribution on the mainland, China-fir also is a major planting species in southern mainland China today. Yu et al. (1981) studied flower bud development in Nanpin, Fukien province. Differentiation of female flowers is about 70-80 days later than that of male flowers. Both microscpores and ovules are formed in January and February. Han et al. (1980) worked on the karyotypes of trees from Hunan and Fukien. They found varying numbers of B-chromosomes.

Chueh (1980) reported on tissue culture, finding that each of four different formulas was equally effective.

A half-sib progeny test of 35 seedlots was reported in Nanking (Anon., 1977). According to the abstract, the 7-year data showed that one seedlot was almost twice as tall as another. There were also differences in stem form, crown form and leaf color. No details of design were given in the abstract.

TABLE 13

SEED SET AND SEEDLING GROWTH OF CONTROL POLLINATED CHINA-FIR AND LUANTA-FIR (from Chiang, 1975)

Type of cross	Seeds/ cone	Germination rate	Height age 2
	no.	%	cm
Selfing			
China-fir	76	43	57
Luanta-fir	63	12	31
Open pollinated			
China-fir	93	34	56
Luanta-fir	83	26	55
Crossed			
Luanta-fir x China-fir	83	50	62
China-fir x Luanta-fir	58	1	47
China-fir x China-fir	81	56	51

Productivity in relation to site and stand density were the topics of papers by Chang et al. (1980), Anon. (1981), Sheng (1980), and Lun et al. (1980).

Hwang (1978) reported 18-month data for a luanta-fir provenance test including seedlings from six stands grown at three elevations in Taiwan. Both seed source and elevation had significant effects on growth rate.

Hwang and Yang (1978) selected phenotypically taller and average luanta-fir seedlings in a nursery and planted them. They measured them five years later. The "plus" seedlings, which started out as 50% taller than the average ones, were 13% taller than average after 5 years.

Work Plan for Further Genetic Improvement

China-fir Half-sib Progeny Test, Started in 1985 with 200 Parents

This trial is needed because each year, NTU Experimental Forest supplies a large amount of China-fir seed from Hoshe Tract to neighboring forest institutions including the Luanta and Nannon District Offices of TFB. The Hoshe plantations are believed to give superior seed and the seed supply is scarce. Few seeds are produced on commercial plantations, probably because they are too crowded. We do not know where seeds are better than those from Hoshe. This test will serve a dual purpose: (1) to find out where the seeds are better, and (2) to establish a seed supply system and offer better seed for commercial planting. Details of the proposed study are as follows.

1. This trial will include seed from Mainland China and from stands in Taiwan. It will include seed from five parents from each of 40 stands, all seed to be kept separate by parent. The trial will include four test plantations, with 4-tree plots and ten replications per plantation.

2. Ask Dr. C. W. Wang of the University of Idaho and Dr. J. W. Wright of Michigan State University for help

in obtaining seeds from four to six stands of China-fir in Mainland China. From each stand, 500 viable seeds are desired.

3. Contact hsien governments of Yilan, Nantou, Taichung, Chiayi, Maioli, Hsinchu and Tainan. Ask for information about China-fir plantations, including area, location, age, growth rate, condition.

4. Contact TFB forestry offices of Wenshan, Chutung, Tachia, Puli, Luanta, Yushan, Nannon, Kwanshan, Yuli, Mukua, Lanyuan, Tahsueshan. Ask for the same information as obtained from the hsien governments.

5. In 1983-84, select 40 plantations having the best growth for their ages and site conditions. Include the Hoshe plantation and plantations on NCHU Experimental Forest.

6. Select four better than average and one poor-formed tree in each stand and collect 50-100 cones from each parent.

7. In 1985, start the nursery test in the Hoshe Nursery of NTU Experimental Forest. Grow 100 seedlings for field planting. Replicate the experiment four times in the nursery and measure the seedlings at the end of the year in the nursery.

8. In spring 1986, establish four test plantations in Hsinchu, Nantou, Tainan, and Taichung Hsiens. Each plantation will contain as many as possible of the 200 families, will have 10 replications and 4 trees per

plot. Spacing will be 2 x 3 m. There will be 1,670 trees per ha. Each plantation will occupy 4.8 ha. Additionally, three border rows will surround each plantation.

9. Be good on weed control in test plantations, weeding 3-4 times per year for the first 3 years and 1-2 times per year for the next 2 years.

10. Check survival after one month and measure at 4-year intervals.

11. Do selective thinnings at ages 8, 12, and 16. After age 16, leave the best 20 trees (600 total) in each of the best 30 (=15%) families in each seed orchard. The intermediate age 8 and age 12 thinnings will be lighter, removing about half the trees at each time. The age 16 thinning will have about 120 trees per ha, at an average spacing of 9 x 9 m.

12. The seed orchards should begin to produce improved seed about 1996. By the age-16 thinning, each of the 600 trees per seed orchard should produce about 0.5 liters per year, or about 300 liters per year per seed orchard.

13. If the experiment shows that certain Taiwan stands produce superior seed, those stands can be thinned and managed to produce additional seed.

<u>Establishment of Luanta-fir Seed Production Areas</u>

Natural stands of luanta-fir are expensive and difficult to collect seed from. Therefore, special seed production areas are needed even though the seed might not be improved genetically. Details are as follows:

1. Select five conveniently located plantations at 1,000-1,800 m elevation and 20+ years of age.

2. In each plantation, thin 3 ha to leave about 100 trees per ha. That has been shown to be a good spacing for maximum seed production per ha in red pine and a number of other American pine species. Thinning to leave 800 trees per ha would increase growth per tree but would probably not be effective in promoting heavy seed production.

Establishment of Luanta-fir Germplasm Bank

Hinkle and others working for the UNDP/FAO Project listed 95 compartments located in 12 working circles in which there were native stands of luanta-fir in 1970. Many of those stands may be cut and their germplasm lost. To prevent such loss, a germplasm bank is proposed. Detailed procedures are as follows:

1. In 1984-85, collect scions and/or seeds from each of five trees in each of two stands in each of the 12 working circles.

2. If enough seeds are collected, establish a combined progeny-provenance test. This should contain the offspring of 5 parents per stand x stands x 5 replications x 10-tree plots x 3 plantations = 750 seedlings per stand. The plantations would contain 18,000 trees if all

24 stands were represented and would occupy 18,000 x 6 = 108,000 m^2 = 10.8 ha at a spacing of 3 x 2 m.

3. If there is no seed, collect scions and establish a clone bank. Use a design similar to that described in step 2 above, except that 2-tree plots would be used, necessitating only 20% of the space required for the seedling experiment.

4. Because germplasm conservation is the goal, manage the above plantations as arboreta. Be good in weed control, keep good spacing for good growth and a moderate amount of fruiting. When thinning, maintain the maximum diversity of parents and parental stands. Do not attempt to convert into a seed orchard for maximum seed production. However, use as a breeding arboretum should be encouraged.

5. If it is possible to collect sufficient seed from a sufficient number of trees, establish an additional combined provenance-progeny test similar to that described in step 2 above. Manage in the same manner as outlined for the China-fir provenance-progeny test, for maximum seed production per ha.

CHAPTER 7

TAIWANIA AND ITS IMPROVEMENT

General Description

Taiwania cryptomerioides Hayata of the Taxodiaceae has the common names of taiwania and Taiwan-fir. It is a Tertiary relic species in Taiwan. It is an interesting species, not only for its rarity and geobotanical aspects, but also for its valuable wood.

Taiwania is a native conifer, growing in the central mountain ranges at 1,800 to 2,600 m elevation, in humid valleys with adequate rainfall and deep, fertile soils. It is usually scattered through the forests of Taiwan red cypress or other conifers and hardwoods. Pure stands are rare. It was first discovered in 1904 in Wu-shoonkeng of Nantou Hsien, a part of the NTU Experimental Forest. Until 1916, Taiwania was also found in the south-western part of Mainland China, about 2,500 km away in Yunnan. Later, it was reported and found in Hupeh, Hunan, and Szechuan (Li and Keng, 1954; Wang, 1961).

Taiwania was planted little in the past. But in recent years, it has become one of the most promising species for planting. From 1960 to 1970, TFB planted about 165 ha, or 330,000 taiwania seedlings. From 1970 to 1980, 1,100 ha of pure or mixed taiwania plantations were established. In NTU Experimental Forest, there were 148 ha of plantations prior to 1970 and 222 ha after that. Taiwania is considered a potentially valuable species because it grows as rapidly as other commonly planted species and is free of squirrel damage.

The wood of taiwania is moderately light, soft, with a specific gravity of .37 - .40. However, it is stiff and strong in bending. The wood is also very resistant to termites and marine borers. It is easy to work with tools and machines and is very stable when seasoned. It is used for general construction, furniture, boat building, wharf pilings, coffins, veneers and plywoods.

Characteristics and Silvicultural Aspects

As mentioned before, taiwania is a native of Mainland China as well as Taiwan. The Mainland China form was named *T. floussiana* Gaussen in 1939.

Taiwania is a large tree, 60 m tall, 2-3 m in diameter. The trunk is straight, of pyramidal shape with pendulous branches when young. The crown of old trees is dome-shaped with few branches. The leaves are dimorphic, linear, sharply pointed on young trees, and scale-like on old trees. The staminate strobili are 5-7 per cluster, densely arranged at the tips of branchlets. Mature cones are small, globose, 12-20 scales per cone, and two seeds per scale. The seeds mature in November. There are about 142,000 seeds or 96 g of seed per liter (671,000 seeds per lb.). Generally, the germination rate is about 17%.

The age of first flowering is not exactly known. A single tree planted in the open in Liukwei at 1,098 m elevation produced seed at age 26, but nearby 40-year-old plantations produced no seeds. At Chitou, I harvested some seeds from widely spaced trees 32-46 years old. Possibly, on favorable sites, widely spaced trees might start to flower at age 20-25. Seed production varies from year to year, generally being on a 3-year cycle.

Vegetative production by cuttings or grafting is possible. Cuttings made from 2-4-year-old seedlings root easily and can be propagated en masse. Grafting is easily done. However, grafted trees do not fruit well. No female flowers were found on trees grafted 10 years previously.

In the nursery stage, taiwanias grow much more slowly than cryptomeria, planting stock is usually 2 years old. Among the factors affecting growth in the nursery is seedling density. Yao (1970) studied this, with results as shown in Table 14. The greater the space per tree, even up to 20 x 20 cm spacings, the greater the seedling growth. With increased space, the top/root ratio increased slightly.

The elevation at which seedlings are grown also affects their growth (Table 15). Top growth is greatest at low elevations in warm areas. The top/root ratio is also highest in low elevation nurseries. As a high top/

TABLE 14

SIZE OF TAIWANIA 1 + 1 SEEDLINGS IN RELATION TO SEEDBED DENSITY (from Yao, 1970)

Space per seedling	Seedling weight	Top/root weight ratio
cm^2	g	no.
100	3.3	1.70
110	3.6	1.71
123	3.9	1.80
139	3.9	1.74
156	4.0	1.91
178	4.0	1.93
204	4.4	1.89
238	5.0	1.92
278	4.8	1.81
333	6.4	1.92
400	6.8	2.12

TABLE 15

SIZE OF TAIWANIA 1 + 0 SEEDLINGS IN RELATION TO ELEVATION (from Tai and Liu, 1970)

Elevation of Nursery	Weight of		Top/root weight ratio
	Top	Root	
m	g		no.
150	11.6	1.9	6.0
650	5.7	7.8	2.8
1,050	5.2	7.5	2.5

root ratio is not desired for subsequent growth, seedlings should be grown at elevations of at least 650 m.

Fertilization affects the nursery growth of seedlings but not the top/root ratio (Wang and Huang, 1971). Light intensity is also important. The higher the intensity, the better the growth. Therefore, according to Lin (1974) and Lin and Chang (1975), taiwania is classified as an intolerant species.

Survival in taiwania plantations is generally low, often less than 50%. The main reasons for the mortality are the scanty root systems and transplanting shock. Researchers have sought improvement by the use of containerized stock and by heavy branch pruning before outplanting (Liu and Ho, 1973; Ho, 1976). Pruning is generally helpful for survival.

The first recorded taiwania plantation was established at Chitou, starting in 1909. Of that plantation, 30 trees remain. Of a plantation established at Toulin on Alishan, 23 trees remain. In 1980, I measured the 30 old trees at Chitou. They ranged from 42 to 71 years old (average 50 years) and averaged 29.7 m tall by 77 cm diameter. The tallest was 35 m tall.

At Chitou, until age 15, taiwania grows slower than cryptomeria or China-fir. After that, however, the growth rate increases, and by age 30, taiwania can grow faster than the other two commonly planted conifers. Growth rates in a Chitou plantation are summarized in Table 16 (from Hung, 1974).

In plantations, growth is affected by stand density. I studied the spacing at Chitou since 1966. At the age of 15, results varied greatly with spacing (Table 17). Spacing affected most aspects of growth--diameter, crown

TABLE 16

GROWTH IN AN EVEN-AGED TAIWANIA PLANTATION AT CHITOU (from Hung, 1974)

Age	Height	Diameter breast high
years	m	cm
5	3.5	2.6
10	9.3	10.5
15	14.5	16.4
20	19.0	22.2
25	23.3	26.2
30	25.5	29.4

TABLE 17

RELATION BETWEEN SPACING AND GROWTH IN A 15-YEAR-OLD TAIWANIA PLANTATION (Yao, unpublished)

Space per tree	Diameter breast high	Height	Dead	Crown area	Height diameter ratio
m^2	cm	m	%	m^2	no.
1.8	12	12.7	20	1.9	120
2.2	12	14.8	22	3.5	119
3.1	14	14.7	5	3.7	104
3.7	14	14.4	1	4.2	101
4.2	16	14.5	3	6.1	93
6.3	18	15.4	1	6.9	84
6.8	18	15.2	1	10.7	86
7.8	18	14.5	0	8.5	79
8.0	19	15.7	0	9.6	85
11.1	19	15.3	0	11.4	79

size, form ratio, and mortality. With more than 6 m^2 per tree, increased space had relatively little effect. Therefore, at age 15, a space of 2 x 3 m can be considered as desirable, giving rapid growth per tree and a large number of trees per ha.

Some people do not accept _T. floussiana_ and consider the genus _Taiwania_ to contain only a single species, that is to be monotypic. Most monotypic genera are pest-free. Taiwania is no exception and is one of the most pest-resistant conifers in Taiwan. Few serious damages have been reported. In nurseries, damping off can be a problem, but it is easily controlled by good nursery management. In plantations, some minor insect damage was found in Chitou. It was caused by yellow-spot bat moth (_Phassua signifer_ Walker). The moths attacked young (age 3) trees by girdling and caused mortality (Wang, 1968). Squirrel damage is generally slight. I checked mixed cryptomeria-taiwania plantations at Chitou for squirrel damage. The results were that 42% of the cryptomeria and 0% of the taiwania trees were injured.

Past Work Related to Genetics

NTU Provenance and Progeny Trials, Sowed 1972

In 1971, TFRI collected seeds from 12 natural stands, the seeds from each stand being bulked. At the same time, seeds were collected from 26 single trees located in four different hsiens. The seeds were sown at NTU Experimental Forest Nursery in 1972 and test plantations were established in 1973. There were two separate experiments, one being the provenance test involving the stand collections and the other being the half-sib progeny test involving the individual-tree collections. Test plantations for each experiment were established at Chitou and Sanpin in 1973. Each of the four test plantations follows a randomized complete block design with 4-tree plots, 10 replications and a 2 x 2.5 m spacing. The trees were measured periodically, the last time at age 7 in 1979. Those measurements are summarized in Tables 18 and 19.

In all plantations there was a strong correlation between height and diameter, the seedlots which were tallest also being the largest in diameter. Hence, Tables 18 and 19 contain only height data. For the provenance tests, both height and diameter differences were highly significant statistically at both Chitou and Sanpin, but not for the two plantations combined. For the progeny test, there were highly significant differences among stands of origin and among families within stands for the Chitou plantation, but only among families for the Sanpin plantation. A combined ANOVA of the two progeny test plantations showed significant differences among families but not among stands of origin. The preliminary information from these tests can be summarized by saying that there are differences among individual trees but not among stands. For practical reforestation work, seeds may be collected from stand. However, improvement can be obtained by selecting individual trees.

TABLE 18

HEIGHT AT AGE 7 OF TAIWANIA SEEDLINGS GROWN FROM SEED COLLECTED FROM 12 NATURAL STANDS

Location of parental stand, locality and hsien	Relative height at age 7 at Chitou (% of mean)	Sanpin
Kwanwu, Hsienshu No. 1	95	98
Kwanwu, Hsienshu No. 2	101	93
Tabachienshan, Hsienchu No. 1	98	106
Tabachienshan, Hsienchu No. 2	97	95
Tahsueshan, Taichung No. 1	99	95
Tahsueshan, Taichung No. 2	97	90
Tahsueshan, Taichung No. 3	97	112
Tahsueshan, Taichung No. 4	105	95
Tachia, Taichung	105	107
Chitou, Nantou	110	121
Tanta, Nantou	88	95
Kwanshan, Taitung	107	100
Actual mean height, m	7.3	4.4
Actual mean diameter, cm	10	6

A Plan for Saving the Species

Wright et al. (1973) discussed the problem of saving this possibly endangered species and providing for its genetic improvement at the same time. Preservation of stands, not individuals, should be the goal. Also, planting large areas at wide spacings would help. For saving the space, interplanting of another species is an idea.

Flowering and Phenology Studies

Taiwania flowering phenology, physiology and pollen storage has been intensively studied at NTU Experimental Forest (Kung, 1965; Kung and Kiang, 1969; Wang, Kung

TABLE 19

HEIGHT AT AGE 7 OF TAIWANIA SEEDLINGS GROWN FROM SEED COLLECTED FROM 26 INDIVIDUAL TREES

No. and location of parent		Relative height at age 7 at Chitou	Sanpin
		(% of mean)	
122	Kwanwu, Hsienchu	88	--
130	Kwanwu, Hsienchu	99	--
131	Kwanwu, Hsienchu	86	--
141	Tabachienshan, Hsienchu	96	102
142	Tabachienshan, Hsienchu	97	98
143	Tabachienshan, Hsienchu	94	90
144	Tabachienshan, Hsienchu	98	106
145	Tabachienshan, Hsienchu	--	95
146	Tabachienshan, Hsienchu	105	100
147	Tabachienshan, Hsienchu	104	100
148	Tabachienshan, Hsienchu	96	102
149	Tabachienshan, Hsienchu	92	99
103	Tahsueshan, Taichung	--	90
106	Tahsueshan, Taichung	--	95
107	Tahsueshan, Taichung	98	92
108	Tahsueshan, Taichung	90	90
110	Tahsueshan, Taichung	109	107
111	Tahsueshan, Taichung	107	108
112	Tahsueshan, Taichung	102	103
151	Chitou, Nantou	111	108
152	Chitou, Nantou	105	113
154	Chitou, Nantou	99	105
155	Chitou, Nantou	102	83
156	Chitou, Nantou	109	107
157	Chitou, Nantou	110	112
158	Chitou, Nantou	106	95
Actual mean height, m		7.7	4.6
Actual mean diameter, cm		11	6

and Kung, 1969; Kung, Kiang and Kung, 1969). Female strobili are generally found in the top crown of the trees and male strobili lower. Seldom do they occur on the same branches. In Chitou, pollen sheds in February and March, while female strobili mature in March, remaining open for pollination for 5-7 days.

Grafting to induce flowering and to conserve germplasm has been tried at NTU Experimental Forest since 1965 (Kung and Kung, 1966; Kung, 1974b; Kung, 1973). Male flowering occurred many years ago but nothing happened on female. Gibberellins were tried on the grafted trees, but without results. Some grafts died out gradually.

The Other Studies

Kuo et al. (1972) made a karyotype analysis from a single tree in Yilan. So far, no aneuploidy or polyploidy has been found. Chiang (1974) studied the germinating seed physiogenetic characteristics and related to its seedsources by means of manometric technique; differences were found only among individuals. Kung (1974a) reported one-year-old results on 6-seedlot provenance test; seed from Tahsueshan was best in growth. Lu (1973, 1975) reported 5-seedlot provenance results in seed characteristics and 2-year-old seedling height; seed from Tahsueshan was poorest in growth.

Hwang and Yang (1978) reported 5-year-old results on plus-seedling selections on one-year-old seedlings. The plus seedlings decreased the superiority from 150 to 107%, while the check group increased from 50 to 95%. The average height at age 1 and 5 were 30 and 253 cm, respectively. Survivals were 80% on average, not significant between groups.

Wang *et al*. (1976) and Wang (1976) reported that no differences were found among seedsources in their isozyme study and neither in nutrient absorption in 2-year-old seedlings, respectively.

Work Plan

A. 400 Half-sib Progeny Test

In the current situation, about 1,500 ha would be planted annually, but one limiting factor is how much seed would be available in that year. Generally about 1,200 liters of seed are needed for a single year's demand.

TFB recently paid much attention to this species. They not only have selected 1,137 parent trees in natural stands within eight regions for seed production, but also established cutting and grafting clone bank at three areas totally 15 ha in size.

In NTU Experimental Forest, they have long been involved in *Taiwania* research, not only in tree improvement but also in growth studies as well. The results certainly are helpful for further improvement.

For *Taiwania* testing, in order to increase the improvement potential, the Mainland China seed source should be included. It serves the purpose of preserving the species for both Taiwan and Mainland China.

1. Ask Dr. C. W. Wang of the University of Idaho and Dr. J. W. Wright of Michigan State University to help

obtain 4 to 6 seedlots of seed from Mainland China in 1983. Each seedlot shall contain 500 viable seeds.

2. Ask for 400 seedlots from TFB selected parents in the eight regions. Each shall contain 200 cones per parent.

3. Based on the results of NTU Experimental Forest trial, collect the seed from superior parents such as Nos. 151, 157, 156 in Chitou; 110 and 111 in Tahsueshan.

4. Start nursery test in Chitou in 1986. Each seedlot must have at least 60 x 1.2 = 72 seedlings for planting and extra 2,400 for arboretum establishment. The young seedlings will be containerized in the second year and then outplanted in spring of 1988.

5. Establish test plantations in three places including Tahsueshan, Moukuashan and Chitou. The Chitou one will be treated as an arboretum. The other two will be converted to seed orchards after several selective thinnings. The test plantations will be 6 trees per plot, 5 replications with 2.02 x 2.02 m spacing. There will be 400 x 6 x 5 = 12,000 trees in each test plantation. Thus, each plantation will occupy 12,000 x 2.02 x 2.02 = 48,600 m^2 = 4.86 ha. For Chitou plantation, there will be 200 x 4 x 3 = 2,400 trees which will occupy 2,400 x 4 x 4 = 38,400 m^2 = 3.84 ha. If more seedlots are available, the extra ones could be included in the Chitou test plantation.

6. Thinnings will take place at ages 12, 16 and 20. (a) Thin first at year 1988 + 12 = 2000 A.D. Remove

25% (=600) families, and 33.33% within family. Thus, there will be 12,000 trees remaining. (b) Thin next at year 1988 + 16 = 2004 A.D. Remove 50% (=150) families, leaving 150 families. In each remaining family, leave half (=20) best trees. Thus, there will be 3,000 trees remaining. (c) Thin third at year 1988 + 20 = 2008 A.D. Remove 70 of the 150 families, leaving 80 families. Leave 15 best trees (of an original 60) per family. Thus, the seed orchard will contain 80 x 15 = 1,200 trees.

7. For Chitou test plantation, thinning is scheduled at age 15, 25. Remove 20% of trees regardless of family.

8. The seed orchard presumably can produce improved seeds in year 2008 A.D. The total among them will be 1,200 trees x 1 liter per tree = 1,200 liters per year.

For summarizing, we are doing combined family and within-family selection, removing 80% of the families and 75% of the trees within family; we will leave 20% of the families and 25% of the trees within family. Thus, we must start with 1,200 x 1/.20 x 1/.25 = 24,000 trees. The number of families and trees per family can be as follows:

Families	Trees per family
100	240
200	120
300	80
400	60

The final spacing should be 9 x 9 m, so the plantations will occupy 1,200 x 9 x 9 = 97,200 m^2 = 9.72 ha. Because only 1 of 20 trees will remain after the final thinning, the intial space per tree should be 81/20 = 4.05 m^2 = 2.02 x 2.02 m per tree. If 400 - family progeny test is taken, the details of the thinnings are as follows:

Age	Year	Families	Tree/family	Total trees	m^2 Area/tree
0	1988	400	60	24,000	4.05
12	2000	300	40	12,000	8.10
16	2004	150	20	3,000	27
20	2008	80	15	1,200	81

B. Improvements in Regeneration by Cuttings

One difficulty encountered in the improvement of *Taiwania* is the delay in flowering and fruiting until the trees are more than 20 years of age. There is a method which could be used to mass produce genetically improved cuttings without waiting for seed. Details of this method follow.

1. Collect seeds from those parents (Nos. 151, 157 and 156 at Chitou and Nos. 110 and 111 at Tahsueshan) which produced the best offspring in the NTU Experimental Forest 1972 trials.

2. Raise the seedlings in a greenhouse, raising 5,000 at a time if there is enough room.

3. When the seedlings are a year old, cut them back and make cuttings. There can be two cuttings per tree the first year and three or four cuttings per tree the second year.

4. Root the cuttings in the proper medium and

transfer them to containers.

5. It should be possible to produce 5,000 x 2 = 10,000 rooted cuttings the first year and 15,000-20,000 per year the second year.

C. Follow-up 1972 NTU Experimental Forest Trial

1. Measure them periodically.

2. The initial spacing was 2 x 2.5 m (2,000 trees per ha). Now thinning is urgent for both test plantations in Chitou.

3. Measure and do first thinning in 1983 at age 12. Remove every other row of the plantations (50% thinning). Thin across plots to leave 2 trees per plot. The density will be 1,000 trees per ha.

4. Measure and do second silvicultural thinning in 1987 at age 16. Another 50% thinning, same as in first thinning. Now only one tree remains per plot. There are 500 trees per ha.

5. Convert the test plantations to commercial plantations and manage them as commercial plantations. Or give wider spacing in the third thinning for seed production, but the seed quality is just as commercial seeds.

CHAPTER 8

TAIWAN RED AND YELLOW CYPRESSES

General Description and Characteristics

Taiwan red cypress (*Chamaecyparis formosensis* Mats.) and Taiwan yellow cypress (*C. obtusa* var. *formosana* Rehd. = *C. taiwanensis* Mas. *et* Suzuki) are both valuable conifers in Taiwan. They are native, happening only in the central mountain ranges of Taiwan at elevations of 1,000 to 2,800 m. Generally they are mixed with other conifers or hardwoods. Few are found in pure stands.

Taiwan yellow cypress differs from Taiwan red cypress taxonomically. In reforestation programs, they are seldom treated separately. The plantations are all called Taiwan red cypress plantations. Taiwan red cypresses are long-lived trees, often hundreds or thousands of years old. A giant red cypress tree in Chitou is estimated as 2,800 years old.

The growth of red cypress is moderate to slow but the wood is super. TFB plants about 340 ha per year. Up to 1975, 8,800 ha had been planted. In recent years, more have been planted. For instance, in the single year 1975, 1,795 ha were planted. So today red cypress is as important as any other species for planting in Taiwan (Chu, 1975).

The wood of Taiwan red cypress is light and moderately soft but very stiff and strong in bending. The specific gravity is .33 to .35. The wood has a characteristic odor. It is exceedingly durable against decay and termites. The wood is also straight and even-grained with an attractive figure. It is used mainly for general construction, furniture, woodenware and carving. Japanese and Chinese are typically fond of red cypress furniture and buildings. The huge logs are especially valuable when they are used for temples and shrines.

Depending on the taxonomic status of Taiwan yellow cypress, there are six or seven species of *Chamaecyparis* in the world. The others are *C. obtusa* S. and Z., and *C. pisifera* S. and Z. of Japan, and *C. lawsoniana* Parl., *C. nootkatensis* Spash, and *C. thyoides* BSP of the United States or Canada.

Silviculture

Taiwan red cypress is a tall tree, sometimes reaching 65 m height and 6.5 m diameter. The bark is more or less smooth, thin and reddish brown. The leaves are opposite and scale-like. The staminate strobili are ovoid or subglobose. The cones are suberect, 11 x 8 mm in size, with 12 scales per cone and two seeds per scale. The seeds are slightly winged.

The seed for reforestation is from natural stands. It matures in November and December. There are about

240,000 seeds (280 grams) per liter (379,000 seeds per lb.). The germination rate is generally 8-10%. It takes 3-4 weeks for germination.

There is no definite information to show when this species starts to flower. One experiment showed fruiting of 6-8-year-old trees treated with gibberellin (Chu, 1975). Propagation by cuttings is also possible with up to 84% rooting. Natural regeneration for red cypress is feasible. Some good naturally regenerated stands happen in Taipinshan of Ilan Hsien. But it is not found in other areas. The question of presence or absence of natural regeneration is important.

The growth in manmade forests varies with age, spacing and other factors. The available data are not consistent. For instance, the growth of Chitou is not merely moderate but is almost as fast as for cryptomeria. Yang and Wu (1956) compared stand growth of cryptomeria and red cypress in Chitou, with results as follows:

Age (years)	10	15	20	25	30
Height, red cypress, m	8.3	11.9	14.5	16.8	18.5
Height, cryptomeria, m	9.7	13.9	17.2	19.5	20.8

Hwang (1977) compared growth of 12 stands at different elevations and ages. The results were diverse. At 1,300 m elevation in Laonon, height at age 10 was 7.0 m. At 1,350 m elevation at Chitou, height at age 45-50 was 23 m. He concluded that Taiwan red cypress grew best at elevations of 1,000 to 2,000 m. Furthermore, the young stands grew best in the open, poorly as understories.

For many years, TFB has planted Taiwan red cypress at a very wide spacing of 4 x 6 m, leaving a space between the rows unweeded. The practice reduces damage from frost. NTU Experimental Forest has practiced planting of Taiwan red cypress at 2,000 m elevation, with severe mortality from frost damage. In recent years, the forest has adopted the TFB practice of wide planting with partial weeding to reduce frost damage.

Although squirrels attack Taiwan red cypress, damage is much lighter than on cryptomeria or China-fir (Hwang et al., 1979; Kuo, 1957). On the other hand, squirrels damaged C. obtusa from Japan severely at Chitou.

Heartwood rot caused by Stereum salcutum Brut. is often found in aged trees. The majority of trunks become hollowed when more than 100 years old. In plantations, the damage is slight because the manmade forests are still too young.

Past Work Related to Genetics

A symposium sponsored by TFB was held for discussion of Taiwan red cypress silviculture techniques in 1974. Eight papers were presented; of them, the ones on natural regeneration and interspecific variation were topics of interest to geneticists (Chu, 1975).

Liu et al. (1975) reported on the seed and characteristics of month-old seedlings of a trial including 22 seedlots from seven species.

TFB in recent years seems especially interested in this species. Since 1974, they established a clonal seed orchard. They also located and labeled 4,598 parent trees for seed production (Chu, 1975).

Work Plan for Taiwan Red Cypress Improvement

Taiwan red cypress wood is valuable, but the area of manmade plantations is much less than for cryptomeria or China-fir. The main reason for that is the generally slow growth and the expected long rotations (80 years for NTU Experimental Forest). In recent years, TFB has planted more than ever.

Taiwan red cypress has such characteristics that no other species can replace it, but the long rotations are a problem. Therefore, improvement in growth rate is urgent. The main experiment to accomplish this is a half-sib progeny test.

True Research Cost of a Large Experiment

TFB has started a mass planting program since 1975, each year more than 1,000 ha are planted. Moreover, TFB has also selected 4,597 plus trees for seed production. This indicates that TFB is interested in this species now, and obviously they are very concerned about the seed supply in quantity and quality.

On the other hand, TFB subsidizes the research institutions every year to work on certain species in which TFB is interested and the species are commonly economically important. No doubt Taiwan red and yellow cypress fit the case.

Most forestry research institutions are capable of carrying out their researches independently. But generally, they are short of land and funds, especially when a long-term project which involves large amounts of money and land is dealt with. Tree improvement works are almost all in this category.

To consider the need and demand of both sides of the institutions, the Taiwan red and yellow cypress improvement work can be carried out jointly by TFB and other research institutions, either TFRI or NTU Experimental Forest. It is possible for TFB to handle the experiment alone, but it is better to let the research institution handle part of the work. Because the quality research is always specialized, researchers are helpful to deal with specialized problems.

In doing this work, some adjustments must be added to the routine silvicultural system of TFB. Some of these adjustments mean more intensive management. Some do cost more, but the results or gains of the improved seed will pay for them. Others involve doing things differently, but may not cost more. Generally, TFB will take care of most silvicultural part of work such as seed collection, seedling raising, plantation establishment and management. Counterpart in research institutions should have a detailed work plan, work closely with the TFB in the field, and all in the test period.

In this work plan, no detail steps will be given, but the general considerations for both sides will be mentioned and especially the workload and cost for a commercial or test plantation will be discussed.

1. The need of seed supply per year in TFB. Assuming TFB will plant 2,000 ha per year, 3,000 seedlings per ha, then 2,000 x 3,000 = 6,000,000 seedlings per year. There are 4,000 seedlings generally produced by one liter of seed. So, 6,000,000 x 1/4,000 = 1,500 liters of seeds are needed per year.

2. The need of parent trees for seed production. Assuming each tree produces .5 liter seed per year, so we need 1,500 x 1/.5 = 3,000 trees to supply the seed for TFB mass planting program, which means that we must retain 3,000 superior parents in the seed orchard to supply improved seed after several selective thinnings. So these 3,000 superior parents are our goal in this half-sib progeny test.

3. To proceed from the initial to the final seed orchard, we should remove 80% of the families and 75% of the trees in each family. Thus, for every tree in the final orchard, we must plant 1/(1-.80)(1-.75) = 20 trees. That means the seed orchards should start with 3,000 x 20 = 60,000 trees. The goal of 60,000 trees could be met with one of the following combinations:

Families	Trees/family
100	600
200	300
300	200
400	150
500	120
600	100

4. The size and spacing of the test plantation and seed orchard. In the seed orchard, we prefer the final spacing of 9 x 9 m, so the size is 3,000 x (9 x 9) = 243,000 m^2, in other words it is 24,30 ha of seed orchards. And the initial spacing in test plantation is 243,000 x 1/60,000 = 4.05 m^2 per tree or 2.01 x 2.01 m.

5. Workload and cost analysis. To understand the test plantation and commercial plantings, a comparison based on the work items is made in Table 20.

It is clear that the workload of 400-family progeny test is only a small portion in the TFB routine work. Comparatively speaking, testing seed collection would be more tedious than other items. And certainly it costs much more, if even one more parent tree or more area is added. But it seems not in this case, because individual trees producing the seed are definite (must exceed 3.75 liters per tree). And it is no question that TFB would like to get the seed from their selected parents and in most of the stands. Other items, such as mapping, measuring and calculating the ANOVA, research fellows are responsible for, expenses are little, and they will be in the joint research project.

6. Use of wood from the tests.

7. Thinning schedule. Taiwan red and yellow cypress grow slower than cryptomeria or China-fir, so the intermediate thinnings would begin at age 20, then 30 and 40. The detail of the thinnings is as in Table 21.

TABLE 20

COMPARISON OF COMMERCIAL AND TEST PLANTINGS FOR TAIWAN RED AND YELLOW CYPRESS

Item	Commercial planting per year	400-family progeny test	Workload ratio (%)	Extra work or included
Seed Supply				
seed amt. (liters)	1,500	1.4	.09	included
seed treatment	bulk	separate	--	extra
seed packaging	bulk	separate	--	extra
no. of parents	3,000	400	13.33	included
Nursery Mgt.				
nursery bed area (m^2)	25,005[a]	400[b]	1.60	included
no. seedlings	6,000,000	60,000	1.00	included
growing in	mix	replicate	--	extra
seedling packaging and shipping	mix	replicate	--	extra
Plantation Mgt.				
site preparation (ha)	2,000	24.3	1.22	included
planting in	mix	replicate	--	extra
thinning (times)	2	3	--	extra
thinning (ha)	4,000	48.6	2.43	extra
thinning	simple	complicated	--	extra
mapping	yes	yes	--	extra
border row planting	no	yes	--	extra
measurement (year)	10	5	--	extra

[a] .06 liter per m^2, 16.67 m^2 per one liter seed.

[b] One family per row, 10 rows per m^2, 10 replicates.

TABLE 21

DETAIL OF IMPROVEMENT THINNINGS IN TAIWAN
RED AND YELLOW CYPRESS

Age	Year	Families	Trees/ Family	Total Trees	Space/ Tree
0	1988	400	150	60,000	5.05
20	2008	200	100	20,000	12.15
30	2018	100	50	5,000	48.60
40	2028	80	37.5	3,000	81.00

Details of a 400-family Test

In the last section, I attempted to show what parts of the cost of a progeny test should be assigned to research and to action agencies. Here I consider detailed steps of the progeny test in chronological order.

1. Start seed collection in 1983. Ask TFB to share the seed they will collect from their selected parents.

2. Ask for 100 cones (about 500 viable seeds) from each parent from their 12 natural areas. The research institution should help in the work.

3. If it is a poor year, additional seed will be collected in 1984 and 1985, and the already-collected seed will be stored in a freezer.

4. Cooperate with TFRI, and ask Mr. T. Liu or T. W. Hu for 8 to 10 seedlots of exotic cypress and join the testing.

5. Start the nursery trial in 1986 at Lanyang

District Forestry Office (Lanyang DFO) which is specialized in Taiwan red and yellow cypress breeding program, according to TFB's tree improvement plan.

6. According to the statement in the last section, if the family size is 400, then the trees within family will be 150 to meet the requirement of 80 and 75%, respectively, on selective thinnings among families and within family. In other words, for this test, we need to raise 60,000 seedlings in total.

7. To give preliminary results in the first one or two years of the test, the replicated randomized design in nursery is needed. The lay-out work is the responsibility of the researchers. And the nursery management is as routine as commercial nursery management.

8. The seedlings will be ready for outplanting in spring of 1988. The three test plantations will be in Lanyang DFO. Based on the seed orchard requirement of 9 x 9 m spacing and 3,000 superior parents, the size of the plantations, as we have mentioned, is 24.03 ha, and the initial spacing is 2.01 x 2.01 m.

9. The selective thinnings will be done at age 20 (2008 A.D.), in 30 (2018) and 40 (2028). The thinnings will follow the schedule shown in Table 21.

10. After the third cutting in 2028, it becomes a seed orchard and will produce the improved seed of 3,000 x .5 liter = 1,500 liters per year.

11. At maturity, the trees will be harvested commercially.

CHAPTER 9

TAIWAN RED PINE IMPROVEMENT PLAN

General Description and Distribution

Pinus taiwanensis Hayata, also called Taiwan red pine or Taiwan two-needled pine, is a native of Taiwan, distributed in the central mountain ranges of the island. It has a straight trunk, is adaptable to poor soils, and grows rapidly. It began to be planted in the early 1920s in Alishan. In the 1950s, it was planted at the rate of 400 ha per year. Since then it has been widely planted. In 1971, it reached the peak of 4,800 ha per year. But in recent years, due to seedsource and silviculture difficulties, the planting rate dropped to about 500 ha per year. It still plays an important role in TFB's reforestation from 650 m at Julianchi to 3,000 m in Pashienshan. Pure, large, natural stands can be found. It is most abundant along the Tachia River Valley in Taichung Hsien between the elevations of 800 and 1,800 m. Today, stands under 1,000 m are rare. Its geographic distribution is limited to a 1° strip along 121° E between $22^{\circ}30'$ and $24^{\circ}30'$N.

The wood is yellowish white in color and moderately heavy. The specific gravity is between .47 and .51. It has high nail-holding ability and is easy to dry. It is used for construction and building, bridges, railroad ties and poles. Also, it is the raw material of pulp.

Taiwan red pine is a large tree growing up to 35 m in height and 80 cm in diameter. Its bark is fissured into small scales. Cones are oblong to ovoid, 6 x 4 cm in size, about 100 scales per cone. Seeds are winged, 5 x 2 mm in size. There are about 37,000 seeds (500 gms) per liter (34,000 seeds per lb.).

Flowering starts at age 3. Flowering times vary with elevation, the flowers appearing from February to April. Individual male catkins shed pollen for 3-5 days and female flowers are receptive for 7-10 days (Wang, 1971; Wang and Lin, 1974).

Variations in growth rate with site quality and elevation are given in Table 22, taken from publications by Hwang (1969, 1970).

Taiwan red pine is one of three hard pines planted in Taiwan, the other two being luchu pine from Okinawa and masso pine from Mainland China. Some of the most important characters differentiating the three are shown in Table 23.

Special Silvicultural Problems

As mentioned before, in recent years, TFB has had some bad experiences in planting Taiwan red pine. Many hectares of plantations have crooked stems, stagnant growth and shrubby form after 10 years growth. However, near

TABLE 22

HEIGHT GROWTH OF NATURAL TAIWAN RED PINE IN DIFFERENT SITES AND ELEVATIONS (from Hwang, 1979; Hwang, 1969)

	Natural Stand				
	Height on site class		Height at elevation		
Age	I	II	1000	1500	2000
(yrs.)	m	m	m	m	m
10	12.6	10.5	7.5	7.6	5.8
15	16.1	13.5	11.7	12.0	8.8
20	19.2	16.2	15.1	16.1	11.8
25	22.2	18.9	17.9	19.8	14.5
30	24.7	21.4	20.2	22.1	16.6
35	--	--	22.0	23.6	18.3

TABLE 23

IMPORTANT DIFFERENCES AMONG TAIWAN RED, LUCHU AND MASSO PINES

Item	Taiwan red pine (*P. taiwanensis*)	luchu pine (*P. luchensis*)	Masso pine (*P. massoniana*)
Elevation range in Taiwan	800-2800 m in cent. mtn. range forming pure forest	Below 1000 m in northern and central Taiwan	500-1300 m in northern and coastal hills
Growth rate	fast	fast	slow
Trunk form	straight	crooked	crooked
Bark color	grey-brown	dark brown	reddish to greyish brown
Needle length	8-11 cm	12-18 cm	12-20 cm

such plantations may be others consisting of tall, vigorous trees.

Wang *et al*. (1980) investigated more than four thousand ha of 10-year-old young red pine plantations in Ilan, Chutung, Tachia and Luanta. They tried to find out the causes of its failures in reforestation. They measured the diameters, took soil samples, collected local climatic data and other site factor information. In the meantime, they inquired the questions concerning the background of the seedlings, including where the seed comes from, nursery practices and methods, planting and management, etc. Their data indicate that roots competition to unfavorable sites, seed sources, and planting of more than one seedling in a hole were major factors responsible for poor growth. Lanner and Hinkle (1970) reported on one specific cause of stem defects. Disease problems are generally minor; the most serious disease is a needle cast caused by *Lophodermium pinastri*.

Previous Work on Genetics

Kuo *et al*. (1972) made karyotype analyses of these three species. They reported no differences in karyotypes.

Hu and Yang (1972) took increment cores and studied wood specific gravity and fiber length of trees in light stands near the Tachia Valley. The stands ranged in elevation from 700 to 2,700 m elevation. Some were the same as sampled in 1971. Specific gravity and fiber length varied considerably, individual tree values ranging from .39 to .56, and 2.78 to 4.41 mm, respectively. Stand means varied from .44 to .54, and 3.17 to 4.01, respectively. Specific gravity decreased with increasing elevation, but fiber length did not vary with elevation.

A combination progeny-provenance test was started in 1972 by NTU Experimental Forest, using seed from different trees than those mentioned in the two previously mentioned experiments. The 1972 test includes the offspring of 24 trees growing in 8 different stands, ranging in elevation from 900 to 2,450 m. The test was planted in three separate areas.

This 1972 experiment was measured by Li (1976), Wang et al. (1972), and Chiang (1977). At the low and medium elevation test plantations, there were strong correlations (r=.93 and .95, respectively) between 16 months and 5 years height, and there were significant differences among the offspring of different stands, low elevation seedlings growing the fastest (Table 24). In the high-elevation plantation, with its high mortality, the differences among stand-provenance were not significant.

In the fall of 1971, B. Y. Yang and others from TFRI collected cones from 200 native trees growing in 15 localities of Taiwan. Wang and Lin (1974) and Yang and I (unpublished) measured the cone and seed characteristics of these 200 trees, with results as shown in Table 25. Seed and cone size differences were statistically significant among trees within locality and among localities, but did not vary consistently with elevation. Cone and seed shapes (length/width ratio) were relatively constant but cone-scale shape was variable. The longest cones had the longest but not the widest scales. There was a negative correlation (r=.59) between elevation and seed weight, low elevation trees producing the heaviest seeds.

TABLE 24

RELATIVE HEIGHT OF OFFSPRING OF EIGHT STANDS PLANTED IN 1972 (from Chiang, 1977)

Place of Origin Locality	Elev.	Percent of mean, age 5 at:		
		Wulai	Chitou	Trefong
Tahsueshan	900	118	120	116
Tachia	930	122	142	90
Puli	1180	126	134	91
Yuli	1200	111	98	108
Chutung	2000	94	90	--
Luanta	2250	82	75	110
Lanyang	2250	83	82	94
Mukua	2300	80	59	96
Actual mean, cm.		140	440	140
Survival, %		48	58	23

The seeds collected by Yang and others from TFRI in 1971 were used to establish another progeny-provenance test. The seeds from 200 parent trees located in 24 stands were sown in 1972 and three test plantations were established in 1973. In 1977-78, Yang and I analyzed the nursery and 5-year data. The results are shown in Table 26.

The two Zuyunshan plantations are located close to each other but were planted one year apart. In both,

TABLE 25

THE RELATIVE VALUES OF SEED AND CONE CHARACTERISTICS OF 200-SEEDLOT, 18-REGION STUDY IN TAIWAN RED PINE

Region	Elev.	Seed*			Seed & Wing*		Cone*		Cone-Scale*	
		Len.	Wid.	Wt.	Len.	Wid.	Len.	Wid.	Len.	Wid.
SH	700	102	102	99	92	80	91	83	83	99
MY	919	101	103	122	105	83	95	92	113	97
KK	981	96	105	123	105	93	101	94	94	115
KT	1125	108	97	115	98	78	94	89	106	107
CS	1230	108	104	111	103	88	100	85	96	107
WT	1263	100	100	116	98	82	102	95	105	112
SK	1621	101	98	86	102	82	101	103	104	111
CY	1643	100	97	101	107	82	107	99	109	116
SM	1745	98	90	84	101	82	98	92	98	108
WS	1803	101	101	100	92	84	97	90	93	108
KW	2050	103	111	94	111	88	104	108	92	115
KS	2100	83	86	84	99	156	102	112	99	56
SY	2300	96	103	89	85	171	93	107	90	52
AL	2400	94	96	65	108	149	119	118	115	48
TY	2523	108	105	107	104	145	106	114	102	116
SC	2537	103	97	94	94	87	98	112	99	110
TH	2623	108	111	102	108	93	104	109	112	120
TT	2654	91	93	72	88	76	90	98	92	104
Actual mean (mm)		5	3	12	15	7	56	30	22	10

*% of mean

low elevation trees grew fastest. Also, there were significant correlations between seed weight-height at age 5 (r=.84, .95) and between heights at age 1 and 5 (r=.68, .66, respectively).

TABLE 26

RELATIVE HEIGHT AT AGE 5 OF OFFSPRING OF 200 TREES LOCATED IN 18 STANDS, TESTED IN THREE PLANTATIONS (from Yang and Yao, unpublished)

Place of Origin		Height at:		
		Zuyunshan		Tahsueshan
Locality	Elevation (m)	1500 m (% of mean)	1500 m (% of mean)	2100 m (% of mean)
Songho	700	133	145	108
Maiyuan	919	121	123	90
Kukwan	981	146	140	101
Kuantochi	1125	142	137	108
Chinshan	1230	120	125	100
Wanta	1263	118	130	97
Sunkwan	1621	84	95	99
Chiayang	1643	106	97	105
Songmao	1745	91	103	102
Wushe	1803	122	140	100
Kwanwu	2050	70	90	71
Kwanshan	2100	--	90	--
Shianyang	2300	--	75	--
Alishan	2400	--	61	--
Tayulin	2523	75	83	110
Songchuankian	2537	71	68	104
Tahsueshan	2623	77	76	95
Tanta	2654	75	88	111
Actual mean ht., cm		250	180	140
Survival, %		61	59	65

Work Plan

Maintenance of NTU and TFRI Provenance-Progeny Tests

These are basically good experiments, sufficiently latge to solve the main questions about geographic variation. They should be maintained, but need not be repeated. The main procedures are as follows:

A. Maintenance. Weed the plantations once a year. Cut vines. Maintain firebreaks.

B. Measurement. Re-measure height, diameter, stem form, fruit production, pest damage at 5-year intervals.

C. At age 10, thin to the two best trees in each plot. Shortly after crown closure, remove the 50% of families having the poorest growth.

D. Thin again (by family and within family) at age 15 to 20.

E. Analysis and publication. Do ANOVAs on the data from each plantation separately and all plantations combined. Do age-age correlations. Publish at 5-year intervals. Include data from both experiments in the same publication.

F. Maintain these plantations as experiments and demonstration areas. Do not convert them into seed orchards. To do so, we would remove 15 or 18 seedlots or leave Kukwan, Kwantochi and Sangho. That is, we would leave 25 families for the seed orchard. With that strategy, there would be no gain in seed orchard, because we could as easily go back to the parent stands to collect the seed there. Furthermore, it is very expensive for running a seed orchard.

If there are some missing plots, then the families would be less than 25. If there were an attempt at improvement by removing the poorest 5 of the 25 families, only 20 families would remain. Because mortality rate averaged 40%, those 20 families would contain only 192 trees, hardly enough to be considered as a seed orchard.

CHAPTER 10

LUCHU PINE AND ITS IMPROVEMENT

General Description and Distribution

Luchu pine (*Pinus luchuensis* Mayr.) is a native pine in Ryukyu Islands. According to Liu *et al*. (1967), it was introduced to Taiwan in 1903 by Tashiro Antey, a Japanese taxonomist. Then, in 1905 and 1906, more seeds were taken in. Since then, it is widespread in low elevation areas all over Taiwan.

The Ryukyu Islands are located between Japan and Taiwan, at latitudes from 24^{o} to 29^{o}N. In most of the areas there, from seashore to mountain slopes, the land used to be covered by luchu pines. Due to the Second World War, most forests were destroyed, but some are left in the southern islands of the group (Mirov, 1967). Except for the original introduction, all seeds used in Taiwan are collected in Taiwan.

Luchu pine is very adaptable to the sites of the northern part of Taiwan. The sites which are good for masso pine (*P. massoniana*) or acacia (*Acacia confusa*) are also good for luchu pines. It is a sub-tropical species, favors warm and wet to humid climate, and prefers sandy loam and red clay soils. It is not suitable for peat or hard clay. Generally, it is planted in areas below 1,200 m in elevation. It grows well in mountain or hilly areas, but very poorly near the sea coast. Before 1960, 2,000 to 3,000 ha were planted annually. From 1966 to 1970, the planting areas were 4,377, 1,959, 2,121, 2,075, and 1,750 ha, respectively, per year. But in recent years, the planting areas dropped sharply, to totals of 263, 48, 58, 0, 158 and 36 ha per year for the years 1971 to 1976, respectively (TFB, 1972a, 1977). For its future plantings, it is expected that about 300 ha per year would be planted.

The wood of luchu pine is heavy and hard. The sapwood is light yellow and the heartwood is yellowish brown in color. The fiber length and width are 4.04 mm and 44.3 u, respectively. The specific gravity is .44 to .49. The major uses are for construction, mining poles, pulp, shipbuilding and oleoresin.

Silviculture and Related Characteristics

Luchu pine is a hard pine. It is in Subsection *Sylvestres*. Its close relatives are Japanese red pine (*P. densiflora*), Japanese black pine (*P. thunbergii*), masso pine (*P. massoniana*), Taiwan red pine (*P. taiwanensis*), etc. It is a medium-size tree of 20 m and 50 cm in diameter. It flowers in March and the cone matures in October and November (Liu, 1977; Chang, 1950; Ho, 1968). There are about 42,000 seeds for 459 grams per liter (41,000 seeds per lb.), and the germination rate is generally high, up to 45%. It bears seeds every three years, and begins to flower when four to five years old.

Luchu pines grow faster than other native pines in the young stage, up to 20 years of age. After 30 years old, the growth rate declines. The general expected rotation ages are 20 to 25 years, with the first thinning at age 10. One private stand in northern Taiwan, 19 years old with 1,290 trees per ha, averaged 16.4 cm in diameter, 9.7 m height, and 130 m^3 per ha volume. In other words, it grew about 6 m^3 per ha per year (JCRR, 1966, unpublished). Lin (1974), Liu and Lin (1970) studied the effects of site quality and spacing on luchu pine growth. The concluded that this species grew best on fine to medium sandy loam soils 20 to 50 cm deep, and 200 to 600 m in elevation. Stand yield at age 30 varied from 275 to 447 m^3 per ha, averaging 350 m^3. Other studies on growth of luchu pines on different sites included Chiang (1956), Hwang (1952, 1968), Hung _et al_. (1976), etc. Most of their data were collected from individual trees or small groups of trees, and the growth per ha was often over-estimated.

Fang (1968, 1969) studied grafting on luchu pine. He found that after 10 months, graft survival rates were 39, 28 and 23%, respectively, for scions taken from trees 10, 20 and 30 years old. Scions from young trees had the fastest growth as well as the highest survival. In another study in spring of 1967, he tested effects of cold storage and date of grafting. Graft survival ranged from 1 to 38%. Grafts stored at 70 to 80% relative humidity were more successful than fresh scions, and grafts made in February survived better. There are no data on flowering of grafted trees or the rooting of luchu pine cuttings.

Two major diseases of luchu pine exist: pine leaf blight (*Cercospora pinidensiflorae*) and blister rust (*Cronartium quercum*). Others are damping off of young seedlings in nurseries and pine canker (*Diplodia* spp.). As for insects, the most important is the pine caterpillar (*Dendrolimus punctatus* W.), doing the most damage on trees less than 10 years old. In 1956, it destroyed about 1,000 ha luchu pines in northern Taiwan. In 1974, it almost destroyed all the luchu pines in NTU Experimental Forest arboretum in Chushan. Its biological control studies have been tried by cytoplasmic polyhedrosis virus (CPV), which seems effective (Ying, 1970; Yie *et al.*, 1967; Koyama, 1967).

Past Work Related to Genetics

In pine root tips, there are 2n = 24 chromosomes. For luchu pine, Shidei and Moromizato (1971) made a complete karyotype analysis in Japan. The ten pairs were metacentric and the other two were submetacentric. Secondary constrictions were observed on the short arms of the third, sixth and tenth chromosomes. The chromosomes were 8 to 13 um long and 1.5 to 2 um thick at meiosis.

No literature has been known on luchu pine's hybridization work so far. Wright (1976) mentioned that most crosses of pines in subsection *Sylvestres* can be made between Asiatic species, but luchu pine was excluded. Yang and Yang (personal contact) of TFRI have tried the crosses between luchu pine and Taiwan red pine and F_1 hybrids have been outplanted, but no further information is available.

In 1969, an island-wide provenance and progeny test of luchu pine was started by Tsou (1976, 1978) of TFB. She collected seeds from 214 trees located in 27 stands in 18 regions over a 3-year period. She included the offspring of 214 different parent trees into 17 test plantations in northern, central, and southern Taiwan from 1971 to 1973. The total area of test plantation is about 35 ha. In the winter of 1975, first measurements were made of the 2-4-year-old tree. The average survivals and height are summarized in Table 27. In luchu pines, it is often mentioned that northern Taiwan is more favorable for its growing, but it is not always true according to these results.

For the performance of the seedlots in each test plantation, there are some very consistent results for certain good seedlots. For instance, seedlot No. 50--Chiaochi (northeastern Taiwan), No. 3--Shiaokotou (northern Taiwan) were both very good in most test plantations. On the other hand, some seedlots grew poorly in all test plantations. Interestingly, seedlots from Yilan and Chiaochi grew at very different rates even though the parent stands are neighbors.

The results of the analysis of variance for Mrs.

Tsou's experiment are shown in Table 28. She made her calculations in terms of deviations from plantation means, so did not calculate plantation mean squares (which undoubtedly would have been significant). There were large and significant differences among the offspring of different trees in the same stand.

TABLE 27

SURVIVAL AND HEIGHT OF 2- TO 4-YEAR-OLD LUCHU PINE PROVENANCE TESTS IN THREE PARTS OF TAIWAN, WHEN MEASURED IN 1975 (from Tsou, 1978)

Location of Plantation	Age when measured	Number of plantations	Height (cm)	Survival (%)
Northern	2	1	207	69
Taiwan	3	3	272	84
	4	1	381	80
Central	2	3	248	--
Taiwan	3	3	350	90
	4	1	488	95
Southern	2	1	---	70
Taiwan	3	3	296	83
	4	1	404	92

This experiment of Mrs. Tsou's is important because it gives needed information on luchu pine. Also, it is a model of a combined progeny-provenance test which can be followed in other Taiwan tree improvement projects. With this model, it is possible to locate specific small areas having the best families. To calculate the ANOVA of such an experiment is sometimes complicated, especially when the

TABLE 28

ANALYSIS OF VARIANCE IN GROWTH OF PINUS LUCHUENSIS
(from Tsou, 1978)

Source of variation	Degree of freedom	Mean square	F value
Seedlot	96	254.9	
Seedlot between stands	14	1059.3	9.01**
Seedlot within stand	82	117.6	6.92**
Seedlot x plantation	452	41.7	2.45**
Replication within plantation	27	117.8	
Error	610	17.0	

**Statistically significant at 1% level.

experiment consists of more than 200 seedlots, 20 replications per plantation and 17 plantations with 10-25% mortality. In such test plantations, irregularities and missing plots are inevitable.

To calculate the ANOVA for combined progeny-provenance experiment, we generally use "nested analysis of variance." That is a technique new to Taiwan but not to the world. I (Yao, 1975) discussed the characteristics of nested analysis of variance and its applications to tree breeding work, and gave examples to show how to calculate the ANOVA including the expected mean squares (EMS).

For missing plots or irregular experiments, Wright (1978) suggested working with deviations from plantation means. I (Yao, 1979b) also followed the method to calculate ANOVA with some examples in Taiwan. This approach is not only to handle the missing plots *per se*, but it is efficient to calculate the ANOVA, especially when several test plantations are combined for analysis. Mrs. Tsou's paper provides a detailed model for the application of this method to practical problems.

Mrs. Tsou selected most of her parent trees for their superiority in growth rate, form, or both. However, in several stands she chose some parents with poor form or poor growth rate, to serve as controls. The results for eight such pairs of plus and minus trees are presented in Table 29. In five of the eight pairs, the offspring of the excellent parent (plus tree) grew faster than the offspring of the poor parent (minus tree). In the other three pairs, the plus family was shorter than or the same as the minus family. These results indicate that the plus tree selection may have resulted in slight genetic improvement in growth rate but that progeny testing can result in even more. For example, the five best families, as measured by the results of the progeny test, grew 22, 29, 31, 38 and 41% faster than average, as opposed to a 2% gain from the plus tree selection alone.

This was a combined provenance and progeny test. Provenance are often undertaken to obtain data on natural selection and natural variation patterns. That was not possible for luchu pine, a recently introduced species. However, the experiment showed that trees from certain plantations grew very well and that others grew very poorly. Therefore, the provenance test was a success in showing which stands yield good seed.

TABLE 29

RELATIVE GROWTH RATES OF THE OFFSPRING OF EIGHT SELECTED PLUS TREES AND EIGHT SELECTED MINUS TREES CHOSEN AS CONTROLS

Parental stand	Relative height of offspring of	
	Selected plus trees	Selected minus trees
	(% of mean)	
Shiaokotou	112	102
Chiaochi	101	103
Kaoshifu	94	93
Pinglin	98	98
Yangminshan	110	102
Yangminshan	105	104
Chushan	104	101
Chushan	101	101
Average	102.9	100.5

Work Plan

Luchu pine used to be a very important economic species; it is generally fast-growing, non-selective as to site requirements, and easy to establish. These qualities made it planted in huge lower hilly stands all over the land. The main use of it is for pulp and mining logs, etc. Today, the planting areas are much less than before, so the tree improvement potentials seem dismal. But the fact is that the major use of the wood does not change, and the amount of wood needed for pulp is dramatically increasing. And in Taiwan, so far, no other species can take the place of the luchu pine. So, in the long run, unless we are to import more wood for pulp, much more luchu pine plantings are expected, because the land is available and so is the market. Therefore, this luchu pine genetic improvement plan is justified. Furthermore, since the progeny testing by E. K. Tsou has already started, more improvement works can be done fast just following the progress of the testing. In the next 10 years, more than 3,000 ha can be expected to be planted with luchu pine. The traits to be investigated will be growth rate, stem form and fiber length. The plan will be as follows.

Follow-up, 1969 TFB Provenance-Progeny Trial

Tsou's progeny tests have shown positive results and should be maintained as part of an improvement program. And further considerations are as follows:

1. Remeasure in 1983 the height, stem form, and count cones per tree to measure stem form in cm, measure departure from a vertical line, or in number of crooks per stem.

2. Publish the results in 1984. The reports should include seed source information, differences in data of measured characteristics, ANOVA tables, comparisons between controls and selected trees. The test plantations site data should show by location map and by brief descriptions. Growth data table must be concise and readable. Table 4 in Tsou's 1978 report (results in height) could be much shortened, and the rest of the tables except Table 5 (ANOVA results) could be taken off or changed to

simpler forms.

3. In plantations Sanwen-C, Sanwen-S, Yuchi-N, Yuchi-C, Liuchi-N, and Liuchi-C, select 15 ha areas with good survival and convert to seed orchards. To do this, thin by family and then cut the poorest trees in the best families. (a) For the next 10 years of 3,000 ha plantings, 60 liters of seeds are needed each year. (b) The seed orchard will be 15 ha in total, each having 100 trees per ha at an average spacing of 10 x 10 m, and approximately producing 5 liters seed per ha per year, then it will meet the need. (c) Improved seeds from seed orchard will be enough for future plantings. So establishment of seed production areas of the parent-tree stands will not be necessary.

4. First thinning should take place in winter of 1983, and one-half of the poor families will be thinned out.

5. Remeasure the trees in 1987 and then do the second thinning, and thin the remaining half. In 1990, thin again and leave 10 families.

6. For immediate plantings, use seed for Chiaochi, Shiaokotou, and Yangminshan. Also, use the seed from thinned seed orchards.

7. Start second generation improvement by controlled breeding in the seed orchards in 1990.

CHAPTER 11

SUB-TROPICAL PINES INTRODUCTION STUDY

Sub-tropical pines are an important group of trees. They have been intensively studied in many countries of the world. They are generally fast-growing, genetically flexible, and adaptable to various sites. The wood can be used as pulp, furniture, power line poles, fuel wood, construction, etc.

In Taiwan since the 1900s, more than 300 tree species have been introduced (Liu *et al.*, 1967). The list includes several exotic pines (Kiang, 1970). Today, more than 80% of the coniferous plantations are of exotic species. So, introducing new species for planting in Taiwan is one of the important steps for improving Taiwan reforestation programs. The "Sub-tropical Pines Introduction Study" is therefore of interest in tree improvement work. The main purposes of this study were as follows: (a) To introduce some potentially useful exotic pines for future planting in Taiwan, and (b) To supply breeding stock which could be used in future attempts at species hybridization.

Past Work

As stated before, introduction activities in the past were numerous. A few exotic pines are still left growing in many parts of Taiwan. Almost all such plantings are in small patches and are without records. The successes but not the failures can be demonstrated.

Kuo and Yao (1972) discussed the selection of exotic pine species for testing in Taiwan. They surveyed commonly planted pine species in other sub-tropical parts of the world and compared the performance of different species in various countries. In addition, the environmental factors of the given areas were examined in detail. Such data should be the main consideration for the selection decision for Taiwan. Other factors to be considered are wood usage, pests and diseases.

Lin (1959, 1965), Hsu (1966), and Hung *et al*. (1976) have reported on pine species adaptability trials in Taiwan. Their results are summarized in Table 30. Other studues include those of Liang (1969) on turpentine quality, of Hung (1955, 1958) on thinning of slash pine, and of Hung (1952) on luchu pine.

In 1973, 25 seedlots representing seven sub-tropical pines from other countries and four pines from Mainland China or Taiwan were planted in Nantou Hsien in the NTU Experimental Forest (Yao, 1974, 1979a, 1981). They were planted in four test plantations, each with eight replications, 2.4 x 3 m spacing and 16-tree plots. The test sites varied in elevation from 820 to 1,200 m, in rainfall from 2,052 to 2,888 mm per year, in mean annual temperature from 17^{o} to 23^{o}C. The test sites vary in loca-

TABLE 30

HEIGHT GROWTH OF DIFFERENT EXOTIC PINES AT DIFFERENT AGES AND SITES IN TAIWAN

Species of pine	Height (m) at			
	Liukwei Age 5	Liukwei Age 8	Taichung Age 12	Several Places Age 22
kesiya	4.7	--	--	--
caribaea	4.3	--	--	--
radiata	2.2	--	--	--
pinaster	1.7	--	--	--
rigida	.6	--	--	--
elliottii	--	6.1	8.1	15.9
taeda	--	5.4	8.5	--
echinata	--	4.6	--	--
luchuensis	4.3	6.1	9.0	11.8
massoniana	3.2	4.8	--	17.6
taiwanensis	--	5.4	--	--
morrisonicola	--	4.1	--	--
Authority	Lin 1959	Lin 1965	Hsu 1966	Hung _et_ _al_. 1976

tion from 120°40' to 120°50' E and from 23°35' to 23°48' N. Generally, the test sites are sub-tropical, warm and humid, with rainfall mostly in the summer.

The test plantations were measured at age 7. None of the Taiwan or Chinese pines grew faster than average. _Pinus_ _kesiya_ from the Philippines but not from Thailand grew 10% or more faster than average. _Pinus_ _caribaea_ var. _hondurensis_ grew well, much better than the other two varieties. _Pinus_ _oocarpa_ seems promising, but most of the _Pinus_ _merkusii_ died out. Slash pine (_Pinus_ _elliottii_), which at one time was considered as an excellent possibility for Taiwan, seems to have been overrated, as it grew less well than several others, including P. taiwanensis. The results are given in Table 31.

TABLE 31

RELATIVE HEIGHTS AT AGE 7 OF SUB-TROPICAL PINE SPECIES TESTED AT FOUR LOCATIONS (from Yao, 1981)

Pinus species	Place of origin	Relative height at Chi-tou	Hsien-gin	Pin-lin	Hoshe	Mean
		(% of mean)				
kesiya	Zambales, Phil.	113	121	106	102	111
kesiya	Abra, Phil.	117	116	107	102	111
kesiya	Bontoc, Phil.	113	124	108	109	114
kesiya	Pangasinan, Phil.	117	120	110	103	113
kesiya	Abra, Phil.	125	125	110	114	119
kesiya	Benguet, Phil.	122	127	110	105	116
kesiya	Copperbelt, Zam.	114	111	104	105	109
kesiya	Chiengmai, Thai.	90	101	91	103	96
kesiya	Petchabeen, Thai.	92	103	93	86	94
caribaea var.						
hondurensis	Alamicamba	116	99	104	104	106
bahamensis	Nicaragua	96	93	106	108	100
caribaea	Bahamas	84	89	92	98	89
oocarpa	Boneto, Nicarag.	116	95	102	106	105
merkusii	Chiengmai, Thai.	--	36	--	--	--
patula	Malawi	128	100	97	109	109
elliottii	Queensland	89	89	90	90	90
elliottii	Rep. S. Africa	85	88	87	93	88
taiwanensis	Taiwan	100	107	94	83	96
massoniana	Taiwan	77	--	--	--	--
armandii	Taiwan	87	100	90	77	89
morrisonicola	Taiwan	61	57	--	--	59
Actual mean, meters		5.7	4.0	4.9	5.6	5.1

Work Plan

NTU Experimental Forest Trial

1. Manage them as arboreta. Give them good maintenance on weed control and spacing. Remeasure at 5-year intervals.

2. Start control pollination and hybridization trials among species of subsection *Sylvestres*, such as *P. massoniana*, *P. taiwanensis*, *P. luchuensis*, *P. merkusii*, *P. kesiya* as soon as they are flowering. Prepare to harvest the seed whenever they begin to fruit.

Second Round Introduction Trial

1. Cooperate with IUFRO for getting the seed. Make an introduction plan of 50 seedlots, based on the results of NTU Experimental Forest trial in "A," emphasizing the species or varieties doing best in that trial.

2. Emphasize on provenance trial on *P. kesiya*, *P. oocarpa* var. *echeternal*, *P. caribaea* var. *hondurensis*. Include also *P. cubensis*, *P. tabulaeformis*, *P. yunannensis*. Give 3 x 4 m in spacing in favor of flowering. Give 20 trees per plot to promote the pollen exchange within the plot. Do better in weed control, maintain good survival on each seedlot. Establish four test plantations in different sites for comparisons.

Collect most subtropical and tropical pine species in the world and establish pine species arboretum in Chushan.

CHAPTER 12

PAULOWNIA AND ITS IMPROVEMENT

General Description and Distribution

Taiwan paulownia (*Paulownia taiwaniana* Hu et Chang) of the Scrophulariaceae is a very fast-growing hardwood native to low elevations. It is also a typical cash tree species. It used to be called the green gold of Taiwan. It used to be planted on private forest land and land of the hsiens (counties). Because its wood is capable of various uses in Japan, the price is much higher than for other tree species. Therefore, Taiwan became the main source of paulownia exports to Japan. The rotation age is relatively very short, 6-8 years. There are about 1,900 ha of paulownia plantations in Taiwan. About 65% of them are in eastern Taiwan, including Hwalien and Taitung.

Taiwan paulownia is native of Taiwan. Because it is accessible and the wood is so valuable, most of the natural stands are gone.

In addition to *P. taiwaniana*, Taiwan has two other native species, *P. kawakamii* and *P. fortunei*. All are distributed along the central mountain range between 500 and 1,500 m in elevation. There are also 6-7 species native to Japan and 4-7 native to Mainland China and Korea.

The wood of Taiwan paulownia is light in weight and color, with little difference between heartwood and sapwood. It is resistant to moisture, water and fire. The specific gravity is .28 to .32. Because it is light, soft and easily worked, it has a wide range of uses such as musical instruments, furniture, wooden boxes, clogs, medicine containers, and gift containers. Especially in Japan, it is considered a high quality raw material for furniture.

Paulownia is a large deciduous tree, up to 20 m tall. The leaves are large, 20 x 20 cm, heart-shaped, and slightly hairy. The fruits are egg-shaped capsules, 4 cm long, containing a large number of very small, winged seeds. The fruits mature in October and November. There are about 47 grams or 240,000 seeds per liter (1.5 million seeds per lb.). The fresh seeds have 50-60% germination rate, which decreases very rapidly with storage at room temperature. When stored at $5^{o}C$, it will retain germination capacity for 3 years.

In planting programs, generally root cuttings are used. Cuttings made from the roots of 1-2-year-old seedlings are best. They should be 10-15 cm long and 1.5+ cm in diameter. The cuttings are buried directly in the planting site in the spring. Average survival is 55-80%. The trees will be 1.5-2 m tall after one year's growth. In the spring of the second year, the tops should be cut off to permit the root system to send up a sprout. This produces a stronger root system than if not cut back.

With intensive silviculture, fast growth is expected. So the density is not less than 1,000 trees per ha. The best density is 500 trees per ha. With the denser spacing, thinning will be done in 3-4 years, when up to 50% of the trees should be removed. The final cutting generally should not exceed age 15, but this depends on the market demands and on the management purposes.

According to growth data supplied by Rin (1979), 4-year-old trees reach 36 cm diameter. In a 6-year-old plantation, trees were 14.1 m tall and 23 cm in diameter. In an 8-year-old plantation having 800 stems per ha, the average size was 13.4 m in height and 21 cm diameter. The above grown dry weight was 28.3 tons per ha and the volume was 129.1 m^3 per ha, for an average growth rate of 16 m^3 per ha per year.

Today, Taiwan paulownias face a severe disease problem. That is the witch's broom disease caused by a mycoplasma. The disease began about 1970 and spread rapidly until 1975, when it occurred in almost all parts of Taiwan. So far, there is no way to control the disease. The disease does not cause death, but it seriously decreases growth. As soon as a plantation is infected, the general practice is to cut, burn and switch to another crop.

Previous Work on Genetics

Taiwan paulownia is a very intensively cultivated species. Therefore, most studies emphasized silvicultural aspects. Some also relate to its genetics. Rin (1979) made a comprehensive silvicultural study. He gave detailed descriptions on all species in the world and a complete bibliography of Taiwan and Japan. Perng (1978) studied its success and failure in plantations. He mentioned that "nearly all the planting materials came from Hualien area. Perhaps they cannot grow well in other sites." Lee (1977) listed the research activities on Taiwan paulownia in TFRI. He gave only brief descriptions of each research project without details, results or references. In the genetics and tree improvement aspects, they are as follows: the selection and breeding for paulownia improvement started in 1973 to 1976 in cooperation with TFB. Tissue culture study in 1974 in cooperation with Department of Botany of NTU. Exotic species introduction trial in 1974 in cooperation with TFB. Hybridization trials on *P. taiwaniana* x *P. fortunei* started in 1974, in cooperation with TFB. Other experiments started were a provenance trial (1975), clone bank (1977), isozymes of three species (1975), and nematode resistance.

Work Plan

Witch's Broom Disease Resistance Trial

Lots of efforts have been done on paulownia in silvicultural aspects, such as improving the growth rate or wood quality by fertilization or pruning. Little has been done on witch's broom disease control. As a matter of fact, this disease is a limiting factor for paulownia culture. If it is out of control, there will be no more paulownia plantings.

A. Progeny test

1. Select 100 parents of healthy paulownia both in the wild and in plantations, especially make selections on infested populations.

2. Start progeny tests at Hualien, Taitung, and Nantou Hsien.

3. Establish test plantations where the witch's brooms are. Each plantation should include 10 replications and 4-tree plots.

4. Measure the growth periodically with emphasis on witch's broom disease.

5. Select families with high resistance.

B. Paulownia species trial

1. Collect the seed by species (about 10) from their original regions, including Japan and Mainland China (cooperate with TFRI).

2. Raise the seedlings in infested areas in Taitung and Hualien.

3. Establish replicated test plantations.

4. Grow them in the same regions and measure the growth periodically and emphasis on the disease.

CHAPTER 13

KADAM INTRODUCTION STUDY

General Description and Distribution

Kadam (Anthocephalus chinensis) is a non-commercial waste tree of tropical Asia. It has rapid growth, good wood quality, multiple possible uses, and an ability to coppice. Thus, it has become a very promising planting species in recent years. In Taiwan, it was introduced in 1962, 1964 (Sheng, 1964; Yang, 1964) and again in 1973 (Yao and Yen, 1979). This chapter is a comprehensive discussion on this species including its geographic distribution, ecology, species description, and growth data both in Taiwan and in its natural ranges. Finally, a work plan of kadam is made for further testing in Taiwan.

Species Description and Distribution, Habitat

Anthocephalus chinensis (Lank.) Rich. ex Walp. of the Rubiaceae (=*A. cadamba* of Troup and others), widely known as kadam, kaatoan, bangkal, kelempayan, or laran, is a rapidly growing evergreen timber tree up to 30 m tall and 87 cm in diameter with a straight axis and widely spreading nearly horizontal branches. Its bark is gray, smooth to slightly fissured. The inner bark is light yellow with a thin green outer layer, fibrous and bitter. Twigs are stout, hairless, with ringed nodes, green when young, and become brown later. Leaves are simple, opposite. Flowers are numerous, fragrant, consisting of a tubular base. Fruits are compound with numerous fruits pressed together like a fleshy ball.

It occurs in Nepal, India, Burma, Thailand, Malaysia, the southern Philippines, and New Guinea (Whitmore, 1975; Troup, 1921; Fox, 1971; Monsalud and Lopez, 1967). In India, kadam is found in the sub-Himalayan tract from Nepal eastward in Bengal and Assam. It occurs in the low country of Ceylon (now Sri Lanka) up to 2,000 feet altitude and in all parts of Borneo, Sumatra and Java. In the Philippines, it is found in Bukidnon, Cotabato, Davas, Basilan, Zamboanya, and Mindanao.

Kadam is a light-demanding tree which colonizes bare areas. It is a tree of moist, warm regions, often occurring on alluvial ground along rivers, and also in swamps. On stiff, badly-drained ground, growth is poor. In its natural habitat in India, the absolute maximum shade temperature varies from 36^{o} to 43^{o}C, the minimum from 3^{o} to 6^{o}C, and the normal rainfall from 1,524 to 5,080 mm or more (Troup, 1921). In Sarawak and Brunei, on the island of Borneo, it occurs mostly at low elevations along river banks (Ohtani et al., 1962). According to Ashton (1964), it is also common on day lithosal soils on hill ridges. In Sabah, it is abundant in the logged-over areas of the low land depterocarp forest, and is one of the few species able to thrive on soils disturbed by heavy machinery. Often it dominates such areas later. It is also found in the virgin forest and forms a constituent of freshwater swamp forests. In secondary forest at higher elevations, it is confined usually to streamside sites up to about 305 m elevation. For the most part, the soils on which it is found in Sabah are clays or clay-loams (Fox, 1971). It is generally distributed below 1,000 in elevation in primary forests. Wyatt-Smith (1965) gives to Anthocephalus/Eugenia densiflora var. angustifolia riverside association, the rank of a sub-seral community--"Riparian Fringe." This community has a secondary or invasive status, found on river banks subject to flooding and on newly formed accreting soil on the inside of river bends. Also, it is reported (Gyekis, 1966) that kadam is present in unproductive swamp forest.

Kadam wood is light in color, of fine and even texture and workable. The timber which has no apparent heartwood is soft and light. According to different authors, the specific gravity varies from .38 to .53, and fiber length from 1.50 to 1.67 mm (Liu et al., 1976).

The wood is generally free of odor or taste. It is not suitable for structure use because of its softness and low durability in the open when untreated. It is rapidly attacked by termites, lasting only 8 months in the Philippines. The timber saws and splits well and seasons rapidly with little structural degradation, despite high shrinkage. It has long been known as potential pulp wood. Among other promising commercial uses are plywood, wooden clogs, matchsticks, pencils, and wood carving.

Fruiting, Growth and Regeneration

Kadam fruits early. It flowers after 4 or 5 years, or when the trees are 12-28 m tall. In the Philippines, annual flowering occurs after age 7. Some trees flowered at age 2 in Taiwan. It flowers from April to June, the fruits ripening from September through February. As soon as ripe, they fall to the ground. In Taiwan, flowers appear in April and May, the fruits ripen in November and December, and its fruits annual after age 10. Seed quality is very good. Seed dispersal is accomplished by bats and birds which feed on the fruits, and also by cattle and other animals, and by water (Troup, 1921; Fox, 1971; Whitmore, 1975). Fox (1971) believes that on exposed soil, it arises from bat droppings subsequently slightly dispersed over the surface by heavy rain.

The seeds are minute, about .63 x .47 mm in size. There are approximately 17,000 seeds per gram, about 10,000 seeds per multiple fruit. The germination rate generally is high. In the Philippines, it is reported 95 percent after two months refrigerator storage, compared with 5 percent with fresh seed. Fox (1971) reports in Sabah it germinates most readily with seed which has been stored for 6-12 months. The air-dry seeds, if kept in airtight bottles and stored in a refrigerator, can retain validity for 2 years (Monsalud and Lopez, 1967).

Germination takes about 3 weeks. The young seedlings are tiny, and growth at first is slow. After it grows to 5 to 10 inches after the first 3 months, it reaches 2 m in the next season. Extensive plantings began in 1933 in Java by the Dutch, then more in east Borneo later by the taungya system (Whitmore, 1975). It has been successful in trail plots in Puerto Rico, and was recommended for west Africa (Puerto Rico, 1963; Lamb, 1966). It is highly recommended in the Philippines. In Taiwan, small-scale-trials have been started. The growth in different areas is summarized as in Table 32.

TABLE 32

GROWTH OF KADAM IN OTHER COUNTRIES

Country	Age	Height (m)	DBH (cm)	Author
India	4	9	19	Troup, 1921
India	22	37	61	Troup, 1921
Philippines	9	18	25	Masalud & Lopez, 1967
Philippines	15	23	41	Masalud & Lopez, 1967
Sabah	4	--	13	Fox, 1968
Sabah	8	--	14	Fox, 1968
Sabah	11	--	18	Fox, 1968
Sabah	30	38	65	Whitmore, 1975
Puerto Rico	2	4	--	Puerto Rico, 1963
Puerto Rico	4	6	--	Puerto Rico, 1963
Puerto Rico	30	20	65	Puerto Rico, 1963

It grows very fast in height until 6 to 8 years old. After that, growth slows down and becomes particularly slow after age 20. It is naturally self-pruning. Small crowned trees usually die off. For volume growth, Whitmore (1975) predicts in Sabah volumes of 373 m^3 per ha at age 30, with the trees 38 m tall and 65 cm in diameter.

Kadam can be reproduced by sprouting. In Philippines, some young sprout shots 16 months old had 6 m in height, 9 cm in diameter (Monsalud and Lopez, 1967). In Taiwan, it is also very common after the thinnings. So copping regeneration is very promising.

Kadam seedlings are sensitive to drought and excess moisture also. Seedlings are much subject to damage by insects, especially during the first few weeks. In dense stands, they are eaten by caterpillars (*Arthosclista hilaralis*) (Mastan, 1969). Fox (1971) noted damages from three other insects. Deer may occasionally browse young trees (Hellinga, 1950).

Planting Experiments in Taiwan

In 1963, 1966, TFRI established two test plantation with seeds sent from Puerto Rico. The first test plantation is in Liukwei, located at 120°38' E, 23°00' N, 250 m above sea level. Annual rainfall is 3,121 mm; raining season is from May to October. The soil is alluvial, a mixture of sandy-loam, and gravel. The next one is at Chungpu, 60 km northwest at an elevation of 180 m above sea level. Annual rainfall is 2,790 mm, heaviest from June through September. The soil is a loam, and deeper and better than at Liukwei.

In 1975, two test plantations were established with kadam seeds from the Philippines in NTU Forest. The one Hoshe Tract, $120^{o}53'$ E, $23^{o}35'$ N, at an elevation of 830 m. It is on an east-facing 15^{o} slope, formerly in tung trees. The soil is well-drained, sandy loam and gravel mixture. This site receives 2,045 mm rainfall per year, mostly from March to September. Average July and January temperatures are 25^{o} and 16^{o}C, respectively. The plantation is a mixture of kadam and three other species. It follows a randomized complete block design with 20 replications. There are 20 trees per plot, each species planted in 4 rows. The spacing is 2.5 x 2 m. The second one is in Shuli about 40 km north of Hoshe, at an elevation of 250 m. Annual rainfall is 2,438 mm. The soil is sandy-loam, deep and fertile. This plantation is pure, the facing is 1.8 x 1.8 m totally 0.17 ha and 435 kadam trees.

Results

In 1975, three trees were cut from each of the Liukwei and Chungpu plantation for growth analysis (Liu *et al.*, 1976). Each of these trees was representative of the dominant, co-dominant and suppressed crown classes. The Liukwei and Chungpu plantations were 11 and 8 years old, respectively, at the time. They remeasured the plantations in 1979 at ages 14 and 11. Height, not diameter growth, seemed to slow down after age 8. The results are shown in Table 33.

TABLE 33

THE GROWTH OF KADAM IN LIUKWEI AND CHUNGPU
(from Liu *et al.*, 1976)

Plantation	4	6	8	11	14
Liukwei					
height (m)	4.3	7.0	9.6	11.3	11.3
diameter (cm)	4	6	9	14	23
Chungpu					
height (m)	6.4	9.8	13.1	12.5	
diameter (cm)	7	12	17	24	

The growth in Chungpu was much faster than it is in Liukwei because of the better site conditions.

The NTU Forest plantations had different growth rates on different sites, too. The growth at age 4 in Hoshe and Shuili is shown in Table 34 (Yao and Yen, 1979).

Work Plan

In Taiwan, most commercial plantations are conifers. Hardwoods are confined to limited species. This is not because of lack of hardwood species, but because they are generally slow-growing. So introduction of exotic, fast-growing hardwood planting in the low elevation areas of Taiwan is an urgent need. Kadam as discussed in the text fits the case. The objective of kadam introduction is to use the wood as light wood industry raw materials except the pulps, veneer, medications-use, and gift boxes, furniture, matchsticks, etc.

TABLE 34

SIZE AND SURVIVAL AT AGE 4 OF KADAM AND THREE OTHER SPECIES TESTED AT HOSHE AND SHUILI (from Yao and Yen, 1979)

Species	Height (cm)	Diameter (cm)	Survival %
Kadam	234	5	46
Taiwan alder	580	7	75
Albizia falcata	512	7	42
Tung tree	219	4	62
Shuili Plantation kadam	1151	18	--

Today, Taiwan's lower elevation areas mostly are so-called fringe lands, the land usage is diversified. If the tree is the objective, mostly they are *Paulownia*, fruit trees, Taiwan acacia or bamboos. Kadam would be a very potential competitor for replacing Paulownia or fruit trees, because the disease problems of them almost become hopeless. Such lands are all over the island, and the area would be very large. For instance, according to 1977 survey, the *Paulownia* plantations were 19,046 ha (Rin, 1979). So for the Kadam, planting rate should be considerable. But when the experimental results showed the site was very selective. So, for the beginning of its introduction, the rate would be expected to be 500 ha for the next 5 years.

According to the Taiwan test plantation's results, the difference between sites was substantial; therefore, the seed sources importance seems diminishing. Nevertheless, the wood property shown before indicated that some differences existed, and maybe they are due to seed sources. If so, we have to select the better ones, because the major usage of the wood is for more specific purposes.

Two major approaches will follow:

A. Site Adaptability Trial

1. Cooperate with hsien governments and coordinate with Council for Agriculture Planning and Development (CAPD) and TFB.

2. Select plantation sites based on site differences, the elevation range will be between 250-800 m.

3. Collect seed from Taiwan kadam trees and raise the seedlings.

4. Plant *Paulownia* and Taiwan acacia for comparison.

5. Measure the growth periodically.

6. Establish the plantation with 3 x 4 m or 3 x 3 m spacing.

7. The plantation size not less than .5 ha; 1.0 ha each is suggested.

8. When *Paulownia* and *Acacia* included 3 replications are needed.

9. Follow-up, tending should be emphasized.

B. Provenance Trial

1. Take 20 seedlots and seeds from its natural range, 3-5 grams each seedlot is enough.

2. Establish 5 test plantations (or more) on different sites, eastern Taiwan must have one.

3. The traits investigated should include growth rate and wood quality (specific gravity, fiber length, etc.).

CHAPTER 14

TREE IMPROVEMENT WORK THROUGH SILVICULTURE

Tree improvement work in Taiwan is built on a mass-planting base. Intensive silviculture system will make the tree improvement significant and important. Poor silvicultural practice could lessen the effect. In fact, the improvement practice should be considered as the products of well-developed and managed silvicultural system. Each year, more than 90 million (30,000 x 3,000) seedlings are planted. That gives the potential of the tree improvement.

In Taiwan, the relationship between silviculture and tree improvement is much correlated, mainly because of several following reasons: (1) environmental factors, (2) replanting systems, (3) social factors, and (4) forestry policies.

Due to Taiwan's geographic nature and its location, the environmental impacts are tremendous. Rugged topography and fragile, thin soil structure are the major features which form a poor combination to affect the environment. The climatic factors are even more fierce. Abundant and unevenly distributed rainfall, high humidity, and generally warm temperatures prevail. These climatic factors help the trees grow, but also hasten the grass growth. The weeds become strong competitors. So survival rates are generally low and there seems no room for tree improvement to function. Even if the survival were improved by some silvicultural techniques, tree growth still will be suppressed by heavy weeds in the plantations. If so, the superior genetic quality may be suppressed. It is common in a large plantation before the first weed control is finished, the second weed control must be started. For such conditions, tree improvement can function only when plantations are well managed.

In Taiwan, labor used to be cheap. But in recent years, labor sources for forestry are scarce. The wage is getting higher. On the other hand, the planting season is short. When the season is due, there are not enough laborers around. This is also true in weeding and other activities.

Silviculture and tree improvement work are both long-range businesses. Credits and gains are cumulative in terms of the time factor. Therefore, a precise, clear and stable forestry policy is needed to ensure that every effort is worthwhile. Changes in policy which lead to changes in species being planted mean that everything must start again. In Taiwan, the planting species are numerous. To face a multi-choice situation, it is hard for tree improvement work to follow the policy change. For instance, seed orchards generally need 20 to 30 years to produce improved seed and may become out-of-date if a species is discarded. Most Taiwan forest lands are public. Profit is not the main interest. Thus, policy changes without strong reasons are possible.

For the most part, silviculture is a leading force, of which tree improvement work is a part. Occasionally, tree improvement becomes the leading factor as with successful tree introduction. Also, strong tree breeding research programs also make the reverse trend possible. That is true when some hybrids are made, or publishing abroad makes scientific fame.

Due to Taiwan's variable sites, the planting areas for any one species are relatively limited. Under such circumstances, very progressive and intensive tree improvement programs for few species seem not possible. However, when certain basic principles in tree improvement work can be accomplished through the silviculture in any species we are dealing with:

1. Better survival means more gains. 10% less mortality = 10% more gain.

2. Seedling quality control is the first step in tree improvement work. Poor, unhealthy seedlings always cause stagnant growth.

3. Seed sources must be controlled. And this must start from the person who is in charge of the seed procurement or seed collection.

4. Seed sources must be labeled whenever seedlings from them are planted.

5. Tree improvement starts from improved seed.

6. In Taiwan, denser plantings are favored. Intensive thinning schedules should be followed. Maximum growth rate by individual trees can be reached only through appropriate spacing.

7. Site selection is a prerequisite for a tree improvement program for every species. Even a superior strain will grow poorly unless a suitable site is met.

8. Whenever possible, a long-term improvement plan should be included in the management plan.

9. Silvicultural improvements such as tending, pruning, vine cutting, thinning, weeding must be adequate to make genetic improvement worthwhile.

10. In NTU Experimental Forest, tree improvement experiment plantations always are better in survival or growth and management than commercial ones. This is also true in other institutions such as TFB or TFRI. It proves two things. Tree improvement works help growth; second, experimental plantations are in good shape because of more careful management. Expand the idea and treat every plantation as an experiment.

11. Large-scale, good test plantations are few but there are many small-scale experiments in different institutions. Coordination among them lags. Teamwork must be emphasized. It is a powerful tool, more efficient and cost-saving and the outcome would be more fruitful.

CHAPTER 15

CONCLUSIONS

Taiwan is an offshore island of Mainland China. Two-thirds of the land is in mountain ranges and covered by forests. It is located in a sub-tropical region with heavy rainfall. Strong typhoons are generally common. Forests become not only economically but also ecologically important. Every year, more than 30,000 ha of forest land are replanted to economic species. Intensive planting programs and clear cutting--establishment of even-aged manmade forest--is the main silvicultural system in which we are engaged. Tree improvement and tree breeding works are playing a main role in it. Only strong and intensive selection makes the progress and the gain. The effects we are talking about are improvements in growth rate, pest resistance and wood quality.

Mass planting programs are essential. Tree improvement work would give little gain if only small, limited areas or a few ha each year are planted. Thus, in this research, only potential and/or large-area planting species are mentioned.

Tree improvement work in Taiwan since the 1960s has been well activated. For more than 20 years, a variety of experiments have been established, and the accomplishments are substantial. These facts are generally included in the text. But when we look carefully at the details, generally we found the works not adequate to meet the need in terms of practical sense. It is quite evident that most of the projects lacked solid goals, with ambiguous objectives and limited gain.

A real and true tree improvement plan should be comprehensive and also it must be on a long-term base. Some would argue and say that may not be so because basic research itself is important. No one can deny that. But here come the key questions: Who are the sponsors of the research projects, and who will be willing to support the research? In other words, several factors are involved in the decision. Among the key parts of research planning are in justification, objectives, literature review, methods, costs, time schedule and review. To meet those requirements, each plan should have clear facts.

In Taiwan, the planting species which I mentioned before are numerous and it is difficult to decide species priority. Even cryptomeria faces controversy on its importance. In fact, criteria on measuring the importance is not the objective of my research. More important here is to emphasize the methodology for a given species. Generally, I take for granted some important species by their planting areas. For other species this is not true, but

I would rather sacrifice some importance than the methodology.

In this research, I presented nine work plans for nine species or groups of species--seven in conifers and two in hardwoods. They are cryptomeria (*Cryptomeria japonica*), China-fir and luanta-fir (*Cunninghamia lanceolata*, *C. konishii*), taiwania (*Taiwania cryptomerioides*), Taiwan red and yellow cypress (*Chamaecyparis formosensis*, *C. obtusa* var. *formosana*), Taiwan red pine (*Pinus taiwanensis*), luchu pine (*P. luchuensis*), sub-tropical pines (*Pinus taiwanensis*, luchu pine (*P. luchuensis*), sub-tropical pines (*P. kesiya*, *P. caribaea*, *P. oocarpa*, *P. merkusii*, *P. elliottii*, *P. pinaster*, etc.), paulownia (*Paulownia fortunei*, *P. kawakamii*, *P. taiwaniana*), and kadam (*Anthocephalus chinensis*).

In each individual plan, general description and past work related to genetics are the first part. That is followed by the work plan itself. The work plans follow a chronological order, and are organized by independent projects. The construction of each plan is based on the supporting information in the first part. For the next 10-year period, each work plan includes a provision for good quality commercial seed to be used before actually improved seed is available.

Progeny testing is generally a feature of each work plan, especially half-sib progeny testing. That is not meant to be the only method used, but is practical for the first generation. Moderate selection and screening process (200 to 400 families per best on the average) are the general strategies. Seed orchards converted from progeny tesns are the final goal of many work plans. The size of the seed orchard is well demonstrated by careful calculation from the seed demand in sequential procedures. For endangered species such as taiwania and luanta-fir, some conservation ideas are also included. These include germplasm banks and arboreta. But in this case, more emphasis is on "planting more" concept rather than a mere garden per se, so some silvicultural approaches are involved.

Intensive as progeny-provenance tests are already underway in Taiwan red pine and luchu pine. For these two species, the work is well done. So in this case, no more new testings are suggested. Only follow-up is given. This policy of follow-up is also applied to some other species and in other established experiments which are worthy of being continued. More important, I put established experiments into the work plan mainly because I considered that this package of plans is for Taiwan in whole, so it must be comprehensive.

Cost is hardly predictable and almost impossible to be well worked out in detail in the work plan. But I tried to be reasonable whenever dealing with a species. In the case of Taiwan red cypress, I did try to demonstrate the workload and cost analyses for TFB (Taiwan Forestry Bureau) in the work plan. The purpose is to show administrators that tree improvement work is actually only a small part of this workload, with small costs and small reasons being no reason for them to neglect or reject them.

Besides the species-by-species work plans, there are several chapters dealing with background information such as forestry history, administration and school system, training programs, funding, NTU Experimental Forest where I work, and my own personal involvement.

In the last chapter, I tried to compare the relationship between silviculture and tree improvement work. As a matter of fact, they are two facets of forest management and are woven together. Some improvements in forest growth may be made by genetic means, others by pruning, thinning, etc.

The work plan of tree improvement for Taiwan which I propose here involves foresters in Taiwan and foreign countries. It should be treated as a team work plan, justifiable and also feasible.

BIBLIOGRAPHY

BIBLIOGRAPHY

Anon. 1977. Progeny test of plus trees of Cunninghamia lanceolata and heritability estimates. Acta Genetica Sinicae 4(2): 152-158 (Chin.), also Forestry Abst. 1980, 41(3): 1532, 128-129.

________. 1981. Studies on the classification for planting area of Chinese-fir. Scientia Silvae Sinicae 17(1): 37-45 (Chin.).

Ashton, P. S. 1964. Ecological studies in the mixed dipterocarp forests of Brunei State. Oxford Forestry Memo. No. 25.

Chang, L. M. 1950. Tree life cycle observations in botanical garden, Taipei. Taiwan Forestry Res. Inst. Notes 53: 389-392 (Chin.).

________. 1969. Abstracts of cryptomeria in Taiwan. Quar. J. Chinese Forestry 2(4): 239-251 (Chin.).

Chang, S. S., K. S. Wu and S. G. He. 1980. Studies on the productivity of Chinese-fir plantations in Jiangxi. Scientia Silvae Sinicae 16, Supplement: 65-76 (Chin.).

Cheng, T. L. 1978. Study on the reforestation of Taiwan red pine and causes of its success and failure. Masters Thesis, Dept. of Forestry, NTU, 107 pp. (Chin.).

Chiang, C. H. 1974. Oxygen consumption in seed germination and early growth of different provenances of Taiwania. J. Chin. Agr. Assn. 88: 23-33 (Chin.).

________. 1975. Controlled pollination of Cunninghamia species. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 116: 329-342 (Chin.).

________. 1977. Progeny-provenance test of Pinus taiwanensis. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 120: 1-20 (Chin.).

________., B. J. Yen, Y. N. Yao, C. F. Shih, G. T. Chu, T. Kiang and Y. N. Wang. 1979. Provenance test of cryptomeria. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 123: 1-22 (Chin.).

Chiang, S. S. 1956. Growth comparisons on three pine species in Chiaochi (P. luchuensis, P. massoniana, P. thunbergii). Taiwan Forests 2(1): 22-34 (Chin.).

Ching, K. K. and F. S. Kung. 1965a. Tree breeding. Nat'l Taiwan Univ. Exp. Forest Serial Publ. 32, 43 pp. (Chin.).

Chu, J. S. (ed.). 1975. Symposium on Taiwan red cypress--Proceedings. Taiwan Forestry J. 1(13): 3-37 (Chin.).

Chueh, K. Y. 1980. The preliminary tissue study on Chinese-fir. Scientia Silvae Sinicae 16, Supplement: 137-146 (Chin.).

Fang, Y. K. 1968. Effects of grafting on the growth and flowering habits of luchu pine with scions of different tree ages. Quar. J. Chin. Forestry 1(1): 174-183 (Chin.).

________. 1969. Experiment on the influence of cold storage of scion and the proper time of grafting for luchu pines. Quar. J. Chin. Forestry 2(4): 134-147 (Chin.).

Fox, J. E. D. 1971. Anthocephalus chinensis, the laran tree of Sabah. Econ. Bot. 25: 221-233.

Goo, M. 1971. On flowering cuttings of Cryptomeria japonica. J. Jap. Forestry Soc. 53(6): 165-169.

Gyekis, K. D. 1966. Anthocephalus cadamba, a fast-growing industrial tree species for the tropics. Turrialba 17: 321-329.

Hellinga, G. 1950. Aan plant scorten op bedrijesgrootte. Tectona 40: 196-199.

Ho, C. P. 1976. The taiwania planting experiments with branch-pruned, bare-rooted seedlings. Quar. J. Chin. Forestry 9(1): 23-28 (Chin.).

Ho, F. C. 1968. Investigation on flowering and fruiting period and the flower and fruit colors in Kentin Park, Henchien. Annual Sci. Bull., Taiwan Provincial Museum 11: 84-107 (Chin.).

Hsu, H. Y. 1966. Growth comparison of Pinus taeda, P. elliottii, and P. luchuensis in Tatung District.

Taiwan Forestry Res. Inst. Notes 222: 2022-2023 (Chin.).

Hu, T. W., C. M. Lu, and Y. L. Chung. 1981. Forest genetic improvement work in Taiwan. Proc. Symp. Forest Genetics and Breeding, Dec. 17, 1981, Taichung: 82-96.

________., and B. Y. Yang. 1972. Variation in wood specific gravity and fiber length of Pinus taiwanensis. U.S.-China cooperative science program seminar on forest ecology and genetics, Mar. 31-Apr. 8, Nat'l Sci. Coun. 1972, 5 pp.

Huang, C. W. 1952. Study on the growth and the management of the standing crops of luchu pines. Taiwan Forestry Res. Inst. Reference 11, 50 pp. (Chin.).

Hung, L. P. 1955. Study on slash pine young plantation growth. Taiwan Forestry Res. Inst. Bull. 45, 2 pp. (Chin.).

________. 1968. Study on thinning and tending effects of slash pine. Taiwan Forestry Res. Inst. Bull. 160, 62 pp. (Chin.).

________. 1974. Study on the stand growth of taiwania plantations. Taiwan Forestry Res. Inst. Bull 236, 26 pp. (Chin.).

________. 1977. Study on the effect of thinning experiments on luanta-fir plantations in Lianhwachih Forest District (I). Quar. J. Chin. Forestry 10 (1): 61-94 (Chin.).

________., H. H. Lo and L. N. Lo-cho. 1976. Study on the growth condition of plantations of three exotic pines planted on different districts in Taiwan (P. elliottii, P. taeda, P. luchuensis). Quar. J. Chin. Forestry 9(1): 29-42 (Chin.).

Hwang, C. W. 1952. Studies on the growth and the management of the standing crops of luchu pines. Taiwan Forestry Res. Inst. Reference 11, 50 pp. (Chin.).

________. 1968. Construction study of yield table of luchu pine in Taiwan. Taiwan Forestry Res. Inst. Bull. 173, 173 pp. (Chin.).

Hwang, K. K. 1969. Studies on the growth of Taiwan red pine stand of various habitats. Taiwan Forestry Res. Inst. Bull. 177, 36 pp. (Chin.).

________. 1970. The compilation of the yield and volume table of Taiwan red pine stands. Taiwan Forestry Res. Inst. Bull. 193, 43 pp. (Chin.).

________. 1977. Studies on plantation growth of Taiwan red cypress. Quar. J. Chin. Forestry 10(2): 95-109 (Chin.).

Hwang, S. G. 1978. Effects of different elevations on seedling growth of luanta-fir provenances. Taiwan Forestry Res. Inst. Bull. 303, 12 pp. (Chin.).

________., Z. Y. Kung and D. C. Tsai. 1979. Investigation control of squirrel damage in Liukwei. Taiwan Forestry Res. Inst. Bull. 318, 17 pp. (Chin.).

________., J. S. Yang. 1978. The effect of phenotype selection on the survival and growth of the seedlings of *Cunninghamia lanceolata*, *Taiwania cryptomerioides*. Taiwan Forestry Res. Inst. Bull. 308, 9 pp. (Chin.).

Kiang, T. 1970. Introduction and contribution of exotic species in Taiwan. Quar. J. Chin. Forestry 3(3): 85-100 (Chin.).

Koyama, R. 1967. An application of nuclear and cytoplasmic polyhedrosis virus against *Dendrolimus punctatus* in Taiwan. Quar. J. Chin. Forestry 1(1): 25-30.

Ku, E. T. 1967. Silviculture practice of cryptomeria. Quar. J. Chin. Forestry 3(2): 149-154 (Chin.).

Kung, C. M. 1970a. Effects of different storing agents of the pollen grains of China-fir and luanta-fir. Quar. J. Chin. Forestry 3(3): 101-111 (Chin.).

________. 1970b. Study on conifer flowering inducing by GAs application. Nat'l Taiwan Univ. Exp. Forest Notes 33: 6-10 (Chin.).

________., and T. Kiang. 1969. Morphological study on the strobilus of taiwania. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 69, 14 pp. (Chin.).

________., T. Kiang and F. S. Kung. 1969. Studies on the storage and the viability of taiwania pollen grains. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 70, 9 pp.

Kung, F. S. 1965. Preliminary studies on the development of the strobilus and the storage, viability of the pollen grains of *Taiwania*. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 45, 5 pp. (Chin.).

Kung, F. S. 1973. The establishment of Taiwania clone bank (I)--Affinity Study. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 111, 8 pp. (Chin.).

________. 1974a. Genetic improvement of Taiwania (I)--Provenance Study. Taiwan Forestry Res. Inst. Bull. 254, 13 pp. (Chin.).

________. 1974b. Study on the flowering effect of gibberellic acid to the grafts of Taiwania. Taiwan Forestry Bureau Planting Notes 1974: 54-61 (Chin.).

________., and C. M. Kung. 1966. Report of the establishment of Taiwania seed orchard. Quar. J. Taiwan Forestry 2(4): 6-28 (Chin.).

Kuo, P. C. 1957. A preliminary survey of squirrel damage to forest trees in Taiwan. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 12, 20 pp. (Chin.).

________., and Y. N. Yao. 1972. Selection of exotic pine species for testing in Taiwan. Quar J. Chin. Forestry 2(5): 1-8 (Chin.).

Kuo, S. R., T. T. Wang, and T. C. Huang. 1972. Karyotype analysis of some Formosan gymnosperms. Taiwania, Nat'l Taiwan Univ. 17(1): 66-80.

Lamb, A. F. A. 1966. Report on a visit to Nigeria. Mimeographed, Ministry of Overseas Development, London.

Lanner, R. M. 1969. Observations of stem form defects in Taiwan red pine. Appendix II: 1-8. In "Final report on silviculture and forest genetics in Taiwan" by E. H. Hinkle, UNDP/FAO Project, 1966-69, Taiwan.

________., and E. H. Hinkle. 1970. Some shoot and cone characteristics of Taiwan red pine. Pacific Sci. 14(3): 414-416.

Lee, H. T. 1972. Silviculture of cryptomeria and cypress. Quar. J. Chin. Forestry 5(3): 51-53 (Chin.).

Lee, S. P. 1977. Summary of the studies and experiments of Taiwan paulownia. Taiwan Forestry J. 3(9): 50-53 (Chin.).

Li, H. L., and H. Keng. 1954. Icones Gymnospermum Formosanarum. Taiwania, Nat'l Taiwan Univ. 1(5):25-84.

Li, S. J. 1976. Seedling variation of Pinus taiwanensis as related to geographic seed origins. Taiwania, Nat'l Taiwan Univ. 21(2): 138-149.

Liang, J. H. 1965. Investigation and study on the yield of turpentine and others of exotic pines in Taiwan. Taiwan Forestry Res. Inst. Bull. 107, 20 pp. (Chin.).

Lin, J. F., and S. Z. Tong. 1980. Studies on the stand density control diagram for Cunninghamia lanceolata. Scientia Silvae Sinicae 16(4): 241-251 (Chin.).

Lin, T. Y. 1974. Estimation of productivity and yield of luchu pine woodland. Quar. J. Chin. Forestry 7(1): 55-83 (Chin.).

Lin, W. C. 1959. Study on the adaptability of exotic pines planted in southern Taiwan (I). Taiwan Forestry Res. Inst. Bull. 62, 34 pp. (Chin.).

________. 1965. Study on the growth of various species of pine in relation to elevations and climatic factors. Taiwan Forestry Res. Inst. 119, 38 pp. (Chin.).

________., and T. Y. Chang. 1975. Effect of shade-screen on the survival and growth of Taiwania seedlings. Taiwan Forestry Res. Inst. Bull. 275, 10 pp. (Chin.).

Lin, W. F. 1974. Effect of altitudes and light intensities on growth of seedlings of Taiwania. Quar. J. Chin. Forestry 7(4): 3-12.

Liu, J. Y. 1977. The observation of plant phenology. "Forests," Nat'l Taiwan Univ. Forestry Dept. 10: 64-80 (Chin.).

Liu, S. C., and F. W. Horng. 1978. Growth and yield of cryptomeria plantation in Taiwan (II). Taiwan Forestry Res. Inst. Bull. 309, 47 pp. (Chin.).

________., F. F. Tai and P. T. Wang. 1976. The growth of planted luanta-fir in relation to site conditions. Taiwan Forestry Res. Inst. Bull. 280, 43 pp. (Chin.).

________., ________., ________., C. C. Chu, and S. C. Lin. 1976. Growth and wood properties of fast growing timber trees--Anthcephalus cadamba. Quar. J. Chin. Forestry 9(1): 9-16 (Chin.).

Liu, S. H., and T. Y. Lin. 1970. Yield tables and volume tables of luchu pine in north Taiwan. Joint Bull. Nat'l Chunghsin Univ. and Taiwan Forestry Bureau, 1970, 50 pp. (Chin.).

Liu, S. H., P. L. Yang, H. Y. Shu, and S. F. Chen. 1955. Yield tables of Japanese cryptomeria in Taiwan. Taiwan Forestry Res. Inst. Bull. 1, 39 pp. (Chin.).

Liu, T., C. M. Lu and T. W. Hu. 1975. Interspecific variation and provenance test in Genus Chamaecyparis. Taiwan Forestry Res. Inst. 279, 37 pp. (Chin.).

Liu, T. S., J. L. Wang, and J. C. Liao. 1967. The exotic tree species in Taiwan. Quar. J. Taiwan Forestry 3(1): 114-163 (Chin.).

Liu, Y. C. 1968. Studies on varieties of China-fir: experiments on the transplanting and planting. Quar. J. Chin. Forestry 1(2): 106-125 (Chin.).

________. 1971. The clone bank and controlled pollination of luanta-fir. Quar. J. Chin. Forestry 5(1): 1-17 (Chin.).

________. 1973. The management of the clone bank of luanta-fir. Quar. J. Chin. Forestry 6(3): 1-16 (Chin.).

________. 1974. Studies on varieties of China-fir (2). Quar. J. Chin. Forestry 7(4): 25-40 (Chin.).

________., and C. P. Ho. 1973. The Taiwania seedling root pruning study for outplantings. Today's Silviculture, Taiwan Forestry Bureau, 48: 14-17 (Chin.).

________., F. Y. Lu, C. C. Tsai, and C. H. Ou. 1979. Provenance test and study of luanta-fir. Quar. J. Chin. Forestry 12(2): 1-9.

________., W. C. Shieh, C. P. Ho, and C. S. Hsiao. 1964. Investigation and studies on varieties of China-fir. Joint Commission of Rural Reconstruction and Chung-hsing Univ. Joint Bull. 1964, 64 pp. (Chin.).

Lu, C. M. 1973. Variations in seedling characters of Taiwania from various provenances (1). Taiwan Forestry Res. Inst. Bull. 246, 18 pp. (Chin.).

________., 1975. Variation in seedling characters of Taiwania from various provenance (II). Taiwan Forestry Res. Inst. 261, 16 pp. (Chin.).

Mastan, K. M. 1969. Prospects of Anthocephalus cadamba as a plantation species. Special subject thesis, CFl, Oxford.

Mirov, N. T. 1967. "*P. luchuensis*" in the Genus *Pinus*. The Ronald Press, N. Y., p. 283.

Miyazaki, Y., and K. I. Sakai. 1969. Use of zymography for identification of a clone in *Cryptomeria japonica*. J. Jap. Forestry Soc. 51(9): 235-239.

Monsalud, K. P., and F. R. Lopez. 1967. Kaatoan Bangkal--"A wonderful tree." Philippines Lumberman 13(1): 60-64.

NSC. 1972. U.S.-China cooperative science program seminar on forest ecology and genetics, 1972: 1-61. Mar. 31-Apr. 8, Nat'l Sci. Counc.

NTU Forest. 1981. The research plots of the Experimental Forest. Nat'l Taiwan Univ. Exp. Forest, 1981, 10 pp.

Ohba, K., and M. Murai. 1971. Recessive genes producing albino and light green seedlings in sugi, *Cryptomeria japonica*. J. Jap. Forestry Soc. 53(6): 177-180.

________., Y. Okada, and M. Murai. 1971. Advancing the generation of sugi, *Cryptomeria japonica*, by greenhouse cultivation. J. Jap. Forestry Soc. 53(5): 133-137.

Ohtani, S., and R. Siepono. 1962. Initial forest regeneration. Survey report of East Kalimantan, Indonesia.

Perng, K. D. 1978. Study on the causes of success and failure of Taiwan paulownia plantations. Masters thesis, Nat'l Taiwan Univ., Dept. Forestry, 145 pp. (Chin.).

Puerto Rico. 1963. Annual report 1963. Institute of Tropical Forestry, Rio Piedras, Puerto Rico, Forest Serv., USDA.

Rin, U. C. 1972. Silvics on cryptomeria and cypress. Today's Silviculture, Taiwan Forestry Bureau, 44: 73-44 (Chin.).

________. 1973. Discussion on efficient silviculture. Today's Silviculture, Taiwan Forestry Bureau, 51: 11-34 (Chin.).

________. 1979. Silvicultural studies on Taiwan paulownia (*Paulownia taiwaniana* Hu et Chang). Nat'l Chunghsing Univ. Exp. Forest Res. Bull. 178, 228 pp. (Chin. and English summary).

Sheng, T. S. 1964. Notes of Kaatoan Banghal's introduction. Taiwan Forestry Res. Inst. Notes 189: 1659-1660 (Chin.).

Sheng, W. T., L. Wang, and H. Y. Chang. 1981. A preliminary study on the climatic regions of Chinese-fir growth areas. Scientia Silvae Sinicae 17(1): 50-57 (Chin.).

Shidei, T., and S. Moromizato. 1971. Karyotype analysis of luchu pine. J. Jap. Forestry Soc. 53(1): 13-18.

Tai, K. Y., and C. S. Liu. 1965. Effects of altitude on growth of seedlings of cryptomeria, China-fir and taiwania. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 42, 24 pp. (Chin.).

TFB. 1972a. "*Pinus luchuensis*" in Forestry in Taiwan. Taiwan Forestry Bureau 1972, pp. 25-30 (Chin.).

________. 1972b. The tree breeding workshop. Today's Silviculture 40: 1-75 (Chin.).

________. 1976. Forest statistics of Taiwan. Taiwan Forestry Bureau, 1976, p. 24 (Chin.).

________. 1977. Forest statistics of Taiwan. Taiwan Forestry Bureau, 1977, 159 pp. (Chin.).

Toda, Y. 1980. On the karyotype of *Cryptomeria japonica* (V)--in Kyushu. J. Jap. Forestry Soc. 62(7): 264-269.

Troup, R. S. 1921. The Silviculture of Indian Trees. Clarendon Press, Oxford: 614-616.

Tsou, E. R. 1976. Luchu pine progeny test and the selection for the seed orchard establishment. Taiwan Forestry J. 2(2): 25-27 (Chin.).

________. 1978. Selection of the juvenile luchu pines before the establishment of progeny test seed orchard. Quar. J. Chin. Forestry 11(2): 31-56 (Chin.).

________. 1979. Current status on tree breeding of Taiwan Forestry Bureau--(I), (II). Taiwan Forestry J. 5(6): 17-24; 5(7): 15-20 (Chin.).

Wang, C. W. 1961. The Forest of China. Harvard Univ., Cambridge, Mass. 313 pp.

________., T. T. Wang, E. R. Kuo, C. H. Chiang, S. J. Li,

T. W. Hu, Y. F. Suen, and P. Y. Yang. 1972. Progeny-provenance test of *Pinus taiwanensis* Hay. Station Paper 11, Forestry and Range Exp. Stn., Univ. Idaho, 11 pp.

Wang, J. L. 1971. Differentiation and development of the pollen of *Pinus taiwanensis*. Taiwan Forestry Res. Inst. Bull. 206, 18 pp. (Chin.).

________., and W. Y. Lin. 1974. The formation of female strobili and the development of cones in *Pinus taiwanensis*. Quar. J. Chin. Forestry 7(1): 43-54 (Chin.).

Wang, K. C. 1968. The control of *Phassus signifer* of taiwania plantation at Chitou. Nat'l Taiwan Univ. Exp. Forest Monthly Notes 12: 4-6 (Chin.).

Wang, K. R. 1975. Discussion on failure of Taiwan red pine plantings. Taiwan Forestry J. 1(7): 9-12 (Chin.).

Wang, T. T. 1976. Studies on the growth and ability of nutrient absorption of taiwania seedlings from different provenances. Memoirs of Coll. Agr., Nat'l Taiwan Univ. 16(2): 54-73 (Chin.).

________., and Y. T. Huang. 1971. Effects of N-P-K fertilizers on the growth of *Taiwania* nursery seedlings. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 89, 40 pp. (Chin.).

________., C. Kao, J. C. Yang, and J. G. Shyu. 1976. Isoenzyme variation of peroxidase in *Taiwania*. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 118-1: 1-16 (Chin.).

________., F. S. Kung, and C. M. Kung. 1969. Studies on structure and development of the strobilus of *Taiwania*. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 68, 20 pp. (Chin.).

________., and P. C. Kuo. 1960. Taiwan economic trees (I). Nat'l Taiwan Univ. Exp. Forest, Forestry Series I, 216 pp. (Chin.).

________., and ________. 1980. Squirrel damage to economic forests in Taiwan. Nat'l Sci. Counc. Monthly 8(6): 527-550 (Chin.).

________., C. W. Lin, and T. L. Cheng. 1980. Reforestation of Taiwan red pine and causes of its success and failure. Taiwan Forestry Bureau, 1980. 58 pp.

Whitmore, T. C. 1975. "Kadam" in Tropical Rain Forests of the Far East. Clarendon Press. Oxford, pp. 84-85.

Wright, J. W. 1970a. Report on Taiwan tree breeding. Nat'l Taiwan Univ. Exp. Forest Serial Publ. 47. 37 pp.

________. 1970b. Some recent Japanese tree breeding experiments. Nat'l Taiwan Univ. Exp. Forest Serial Publ. 48, 12 pp.

________. 1976. "Hybridization" in Introduction to Forest Genetics. Academic Press, pp. 324-328.

________., Y. N. Yao, and T. W. Hu. 1972. Plans for the genetic improvement of Taiwan red pine. Nat'l Taiwan Univ. Exp. Forest Serial Publ. 58, 28 pp.

________., ________., F. S. Kung, T. W. Hu, and T. Liu. 1973. Profitable approaches to saving and improving Taiwania. Quar. J. Chin. Forestry 6(4): 7-12.

________. 1978. Analysis of variance calculations for irregular experiments. Lake States Forest Tree Improvement Conf. Proc. 13, 1978, pp. 147-157.

Wyatt-Smith, J. 1965. Manual of Malayan silviculture. Part III. Malaysia Forestry Rec. No. 23.

Yang, B. Y. 1964. Introducing cadamba. Taiwan Forestry Res. Inst. Notes 189: 1660-1661 (Chin.).

Yang, Y. C., and C. Y. Wu. 1956. Comparison of the growth of Taiwan red cypress and cryptomeria at Chitou. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 7, 20 pp. (Chin.).

Yao, Y. N. 1970. Effects of transplanting density on the growth of seedlings of cryptomeria, China-fir and taiwania. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 81, 20 pp. (Chin.).

________. 1974. Introduction of exotic pine species for testing in Taiwan. Nat'l Taiwan Univ. Exp. Forest Tech. Bull. 114: 57-68 (Chin.).

________. 1975. The characteristics of nested analysis of variance and its applications to tree breeding work. Quar. J. Chin. Forestry 8(3): 59-75 (Chin.).

Yao, Y. N. 1979a. Introduction of tropical and subtropical pine species for testing in Taiwan--4-year, 9-month results. Memoirs of Coll. Agr., Nat'l Taiwan Univ. 19(1): 53-65 (Chin.).

________. 1979b. Analysis of variance for an experiment with missing plots. Quar. J. Chin. Forestry 12 (2): 79-90 (Chin.).

________., and B. J. Yen. 1979. The fast-growing species: kadam. Its silvicultural techniques, wood properties, usage, introduction status in Taiwan, and its growth comparisons. Quar. J. Chin. Forestry 12(1): 101-109 (Chin.).

________. 1981. Introducing tropical and subtropical pine species for testing in Taiwan, 7-year results. Proc. Symp. Forest Genetics and Breeding, Nat'l Chunghsin Univ., Taichung, Taiwan, pp. 30-51.

Yie, S. T., P. P. Lee, S. T. Hsu, and M. Y. Tang. 1967. Biological study on the more important insect-pest attacking Genus *Pinus* introduced from the U.S.A. Quar. J. Chin. Forestry 1(1): 1-24 (Chin.).

Yu, S. T., C. J. Chen, Y. L. Bai, and M. L. Huang. 1981. A preliminary observation on the flower-bud initiation of Chinese-fir in Nanpin, Fujian. Scientia Silvae Sinicae 17(1): 46-49 (Chin.